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Public policy and strategies to support institutional and technological innovations in the new water economy: the example of innovation technology clusters in developing and diffusing water technologies.

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PUBLIC POLICY AND STRATEGIES TO SUPPORT INSTITUTIONAL AND TECHNOLOGICAL INNOVATION IN THE NEW WATER ECONOMY: THE EXAMPLE OF INNOVATION TECHNOLOGY CLUSTERS IN DEVELOPING AND DIFFUSING WATER TECHNOLOGIES

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DEDICATION

This dissertation is dedicated to my wife and children

Mrs. Collette Barham

Matthew Barham

Rachel Barham

Sarah Barham

Who sacrificed so much to afford me the opportunity to pursue my studies.

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ABSTRACT

PUBLIC POLICY AND STRATEGIES TO SUPPORT INSTITUTIONAL AND TECHNOLOGICAL INNOVATION IN THE NEW WATER ECONOMY: THE EXAMPLE OF INNOVATION TECHNOLOGY CLUSTERS IN DEVELOPING AND DIFFUSING WATER TECHNOLOGIES

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A long list of water technologies has been central to human development throughout history. From the well in ancient times to desalination in the contemporary period, water technologies are needed to produce, distribute and treat water to support human life, industry, agriculture, and environmental health. As human development puts intense pressure on the planet's limited fresh water supplies, society is turning to increasingly innovative water technologies to close the supply-demand gap. The water economy represents a significant share of total economic output it its own right, while at the same time water directly or indirectly underpins all other economic activity. The water technology sector within the water economy has emerged as one of the world's biggest and most interdisciplinary industries employing scientists, engineers, information technology specialists, and a range of different management and policy professionals.

The international market for water technology is large and growing. This market represents a significant business opportunity for individual firms and a local economic development opportunity for regions seeking to develop dynamic industrial clusters that provide high paying jobs. This opportunity has motivated governments around the world to pursue policies to support water technology firms in what has historically been a highly fragmented industry which was highly dependent on local investments in public water infrastructure. To understand the growth and development of water technology clusters, this study utilizes a nine-part cluster development strategy developed by the United States Environmental Protection Agency (EPA) to support its own clean technology initiatives. The applicability of the model was tested using case studies of six clusters – three in the United States, and one each in The Netherlands, Singapore, and Israel. An analysis of the case studies shows a high correlation between the EPA strategy model and the policies and practices pursued in each cluster. This suggests that this strategy-model could be used by policy makers and planners in other regions as a framework for analyzing growing or mature water technology clusters, or a framework to drive the development of nascent or emerging water technology clusters.

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INTRODUCTION

I. Innovation, Entrepreneurship, and Clusters in the Water Economy

A. Background

A wide collection of water economy actors, which includes scientists, engineers, technologists, policy makers, economists and planners, are working both unilaterally and collaboratively to transform the global water economy to align its functioning with the needs of the 21st century. The goals sought by these water economy actors broadly include supporting economic development, protecting environment health, and improving the quality of lives of people through better sanitation and hygiene. The functioning of this emerging water economy, and its impact in terms of whose interests it serves and how well it serves those interests, is broadly determined by two overlapping domains: the governance framework that manages this sector and the technological capabilities that address issues of water quality, water quantity and availability, and production and distribution efficiency (Kiparsky et al., 2013). This dissertation focusses on the intersection of the governance and technological domains, the importance of achieving synchronicity where the domains overlap, and some of the public policies that are required to overcome the market and institutional failures that inhibit achieving synchronicity. In the emerging water economy several trends related to water technology can be identified: sophisticated technologies are increasingly being employed to improve the management of scarce water resources and protect its quality; increasingly sophisticated entrepreneurial and innovative activities are being employed to develop these new technologies and bring them to market; and a more facilitative organizational and economic environment is being created in local and regional technology clusters to support this water-technology-focused entrepreneurship and innovation.

Improving the performance of water institutions and deploying more innovative water technologies are necessary in the emerging water economy which is facing increasing gaps between supply and demand, and threats to water quality and ecological sustainability (When & Montalvo, 2017). Billions of people have increasing difficulty accessing a reliable supply of clean water which limits their economic productivity and their ability to meet basic hygiene needs. Growing demand for fresh water drives an excessive draw-down of water from diminishing reserves, and the return of polluted water to the natural environment is threating the health and proper functioning of nature's ecosystems. These water resource challenges, while creating great risks for many regions and nations, and placing a burden on policy makers for solutions, offers huge business opportunities for the private sector. Water innovators and entrepreneurs who have the technology, knowledge, and skills to deliver clean water at affordable rates, and treat wastewater to protect the environment and sustain the water cycle, are positioned to potentially reap huge financial benefits for their firms. Equally, there are also opportunities for regions with globally competitive industrial clusters focused on water technology to also reap huge economic benefits for their local economies. According to Mitra (2013, p. 2) there is a relationship between entrepreneurship, innovation and economic development:

> "It is in the creation of value that innovation and entrepreneurship find their meaning. Where innovation can be defined as the generation of new products, services and processes, entrepreneurship is associated with the identification of opportunity in society for such products and services, and in the realization or exploitation of that opportunity through the organization of resources with which to make the products available to the market. They enjoy a symbiotic connection and together they create value. The value creation process takes the form of organizing resources with which to develop new products and services for the market and for society."

B. Social, Economic, and Environmental Aspects of Water

Water possesses important social, economic, and environmental characteristics. Clean water is vital for sustaining all life on earth and is also essential for supporting, directly or indirectly, all economic activity. The social, economic and ecological importance of water can be gleaned from the importance the global community places on having predictable and reliable access to fresh water of sufficient quality and quantity to sustain human life, support economic activity, and renew natural ecological processes. The central importance of water has also been articulated and agreed upon by members of the global community at many international forums, and in many important documents, which together helps to shape the global agenda in relation to sustainable development. In respect of the Millennium Development Goals (MDG), water is the most widely reported target of MDG 7 (UNDP, 2006, 2015); and in respect of The Global Risk Report 2015, water was identified as facing an emerging global crisis that represents the most significant risk the world will face over the next several decades (World Economic Forum, 2015).

The relationship between water and human society, the economy, and the natural environment is complex and systemic; however, for conceptual simplicity, this relationship is often considered along the dimensions of quantity, quality, time and space that constrain availability of and accessibility to water. From a natural resource conservation perspective water of the desired quantity and quality is unevenly distributed across time and space: only about 2.5% of all water is fresh, and three-quarters of this is stored as ice and glaciers; about one-quarter of fresh water is stored as ground water; and 1% is stored in lakes, rivers and soils. Worldwide there are threats to biodiversity and to hydrogeologic and hydrologic processes in watersheds that threaten both the quantity and quality of water supply.

These increasing risks to water resources are primarily driven by population growth, agriculture, urbanization and land-use changes, increased material affluence, and modern lifestyles that are very water intensive. In the 20th Century there was a three-fold increase in the global population, a more than three-fold increase in the level of urbanization, and a six-fold increase in water use (Bogardi et al., 2012). On a global scale about 1.2 billion people face conditions of water scarcity, defined by the UN as less than 1000 m^3 per capita per year (UN-Water & FAO, 2007). On a regional scale around half of the countries in relatively water secure Europe, representing almost 70% of the population, are in a state of water stress, which occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use (European Environment Agency, 2016, 2018).

There are also increasing risks to water quantity and quality due to the absorptive capacity of ecosystems being overwhelmed by pollution, the increasing frequency of natural disasters, and the over-exploitation of both ground and surface water beyond nature's capacity to regenerate this resource (Vörösmarty et al., 2010). Climate change is also likely to affect water temperatures and salinity which will affect water quality and impact aquatic wildlife, exacerbating the direct effects of pollution; and it will also affect the patterns of rainfall which determines the timing, location and severity of drought and flooding, (Bates et al., 2008; Bogardi et al., 2012). The pollution of water from domestic, agricultural and industrial sources presents a substantial threat to human health with at least half the world's population exposed to risks from polluted water. Water is critical to carrying away, absorbing, and neutralizing the wastes human society produces while maintaining at all planetary scales the natural ecological functions without which life would not be possible.

After a decade of increased focus on water, the United Nations estimated that as of 2011 about 800 million people worldwide remained without access to an improved source of drinking water, about 2.5 billion people worldwide remained without access to improved sanitation, and about 1.5 million children die each year due to diarrhea, primarily caused by unsafe drinking water and inadequate hygiene and sanitation (WHO/UNICEF, 2008, 2014). In many countries most illness, and the resultant burden on the health care system, is the result of poor water supply and sanitation. Despite the lack of access to fresh water the poor often pay more for water, both directly and indirectly, than the rich (WHO/UNICEF, 2008, 2014). Only about 10% of all water consumed is used for private consumption as drinking water and to support sanitation and hygiene; while the remaining 90% is used to support agriculture and industry.

To safeguard water in enough quantity and quality for both human activity and natural ecosystems, society must develop governance regimes to carefully manage water, and technology diffusion processes to facilitate the development and commercialization of technologies to economically collect, treat, convey and store this precious resource. Water governance regimes and water technologies diffusion processes must be adapted and upgraded to face new water resource challenges driven by climate change, as well as long-standing water resource challenges driven by population growth, urbanization, economic growth, and pollution. Good water governance facilitates coordination and cooperation between stakeholders, supports forward-looking public and private entrepreneurs who seeks out and exploit business and policy opportunities, drives and incentivizes innovation that promotes technological advancements, and transforms organizational structures and institutional processes that together make the water economy function more efficiently and effectively. Better water technologies ensure that water can be collected, moved, treated and stored at a lower financial cost, and with a lower or even neutral impact on the natural environment. Governance regimes will be required to change human behavior to consume water more responsibly and incentivize innovators and entrepreneurs to find solutions to better manage water resources; sophisticated water technologies will be required to recharge aquifers, treat and reuse wastewater, desalinate seawater, and ultimately close the water loop with minimum energy requirements.

None of these various social, economic and ecological aspects of water can be considered in total isolation from the others because they are all interrelated. These water issues present challenges which require concerted public action by public policy entrepreneurs and innovators. These water issues also present opportunities for both private entrepreneurs and innovators to offer commercial solutions which could be highly profitable. Joint and coordinated public and private action could also address climatic and ecological concerns while supporting sustainable economic development. At the highest conceptual level, this complex water challenge can be described as a careful balancing act. On one hand is the need to ensure that fresh water, in an acceptable quantity and of an acceptable quality, is consistently and predictably available across time and space to maintain human health and support economic livelihoods; while on the other hand fresh water is required to ensure that the natural environment and the hydrologic cycle is protected from pollution and overexploitation of water resources.

C. The Case Studies

This dissertation contains six case studies that focus on identifying the public policies and strategies designed to create economically competitive water technology clusters along three dimensions: strategies that stimulate and nurture technological innovation and entrepreneurship at the firm level, strategies that foster innovative governance and institutions at the cluster level that supports firms, and strategies that foster the diffusion of water technologies through commercialization and adoption by users. Water technology clusters are emerging worldwide and have become the focus of public policy attention as governments attempt to address existing and emerging challenges within their national water economies. Three of the case studies look at water technology clusters in the United States and the efforts of the US Environmental Protection Agency (EPA), under its Clean Technology Initiative, to support the growth of these clusters. The goal is for them to become global leaders in water technology and water management solutions. Three of the case studies look at water technology clusters outside the United States, namely The Netherlands, Singapore and Israel. The concluding discussion and analysis compare all six clusters to a generic set of nine strategies developed by the EPA for the development and support of clean technology clusters. The generic strategies are critically examined within the context of a conceptual framework built around the three complementary theories: international competitiveness by Michael Porter, for the building of competitive firms through the strengthening of industrial clusters; institutional strengthening by Douglass North, for the improving of economic performance of industries and regions; and the diffusion of innovation by Everett Rogers, for the improving of processes through which innovative policies, practices, and technologies are adopted.

D. Research Questions

Although empirically difficult to prove it is widely accepted that when innovative, technology-based firms geographically cluster - and engage in synergistic relationships that involve a combination of coordination, cooperation and competition - they collectively have a capacity to transform and revitalize local economies, create and sustain international competitive advantage out of local advantage, create wealth and jobs, and deliver scientific, technical, and managerial solution to social, economic and ecological challenges (Porter, 1990; OECD 1999, 2003; Tether & Storey, 1998). This proposition has been extended to water technology clusters and public policy makers in several countries have taken up the challenge of strengthening their water innovation ecosystem through attempts to accelerate the creation, assessment and adoption of innovations in technology, finance, organizational structures, contractual relations, and regulation (EPA, n.d.; Fieldsteel, 2013). This policy of public intervention reflects the widely accepted position that institutional failure inhibits coordination and collaboration in a highly regulated and fragmented water sector; and that market failure produces information deficits and asymmetries which increase innovation risk for a traditionally risk averse industry, channel insufficient funds for innovation, and lengthen the time for technology commercialization beyond a socially desirable period (EPA, n.d.; Fieldsteel, 2013; Bartlett et al., 2017).

This dissertation will thus seek to answer the following questions:

- Do governments intervene to promote the development of industrial clusters for water technology firms?
- What public policies and strategies do governments employ to support the development or expansion of water technology innovation clusters?
- What are examples of successful clusters in which specific strategies of government intervention can be used as good practices?
- What are the roles and responsibilities – or the division of labor – between public and private partners in developing or expanding water technology innovation clusters?
- Do individual or organizational champions facilitate the development and diffusion of water-related technologies and enhance the competitiveness of water technology innovation clusters?
- Does the institutional setting of a jurisdiction affect the development and diffusion of innovative water-related technologies?

E. Significance

Water underpins and touches on every aspect of social and economic life and is critical for the functioning of all types of natural ecosystems. Water is life itself but the water economy in many parts of the world is either in crisis, or will soon face crisis, and is failing to deliver critical benefits to large segments of the global population. This study reinforces the important and integrated role that governance, institutions, and technology play in the water economy and seeks an understanding of some of the key challenges this sector faces as public and private innovators and entrepreneurs seek solutions to water challenges.

In understanding the relationship between governance, institutions, and technology in the water economy, this study will address three specific issues. First, this study will seek to more clearly define the term 'water economy,' which is currently poorly defined in the literature although it is coming into increasing use (Kislev, 2001; Gleick et al., 2002; Briscoe & Malik, 2006). A clear understanding of what represents the 'water economy' is important for any examination of the relationship between the governance, institutions, and technologies employed in this sector. Water and sanitation have been extensively studied by academics and policymakers, but this has not been reflected in a thorough theoretical examination of the 'new water economy' that is emerging. This study seeks to help fill that gap by providing a conceptual framework and a working definition for the 'new water economy.' The 'new water economy' which is emerging represents a transition from one dominated by the public sector - where water was treated primarily as a public good and not priced to reflect scarcity or environmental health – to a water economy with a greater role for the private sector and market forces - where water is priced at full-cost to ensure that it is allocated it to the highest value uses and managed in an environmentally sustainable manner.

Second, this study also examines the emerging phenomenon of water technology innovations clusters, which is one means of addressing key challenges to the water economy, especially as it relates to the supply of fresh water and treatment of wastewater. While clusters have also been extensively studied in the literature on economic development, its specific application to the water economy has not been extensively examined. This study will present a conceptual framework for understanding the development of water technology innovation clusters by situating it in the literature of industrial clusters, institutions and economic development, and diffusion of innovations, both technological and policy.

Finally, this study will examine in detail the efforts of the United States Environmental Protection Agency to foster the development of water technology innovation clusters and compare the policy instruments and strategies of the agency to the theoretical framework that has been developed for this study. This is intended to guide future researchers and policymakers as they examine the performance of water technology clusters and employ this policy approach to influence outcomes in the water economies of the regions in which these clusters are located.

CHAPTER 2

LITERATURE REVIEW

I. The New Water Economy: Governance and Technological Trends

The collection, treatment, storage, and distribution of fresh and wastewater are the key dimensions of a complex social, economic, political and ecological system called the 'water economy.' The water economy is a framework in which institutions and actors, both public and private, and in different spatial and temporal contexts, engage in a mix of collaborative, cooperative and competitive activities to produce, consume and exchange water and sanitation goods and services, and exploit or conserve water resources (FAO, 1993; Maxwell, 2009; Boccaletti et al., 2009; Libecap, 2010). A well-functioning water economy must balance the often-conflicting demands that arise in the key dimensions while meeting a triple performance criterion of efficiency, effectiveness and equity. The existence of these multiple and interrelated dimensions and performance criteria mean that water exhibits characteristics of both a public and a private good (Ostrom, 1962; Gleick et al, 2002; Hanemann, 2006; Maxwell, 2009; Adams et al., 2009; Libecap, 2010); and the structure of the water economy and the functioning of the institutions that constrain and enable interactions between agents means that it is subject to both market and government failure (Stiglitz, 1989; North, 1991).

Water has been recognized as an 'economic good' for many centuries; however, the public-good nature of water was emphasized for much of the 20th Century resulting in a dominant tradition of public ownership and management, and heavy public subsidy, which led to the fundamental challenge of water not being treated as a scarce resource (Rodgers et al., 2002; Rosegant & Cline, 2002). Some of the key results of this conceptualization of water has been overexploitation and waste of the resource, because it was underpriced; an underinvestment in infrastructure, because revenue streams did not align with capital, operation and maintenance costs; and a failure to cost the ecological services which are provided by the regenerative processes of the water cycle, which resulted in greater pollution. The employment of the term 'water economy' signifies a shift in public policy and institutional arrangements toward water and sanitation with both primarily seen as an 'economic good' where price mechanisms and the market will primarily determine its value and govern its production, allocation, distribution. This does not imply that public action and oversight has been removed from the institutional framework: it is widely accepted that unregulated market forces can never completely and equitably satisfy social and ecological objectives; and the presence of market failure and the public good nature of water and sanitation requires an active role for the state (Gleick et al., 2002).

II. Actors and Sub-sectors in the Water Economy

The water economy can broadly be divided into three parts: (1) public and private municipal water and sanitation providers; (2) commercial and industrial water technology firms; and (3) firms that are either water-intensive or water-enabled (Coy, 2002). Explicitly absent from this framework are those entities engaged primarily in water resource and environmental conservation, which should also be included in any conception of the water economy. Water resources management and environmental conservation are important and very much related to the water economy, despite being largely a public-sector responsibility and a public good, and these services not being produced, consumed nor exchanged in the traditional market-economy sense. Water resources management and environmental conservation are equally subject to the type of entrepreneurial and innovation actives which the dissertation seeks to explore. This broader, holistic and systemic conceptualization of the water economy fits in with the recognition that ecological services have a value that can and should be monetized, that both improved water governance and water technologies are required to address water challenges, and that the emerging paradigm is of 'one water' where water is valued and managed along the entire water cycle (Dyson, 2016; Feenstra, 2016).

III. From Traditional to Emerging Water Economy

The policies, institutions and practices that governed the water economy during the 20th Century were laid down in the reforms of the 'Sanitary Revolution,' which occurred during the latter decades of the 19th Century. Initially there was a significant role for the private sector, but the scale and scope of the investments required, and the social and public health challenges, led to a greater role for the state (Solomon, 2011; Smith 2013). The current state dominated delivery framework for fresh water and sanitation no longer delivers service of sufficient quantity and quality to the more than seven billion people on the planet (World Water Commission, 2000). Since at least the 1970s governments and water-based non-governmental organizations have been exploring ways of transforming the water economy so that it simultaneously delivers social, economic and ecological benefits that satisfy human needs but in an environmentally sustainable manner. The consensus that has emerged is that this transformation is best achieved with a combination of better technology, management, institutions and governance - combined in the correct proportions to reflect local water realities – and by having water and sanitation services organized and managed along economic principles, but with an economic model which recognizes that the unique nature of water causes it to be subject to multiple market failures (Gleick et al., 2002; Solomon, 2011; Feldman, 2017). This would mean that the new water economy would use market forces to more efficiently and effectively manage demand and encourage conservation through prices; incentivize private investment in building and rehabilitating infrastructure; and leverage the financial resources of capital markets in support of investment, research and development. The new water economy would also see a new role for the public sector which would increasingly move away from the direct provision of water and sanitation services to that of regulator, coordinator, and facilitator - with a focus on overcoming market failures - while ensuring that equity exists in the delivery of water services to poor and marginalized groups who may be underserved by market forces.

This study highlights the fragmented institutional structure of the traditional water economy, which has put water resources on an unsustainable and inequitable path (World Water Commission, 2000; Conway et al., 2010). The old water economy must be replaced by a system that is more adaptive to change, efficient in the use of resources, effective in delivering both quantity and quality, sustainable in financial and ecological terms, and equitable between competing demands among all users. Achieving these goals requires drastic changes in the way water is managed, how water institutions are structured, how it is governed to reconcile competing and conflicting demands, and how technology is brought to bear to address water quantity and quality issues.

The challenges facing the water economy are diverse and multi-dimensional – they include political, economic, social, ecological, scientific, technological and governance challenges (World Water Commission, 2000; Rogers & Hall, 2003; Conway et al., 2010). Political challenges include water and sanitation not always being given a high priority in government against competing policy demands; responsibility for water, sanitation, resource conservation, and environmental protection are often spread among numerous ministries and agencies of government; and the work of donors and non-governmental organizations is not always well coordinated (Conway et al., 2010). Economic challenges include a shift from water being treated as a free or heavily subsidized public good to being treated and managed as a scarce commodity. The full-cost pricing of water services ensures that all costs – capital, operations and maintenance – are covered, water is allocated to its highest value uses, pollution is reduced, and conservation is encouraged (Conway et al., 2010). Social challenges include the continued recognition that water and sanitation have public good characteristics and that universal access is fundamental to physical and mental health, economic and social development, and public safety. Carefully targeted and transparent subsidies will be required for some groups of people; however, it is important to separate the welfare task, which is a government responsibility, from the business task, which is a utility responsibility, and to avoid water pricing and distribution being manipulated for political purposes (Conway et al., 2010). Scientific challenges include a long-standing split between ecologists and hydrologists, who address the generation and distribution of water resources arising from catchments, and engineers and public health specialists, who address the supply of fresh water and sanitation to communities (Conway et al., 2010).

Ecological challenges include government responsibility to protect the public goods nature of watersheds, wetlands and groundwater against pollution and over-extraction to ensure sustainable water resource management and intergenerational equity (Conway et al., 2010). Technological challenges include creating the incentives to mobilize entrepreneurship and innovation and overcoming impediments to promote the development, commercialization, diffusion, and adoption of new environmentally friendly and cost-effective technologies (Conway et al., 2010). Governance challenges involve creating the institutional mechanisms for mediating between competing values, norms and ideologies to ensure that the provision of water and wastewater services are equitable and economically sound, and that water resource management is carried out in an environmentally sustainable manner (Rogers & Hall, 2003).

Coming out of this review of the literature, eight conceptual domains have been identified that can be used to analyze and understand the emerging water economy: (1) the nature of water as a natural resource, (2) the complex and systemic nature of the water economy, (3) the existence of multiple stakeholders with competing needs, (4) power relations between stakeholders with competing claims on water resources, (5) property rights related to water, (6) the fragmented structure of water economies, (7) the framing of 'water economy problems,' and (8) the relationship between the state and the market in the water economy (World Water Commission, 2000; Rogers & Hall, 2003; Conway et al., 2010). The domains underscore the importance of robust governance and institutional arrangements to the smooth functioning of all aspects of the water economy.

IV. Water Technology Innovations Clusters: How Entrepreneurship & Innovation are Transforming the Water Economy.

The scale and scope of the water economy, its cross-cutting nature and complexity, and the gaps between demand and supply all provide fertile ground for public and private entrepreneurship and for innovations in technology, management, institutions, and policy. One solution that has been offered has been the development of water technology innovation clusters, which foster, facilitate and leverage the entrepreneurship and innovation that the water economy is widely seen to need (Feldman & Francis, 2004, 2006; Feldman et al., 2005; Conway et al., 2010). An innovation cluster refers to agglomeration of firms within one specialized industry, concentrated within the same local geographical area, with a vertically and horizontally integrated infrastructure of related and supporting public and private firms and organizations, and proximity to a strong science and research base (Porter, 1990; OECD, 1999; Miranda & Potter, 2009; Feldman & Francis, 2004, 2006; Feldman et al., 2005). Water technology clusters are believed to create the organizational structure that facilitates the types of social and economic interactions between water stakeholders that overcomes barriers to the effective and efficient creation, commercialization, diffusion, and widespread adoption of technical and management solutions to water challenges.

Clusters usually emerge naturally, however, the water economy is a highly fragmented sector, which makes it hard to organize a cluster and define its boundaries; and it is also subject to market failures, in the form of missing and incomplete markets and information failures (EPA, n.d.; Fieldsteel, 2013; Bartlett et al., 2017). These factors lead to calls for public intervention to support the development of water technology clusters. The fragmented elements of the water economy include manufacturers of water devices and chemicals, major industrial and commercial users of water and water technologies, sources of finance for R&D, utilities and infrastructure, and centers of scientific and technological excellence in water R&D. These actors may all have an interest in the water economy but be unable to properly coordinate and collaborate their activities. Market failure may occur because the private sector may find it unprofitable, or too risky, to invest in the universal provision of water and sanitation; or investors may consider the sector too risky to channel financial capital to technologies and infrastructure with long periods for commercialization and payback. Public intervention could also be justified because key components of the water economy are often anchored around state owned utilities and infrastructure, while utilities, water resources, and the environment are heavily regulated by government.

Business clusters and business ecosystems have received increasing public policy, academic and media attention in recent years, which has led to increased public resources being devoted to their creation or enlargement (OECD, 1999; Sallet et al., 2009; Miranda & Potter, 2009; Wessner, 2012). Despite their existence, their potential importance, and the public resources devoted to fostering, facilitating and studying them, policy makers and academics have a limited understanding of how innovation clusters emerge, grow into competitive industries, and transform the regional economies in which they are intimately imbedded (Feldman & Francis, 2004, 2006; Feldman et al., 2005). Public policy has attempted to replicate these features but a number of issues remain unclear: (1) are specific features of clusters - such as a local research university, the availability of venture capital or grants, and social networks and support services such as trade associations and marketing agencies - drivers and enablers of cluster development, and do they lead or lag cluster formation; (2) what is the role of innovators and entrepreneurs – both public and private – as agents of change, in resource mobilization, and in institutional development; and (3) to what degree does local history and regional context influence the process (Feldman & Francis, 2004, 2006; Feldman et al., 2005). In addition, clusters are complex adaptive systems, and systems exhibit characteristics of path dependence, emergence and self-organizing which make them unpredictable and nondeterministic (Dooley, 1997; Feldman & Francis, 2002; Rogers et al., 2005). Public policy traditionally faces a challenge in understanding the drivers and enablers behind the emergence of clusters in a region or industry that previously would not be characterized as innovative; however, it is widely believed that the location of entrepreneurs with the skills and opportunity to capitalize on an emerging technology, and transform institutions in support of that technology, significantly affects the emergence of high technology innovation clusters (Schumpeter, 1939, 1942; Feldman & Francis, 2004, 2006; Feldman et al., 2005).

Science, innovative technology and institutions, working together in a systematic framework, are the basis for solving problems created by human activity and underpin most improvements in human welfare and environmental protection. Science is the process of generating knowledge based on evidence; technology - which can involve both invention or the adaptation of novel products, processes or techniques - is the application of scientific knowledge to specific problems; innovation is the process by which science and technology are applied in novel ways, to specific situations, in specific contexts; and institutions are ways of organizing human activities to address specific problems

(Ostrom, 1990; North, 1990; Conway et al., 2010). Modern innovation usually takes place within a ‘science-innovation-diffusion system’ – which can be formal or informal – and one of the best science-innovation-diffusion systems is the technology innovation cluster (Feldman & Francis, 2004, 2006; Feldman et al., 2005; Conway et al., 2010). Modern science and innovation have evolved to be largely the result of teamwork - as opposed to the lone inventor of the past toiling away quietly in his or her laboratory - and modern R&D interactions usually involve a diverse system of players and institutions that influence its progress and success (Conway et al., 2010). Science and innovation now take place on different temporal and spatial scales and is increasingly regional, national and international with the pace of development from laboratory to market for many innovations greatly accelerated (Conway et al., 2010). There is a process in scientific innovation - basic research, to translational research, to product development – but this process is not always neatly linear, and it often involves a back-and-forth interplay between basic, translational and applied research stages (OECD, 1999; Rogers et al., 2005; Conway et al., 2010). Where science does not lead to innovation and new products, key players and institutions may be absent, or some type of information failure may be blocking the two-way flow of ideas.

The range of stakeholders in an innovation system is wide and includes private enterprise, universities, government and civil society: public and private research facilities and universities tend to be responsible for much of what we refer to as science, from basic through to applied research; private enterprise tends to be responsible for much what we refer to as innovation, through business investment, which provides security and capital for product development and marketing, which supports product commercialization and diffusion; public policy makers tend to be responsible for a conducive policy and regulatory environment; and civil society tends to shape preferences and influence demand for goods and services (OECD, 1999; Rogers et al., 2005; Conway et al., 2010). All of this demonstrates that a range of elements operating synergistically must be in place and functioning before locally valuable technologies can result from scientific innovation. Technology innovation clusters form the perfect enabling environment – of policies, regulation, institutions, finance, networking and information sharing, and protection of intellectual property rights – for the science-to-technology-to-innovation diffusion pathway to turn out solutions to challenges faced by the water economy.

Entrepreneurs are widely believed to be a critical element in the formation, growth, vibrancy and sustainability of firms in technology-intensive innovation clusters (Feldman & Francis, 2004, 2006; Feldman et al., 2005). Entrepreneurs can be defined as agents who are central to cluster formation, who in perceiving and responding to opportunities and incentives, act collectively by building relationships to re-define, combine and deploy resources to create new products, services, and organizations (Schumpeter, 1939, 1942; Knight, 1921; Kirzner, 1973; Drucker, 1985; Feldman & Francis, 2004, 2006; Feldman et al., 2005). This definition assumes that entrepreneurial decision-making and action is a complex mix of individual preferences and interests, prior experiences, knowledge and skills, opportunities, incentives, social networks, and access to capital markets and human resources (Feldman & Francis, 2004, 2006; Feldman et al., 2005). It also makes the further assumption that entrepreneurship is inherently a local phenomenon and that entrepreneurs are predominantly local actors who are shaped by, and in turn reshape, their environment during the innovation process (Feldman & Francis, 2004, 2006; Feldman et al., 2005). The nature of entrepreneurship is one of interdependence between actors, government policy, available resources, and the local geographic and environmental context: this gives rise to a creative feedback loop between the entrepreneur and his or her environment that determines the nature, stability and uniqueness of technology-intensive innovation clusters, that helps to give clusters competitive advantage, but also means that clusters are path dependent and heavily influenced by history (Feldman & Francis, 2004, 2006; Feldman et al., 2005). These assumptions suggest that the entrepreneur can be influenced by exogenous forces - such as a response to public policy, a crisis, or an opportunity - that can either turn latent entrepreneurship into active entrepreneurship or redirect existing entrepreneurship to align with new policy (Schumpeter, 1939, 1942; Hébert & Link, 1988; Feldman & Francis, 2004, 2006; Feldman et al., 2005).

The literature suggests that if technology innovation clusters are to help solve challenges within the water economy, there is a need for both robust institutions and advanced technologies to balance supply and demand and protect water quality. Despite the social, economic, and environmental importance of the water economy, less that 0.2% of all inventions patented worldwide in recent decades are water-related technologies; and although many countries are affected by water scarcity and pollution, absolute scarcity of water or severe pollution are not the prime drivers to create the institutions, nor develop the technologies, to address issues of water quantity or quality (Conway et al., 2015). Most water stressed countries are in the developed world and these countries have the weakest institutional regimes, and the least technological capacity, and are least likely to develop technologies to address local water problems (Conway et al., 2015).

Robust water institutions and advanced water technologies generally arise in places where the correct governance and institutional framework, along with sufficient human, financial, and technological resources, have been purposively developed and put in place. Water technology innovation clusters develop when the following factors exist: (1) economic and financial incentives to make investments in water R&D and water technologies profitable; (2) institutional arrangements to ensure the timely diffusion and adoption of water technologies; (4) social capital and networks which encourage and facilitate cooperation and collaboration; (4) a legal framework to support and facilitate public-private partnerships for the appropriate allocation of roles and responsibilities; (5) an innovation-diffusion process which moves a technology from research through development to commercialization and facilitates the scaling of both technologies and business models; and (6) public and private procurement policies and practices that build a relationship with technology firms that increases the speed and encourages the direction of technology development and diffusion (Rogers & Hall, 2003; Bartlett, 2017). To test the applicability of these considerations this study will briefly examine water technology clusters in three US regions – Cincinnati, Milwaukee, and Tacoma - and of three small nations – The Netherlands, Israel, and Singapore to find evidence of their existence.

V. Water Technology Innovation Clusters in the United States

The United States is the global leader in the development, commercialization and consumption of water technologies; however, this is primarily related to the size of its economy and an across-the-board global leadership in R&D and patenting rather than a focused commitment to water technologies (Conway et al., 2015; Bartlett, 2017). Beginning in 2012 the Environmental Protection Agency (EPA) began assisting water technology innovation clusters because this sector is now recognized as vital to the economic, environmental and public health of the US, and because the current US water technology sector is perceived to be too fragmented to solve complex problems that require collective action on the part of both the private and public sectors (EPA, 2013, 2014, 2015). Across the US water companies, universities and other organizations have established clusters in the field of water technology to seize opportunities for collaborations in scientific research and the development and commercialization of water technologies (Bosma, 2013; Picou, 2014). The strengthening of existing or nascent water technology innovation clusters through well-designed and carefully targeted public policy is believed to be critical to addressing water challenges and putting the US on a more sustainable economic and environmental path. The EPA believes a failure to upgrade water and sanitation infrastructure, improve service quality, safeguard water resources, and protect water ecosystems over the coming decades will risk reversing decades of environmental, public health, and economic gains; and sustainable solutions to challenges in the water economy are difficult to envision without technological innovations (EPA, 2013, 2014, 2015).

The EPA aims to be a catalyst to promote and support technology innovation to protect and ensure the sustainability of US water resources (EPA, 2013, 2014, 2015). Innovative technologies, public policies, institutional arrangements, and management approaches are believed to offer the promise of addressing water challenges more quickly and more cost-effectively. Although the large size and varied geography of the US means that challenges in the US water economy vary across time and space, the challenges which the US water economy faces can be summarized along the following four dimensions: (1) water scarcity, where many aquifers are being depleted at a much higher rate than can be replenished by natural precipitation and ground water recharge; (2) water quality, where many of the nation's coastal waters, estuaries, rivers, streams and lakes remain impaired as a result of pollution and physical alterations to the land; (3) aging infrastructure, where much of the US water and wastewater infrastructure is aging and leaks, breaks down, or exposes users to harmful contaminants; and (4) climate change impacts, which exacerbates the challenge of protecting natural ecosystems, water resources, and water infrastructure. While these water resource challenges and market opportunities are traditionally framed as separate problems, they are best addressed in an integrated manner.

In 2013, the EPA put out its business case for using various water programs to advance technology and innovation in the water economy (EPA, 2013). The business case identifies opportunities where technology and innovation could help solve water and environmental challenges of providing a reliable supply of clean and safe water, while using less energy, and protecting water resources with a combination of new technologies, new management and institutional approaches, and increases in the efficiency and effectiveness of existing systems and technologies. Water technology innovation clusters will provide part of the foundation to a greener and more sustainable economy and society that conserves natural water resources, reuses and recycles waste water, recovers nutrients from waste water, produces clean water and handles waste water using less energy, reduces the cost and improves the effectiveness of water monitoring, and develops more resilient water and sanitation infrastructure, especially in the face of the risks from climate change.

The EPA envisions itself as facilitating inventors, investors and entrepreneurs through the following strategies: (1) advocating for the water technology innovation sector in the public and private sectors, including efforts to support research and development, verify and certify emerging technologies, pilot promising technologies, and deploy proven technologies; (2) communicating actions, successes and best practices by showcasing and celebrating examples of technology, policy and management innovation; (3) maintaining an inventory of U.S. environmental technology clusters; (4) creating the regulatory space, and providing targeted incentives, to foster entrepreneurship and innovation; (5) encouraging collaboration between regional clusters; (6) connecting EPA programs to cluster needs; (7) providing funding for research and development, and financing opportunities for inventors and innovators; (8) encouraging and supporting partnerships that foster innovation and entrepreneurship in the water economy; (9) creating an environment where businesses and other organizations can easily share ideas and solutions; (10) connecting businesses and other end users to new technologies, startups to new markets, and researchers to commercial partners; and (11) working within and across states to overcome local policies and regulations that impedes innovation and entrepreneurship (EPA, 2013, 2014, 2015).

The EPA supports water technology innovation clusters through the Environmental Technology Innovation Clusters Program (EPA, 2013, 2014 & 2015). Environmental technology innovation clusters are regional groupings of businesses, government, research institutions, and other organizations focused on innovative technologies for clean air or clean water. To date the EPA has identified 14 regional clusters spread across the lower 48 states, which represent the range of challenges faced by regional water economies because of geography, geology, local climates, local economic conditions, and local custom and law. The EPA is following a well-established principle guiding public support for clusters, which states that most successful cluster initiatives begin in regions where the targeted industry already has a strong presence (Muro & Katz, 2010; Wessner, 2012).

The services the EPA provides each cluster include assistance with planning and structuring the cluster, recruiting participants, building capacity, and securing the sustainability of institutions that will support the cluster (EPA, 2013, 2014, 2015). The EPA achieves this by employing the following approach before undertaking a cluster initiative: (1) survey and evaluate regions for their cluster potential; (2) meet with individual stakeholders with the eventual goal of convening a large group of interested stakeholders; (3) secure a commitment from stakeholders to proceed with the cluster initiative under the auspices of the EPA; and (4) form a steering committee and develop an operating framework which sets out objectives and outcomes for the cluster, establishes an organizational structure, and proposes an initial schedule of activities. The EPA cluster program is part of a wider federal approach to supporting local economic development through clusters, and the departments of Energy, Commerce, Defense, Agriculture, Labor, and Education now all have programs devoted to regional innovation clusters. A similar program, started in 2010 as the Regional Innovation Cluster (RIC) Initiative, exists within the US Small Business Administration (SBA) (Monnard et al, 2014). Of 58 clusters currently receiving federal support through the SBA, two are water technology innovation clusters. There are three primary goals to all federal cluster initiatives: (1) to increase opportunities for small business participation in industry clusters, (2) to promote industry innovation, and (3) to enhance regional economic development and growth.

CHAPTER 3

PART A - METHODOLOGY

I. Overall Research Approach

The goal of this study is to refine our understanding of the public policies and strategies that are employed to develop and strengthen water technology innovation clusters. Clusters with innovative firms led by entrepreneurs are assumed to have a far higher success rate in commercializing and diffusing innovative water technologies that are needed to address critical technical and environmental challenges in the water economy, namely the sustainable supply of sufficient clean water at the lowest cost, using the least energy, and with the smallest environmental footprint. The specific objectives of this research include (a) determining if governments intervene to facilitate the development and diffusion of water-related technologies and promote the development of industrial clusters for water technology firms; (b) determining what public policies and strategies governments employ to support the development or expansion of water technology innovation clusters; (c) identifying examples of successful clusters in which specific strategies of government intervention can be used as good practices; (d) determining the roles and responsibilities – or the division of labor – between public and private partners in developing or expanding water technology innovation clusters; (e) determining if individual or organizational champions facilitate the development and diffusion of water-related technologies and enhance the competitiveness of water technology innovation clusters; (f) determining if the institutional setting of a jurisdiction affect water technology policy outcomes. These avenues of exploration take place with the realization that innovative water technologies face institutional deficiencies and market failures that raise hurdles to their successful development and diffusion. This constrains the degree to which market-based solutions can be exclusively relied upon to address challenges in the water economy generally, and water technology clusters specifically, and leaves a space for the active involvement of the government in this sector.

The overall research design of this study will take a qualitative approach, which employs a formal, objective, systematic process of data collection and data analysis to test the research questions (Babbie, 2007; Schutt, 2009). Social life is complex in its range and variability, it operates at different levels and at different scales, and the same can be said of the water economy. Qualitative inquiry accepts the complex and dynamic quality of the social world, uses a naturalistic approach that seeks to understand phenomena in context-specific, real world settings, facilitates a deep and intimate involvement with a topic of investigation in its natural setting, and allows the researcher to uncover and lift its many layers of meaning (Babbie, 2007; Schutt, 2009). Qualitative research is ideally suited for building theory, identifying themes and conceptual domains, and generating hypotheses for later testing (Babbie, 2007; Schutt, 2009).

II. Research Approach.

This study seeks to understand the emergence in four countries of water technology innovation clusters and the relationship between these cluster and the development and diffusion of water-related technologies. Clusters are geographic concentrations of interconnected businesses and associated public and private institutions in an economic sector. Water technology clusters can also be considered as local networks interacting strategically through a combination of cooperation, collaboration and competition to leverage local capabilities to produce policy, management and technological solutions, which address specific challenges within the emerging water economy. While many of these water technology innovation clusters emerge to address local needs they often increase in size and capability until they have global impact. The discourse around clusters was popularized within the discipline of strategic management by Michael Porter (1990) and within geographical economics by Paul Krugman (1991). The development of clusters has since become a focus for many government economic development programs, to include in recent times the development of water technology innovation clusters. Proceeding from this frame of reference the research approach will involve collecting information using systematic processes and procedures, which include the following qualitative approaches:

A. Exploratory. Exploratory research is often conducted under the following conditions: when there are few or no earlier studies to which references can be made for information; when the researcher needs to carry out an initial survey to establish areas of concern; when the research project seeks to identify patterns, ideas or hypotheses rather than testing or confirming a hypothesis; and when there is a desire to gain insights and familiarity with the subject area to set the foundation for more rigorous investigation later, thus facilitating a shift to explanatory research (Babbie, 2007). While there is extensive literature on the phenomenon of clusters – which will help to establish a theoretical framework for this study - there is very little literature on the specific phenomenon of water technology innovation clusters. It will therefore be necessary to identify patterns and themes in the case studies that will form the empirical component of this study to allow a conceptual framework for water technology innovation clusters to be developed.

B. Descriptive. Descriptive research seeks to identify and describes phenomena as they exist and thus goes further than exploratory research in examining a problem (Babbie, 2007). This study will seek to describe the characteristics of water technology innovation clusters - as they are found in the specific contexts of Cincinnati, Milwaukee, Tacoma, Singapore, Israel and The Netherlands – as well as the specific problems to which these clusters were a response.

C. Explanatory. Explanatory research is a continuation of descriptive research but goes beyond merely describing the characteristics, to analyzing and explaining why or how something is happening (Babbie, 2007). Explanatory research aims to understand phenomena by discovering and measuring causal relations (Levy, 2008; Bennett, 2004). This study will seek to understand and explain how and why water technology innovation clusters arose in the six clusters under examination.

D. Case study. This study will employ the case study approach to gather empirical data on water technology innovation clusters. Six case studies will be included in the study. Case studies are a specific approach to ethnographic research, which may be defined as both a qualitative process or method, and a product or outcome of this process. A case can be defined as an instance of a spatially and temporally bounded and theoretically defined class of event of interest to the researcher – such as a water technology innovation cluster; while a case study is a well-defined aspect of a historical happening that the investigator selects for analysis to test historical explanations that may be generalized to other events– such as the causes of the emergence of water technology innovation clusters (George, 1979; George & Bennett, 2005). Case studies are designed to collect extensive narrative or non-numerical data based on many variables over an extended time in a natural setting, and support interpretation of a phenomenon within a specific context (Levy, 2008; Bennett, 2004). The researcher goes beyond reporting events and instead details the experience of one or more individuals, communities, organizations or institutions; and the researcher then analyzes the resulting data for patterns in relation to internal and external influences to provide a complete description and interpretation of a phenomena (Levy, 2008; Bennett, 2004). Given the close relationship of case studies with the case data, case study analysis provides the opportunity to identify new or omitted explanatory and contextual variables and hypotheses, develop historical explanations of particular cases, specify complex causal mechanisms, path dependencies, and multiple interaction effects, and set scope conditions which guide an iterative research process (Levy, 2008; Bennett, 2004). Case studies therefore aim to produce causal explanations based on a logically coherent theoretical or conceptual framework that can generate testable inferences; case study methods to refer to both within-case analysis of single cases and cross-case comparisons among a small number of cases; and many research projects using case studies involve both kinds of analysis due to the limits of either method used alone (Levy, 2008; Bennett, 2004). The six cases in this study will be subject to both within-case and cross-case analysis to identify causal antecedent conditions and outcomes both within and between cases. Where two or more cases have the same causal antecedent conditions and same outcomes – referred to as method of agreement - these may turn out to be a necessary conditions; where two or more cases have the same causal antecedent conditions and different outcomes – referred to as method of difference – it would not be possible to claim to have identified necessary conditions and a causal relationship (Levy, 2008; Bennett, 2004).

These six clusters have been chosen as case studies because they have a very special relationship to water and their very existence is dependent on how they have approached extreme challenges in water and sanitation. All six clusters are considered to have had some degree of success in addressing - through a combination of public policy, management, institutions, and technology – their respective water challenges: Tacoma has been very successful in managing storm- water and in cleaning and restoring parts of the Puget Sound estuary; both Israel and Singapore face a severe shortage of water, but for very different reasons, and both have successfully leveraged investments in science and technology to expand sources of water, conserve existing sources and reuse waste water; Singapore and The Netherlands have been very successful in developing a financially sustainable water economy; while The Netherlands, much of which is below sea level, has waged a long battle to maintain water quality and to reduce or mitigate the risk of flooding (Tortajada et al., 2013; Vossestein, 2014; Siegal, 2015).

E. Inductive. This study employs an inductive approach, which is common in many qualitative research projects, particularly case studies, where the researcher makes broad generalizations from specific observations (Levy, 2008; Bennett, 2004). The review of the literature on institutions and economic growth, cluster development, and diffusion of innovation will provide a well-developed conceptual framework to guide the inductive examination of the development and diffusion of innovative water-related technologies from water technologies clusters. The conceptual framework will focus attention on specified aspects of each case that will facilitate development of a 'thicker' description of patterns that emerge. The inductive approach provides this study with the opportunity to use these discrete cases to provide more grounded interpretation and robust explanations that lead to a deeper understanding of the key aspects of the phenomena. The more structured the case analyses, the more case interpretations are guided by theory, the more explicit their underlying analytic assumptions, the fewer the logical contradictions, then the more explicit the causal propositions that can be derived, and the easier they are to empirically validate or invalidate (Levy, 2008; Bennett, 2004). The analysis of the six case studies will allow for the generation of new insights, principles or themes that relate specifically to the development and diffusion of water-related technologies from water technology innovation clusters.

The inductive approach is also best suited to exploring new phenomena - or approaching previously researched phenomena from a different perspective – and may facilitate some generalization beyond the data in the discrete case (Levy, 2008; Bennett, 2004). An inductive approach will usually use research questions to narrow the scope of the study.

F. Process tracing. There are several methods of within-case analysis, but the method employed in this study is process tracing, which has inductive elements. Qualitative researchers have long argued that the methodology of process tracing, which involves an intensive analysis of the development of a sequence of events over time, is particularly well-suited to the task of uncovering intervening causal mechanisms and exploring reciprocal causation and endogeneity effects (George, 1979). Process tracing focuses on whether the intervening variables between a hypothesized cause and an observed effect move as predicted by the theories used to analyses a case; and process tracing tries to establish which of several possible explanations for this relationship is consistent with an uninterrupted chain of evidence from the hypothesized cause to the observed effect (Bennett, 2004; Levy, 2008). Process tracing allows case study researchers to get inside the 'black box' of decision making and explore the perceptions and expectations of actors, both to explain individual historical episodes and to suggest more generalizable causal hypotheses (Brady et al. 2004). In essence, the focus of process tracing is on establishing the causal mechanism by examining the fit of a theory to the intervening causal steps. By emphasizing the causal process that leads to certain outcomes, process tracing lends itself to validating theoretical predictions, hypotheses, and research questions.

II. Research Questions

The following research questions are used to guide this research project:

- Research Question 1. Do governments intervene to facilitate the development and diffusion of water-related technologies and promote the development of industrial clusters for water technology firms? This is an exploratory research question, which seeks to identify and describe this phenomenon both within and between cases.
- Research Question 2. What public policies and strategies do governments employ to support the development or expansion of water technology innovation clusters? This is an explanatory research question, which seeks to discover if there are differences within and between cases.
- Research Question 3. What are examples of successful clusters from which specific strategies of government intervention can be used as good practices? This is a descriptive research question that seeks to discover if there are differences between cases.
- Research Question 4. What are the roles and responsibilities – or the division of labor – within water technology innovation clusters? This is a descriptive question that seeks to discover if there are differences between cases.
- Research Question 5. Do individual or organizational champions facilitate the development and diffusion of water-related technologies and enhance the competitiveness of water technology innovation clusters? This is an

explanatory research question that seeks to discover if there are differences between cases.

- Research Question 6. Does the institutional setting of a jurisdiction affect water technology policy outcomes? This is an explanatory question that seeks to discover if there are differences between cases.

III. Variables

Below are qualitative variables which will help identify specific and important inter-relationships in the study. Where cases are addressed in a comprehensive manner, process tracing is a particularly useful technique in helping to ascertain the causal process linking an independent variable to the outcome of a dependent variable, particularly in small-n studies. The purpose of this study is to investigate the influence of public policies and strategies on the emergence of technological and institutional innovations that arise out of water technology clusters. Thus:

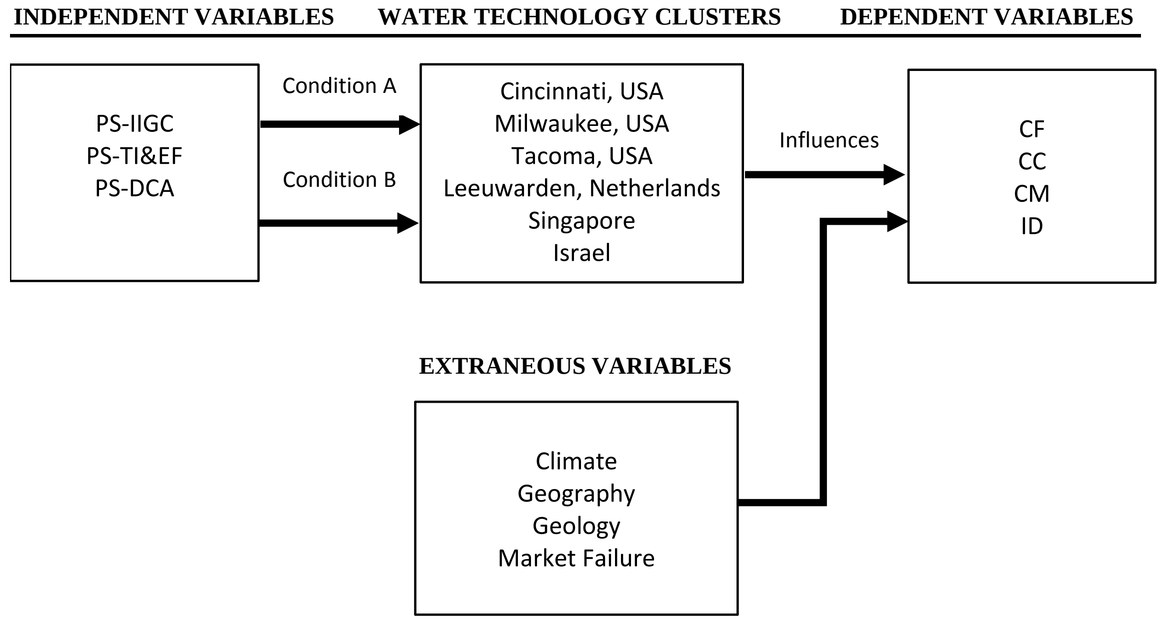
- Independent variable. The independent variable is that antecedent factor (cause) which is presumed to affect a dependent variable. The independent variable is selected by the researcher and is measured, manipulated, or simply observed to determine its relationship to an observed phenomenon (Jaeger, 1990; Creswell, 2009). In this study independent variables are the specific public policies and strategies towards innovation, entrepreneurship and the development and diffusion of water-related technologies. The policies and strategies that form the independent variables (causes) fall into three broad categories: (1) those that foster innovation in institutions and governance at the cluster level (PS-IIGC); (2) those that foster technological innovation and entrepreneurship at the firm level

(PS-TI&EF); and (3) those that foster diffusion of water technologies through commercialization and adoption (PS-DCA).

- Dependent variable. The dependent variable is the principal focus of research interest and the outcome factor which is observed and measured to determine the effect of the independent variable phenomenon (Jaeger, 1990; Creswell, 2009). In this study the dependent variables are the specific responses of the six study subjects to the public policies and strategies towards innovation, entrepreneurship and the development and diffusion of water-related technologies. The dependent variables (effect or outcome) that were identified to be of interest include firm-level competitiveness (CF), cluster-level competitiveness (CC), cluster maturity (CM), and institutional development (ID).
- Extraneous variable. Extraneous variables are independent variables which cannot be controlled by the researcher which may influence the results (Jaeger, 1990; Creswell, 2009). Extraneous variables were identified in the Literature Review and the Conceptual Framework. Examples of key extraneous variables in relation to the six subjects in this study include climate, geology, geography, and market failure.

Figure 1 below provides a conceptual framework for the relationship between the independent and dependent variables in the study and the six subjects of the study.

Figure 3.1 Relationship between Independent and Dependent Variables and Water Technology Clusters



IV. Research Sites/Population/Sampling/Subjects/Participants

The research sites will be the water technology innovation clusters in Cincinnati, Milwaukee, Tacoma, The Netherlands, Israel, and Singapore. This study will employ convenience sampling, purposive and stratified sampling techniques (Babbie, 2007; Schutt, 2009; Rubin & Babbie, 2009). The sample size for the documents selected will be set at 90 documents with the following weighted strata selected:

a) Peer reviewed journal articles - at least 7 documents for each country for a total of 42 articles.

b) Government public policy documents – at least 3 documents for each country/cluster for a total of 18 documents.

c) Statements and reports from international organizations - at least 3 documents for each country/cluster for a total of 18 documents.

d) Authoritative books on the water economy and water resource management - at least 2 books for each country/cluster for a total of 12 books.

V. Instruments/Measures/Sources of Data

The primary instrument for sourcing data was the Internet and specifically the search engines Google and Google Scholar. Key words and phrases were entered into the search engines and the documents which were returned by the search were examined to determine how frequently they had been cited and if their own bibliographies include frequently cited documents within the field. The search is broken down by the following themes:

a) Water, sanitation and hygiene organizations in Cincinnati, Milwaukee, Tacoma, Singapore, Israel and The Netherlands.
b) Water, sanitation and hygiene policy in Cincinnati, Milwaukee, Tacoma, Singapore, Israel and The Netherlands.
c) Water, sanitation and hygiene management in Cincinnati, Milwaukee, Tacoma, Singapore, Israel and The Netherlands.
d) Water, sanitation and hygiene infrastructure in Cincinnati, Milwaukee, Tacoma, Singapore, Israel and The Netherlands.
e) Water, sanitation and hygiene challenges in Cincinnati, Milwaukee, Tacoma, Singapore, Israel and The Netherlands
f) Water technology innovation clusters in Cincinnati, Milwaukee, Tacoma, Singapore, Israel and The Netherlands.

VI. Procedures

The following steps were followed according to guidelines in the literature (Bennett, 2004; Goodrick, 2014):

(a) Identified and clarified research questions and the purpose of the study. The appropriateness of a comparative case study design was considered;

(b) Chose categories of literature and identified their sources. Comparative case studies are strengthened when they are informed by theory which guided the selection of cases and the characteristics of the cases explored;

(c) Chose main methods for research. Conceptual clarity is important in the selection of cases: cases were selected on objectives which were informed by the literature, the data collection strategy and the research questions;

(d) Determined methods of documentation and categorization of data. A clear protocol with systematic procedures was developed to outline the process of data collection, data analysis and data synthesis occurred within and across the cases;

(e) Decided what literature to collect;

(f) Clarified the role of the researcher in the collection of the research material and considered any ethical implications of the study or any issues of confidentiality and sensitivity;

(g) Reviewed and refined research questions, identified goals and objectives, and selected variables for examination;

(h) Reviewed literature;

(i) Interpreted data collected and identified concepts. If there were divergent outcomes across cases, used the observed patterns and relationships to seek out additional evidence and considered alternative explanations for those outcomes;

(j) Revised the research questions;

(k) Verified the validity and reliability of the data;

(l) Completed conceptual and theoretical work to make findings;

(m) Presented the findings in an appropriate form to the intended audience.

VII. Data Analysis

The study consists exclusively of the review and analysis of documentation and interviews related to the following: the general phenomenon of business clusters, and the specific phenomenon of water technology innovation clusters; and the related concepts of innovation and entrepreneurship which take place within cluster and which significantly shape the functioning of clusters. Documents reviewed and analyzed include journal articles, policy papers and official or public records. The document review and analysis process employed in this study follows the six steps adapted from Altheide's 'Process of Document Analysis' (1996) as well as the four quality control criteria for handling documentary sources of authenticity, credibility, representativeness, and meaning (Platt, 1981; Scott, 1990). Finally, to enhance reliability and the validity, 'data triangulation' was used to overcome threats from personal biases and intellectual myopia (Grix, 2001). Through data triangulation, the researcher can rise above the problems that stem from using a limited number of sources or avoid the problems that may arise from drawing from one field or discipline. Using documentation from a combination of sources will offer the widest range of perspectives.

When case studies form the basis of a study Bennett (2004) suggests several issues that must be taken into consideration by the researcher. First, the researcher must define the research objective, including the class of events to be explained, the alternative hypotheses under consideration, and the kind of theory building to be undertaken. Second, the researcher must carefully examine multiple sources – to include histories, archival documents, interview transcripts, and other similar sources pertaining to their specific case - in order to determine whether a proposed theoretical hypothesis or conceptual framework is evident in the case. The researcher must also be alert for examples of deviant cases and determine the specific factors that lead these cases to diverge from expected trends, an issue for which process tracing can greatly assist in narrowing the range of possible explanations or disprove claims that a single variable is necessary or sufficient to produce an expected outcome. Third, the researcher must specify the independent, dependent, and intervening variables and decide which of these are to be controlled for and which are to vary across cases or types of cases. Fourth, the researcher confirms the cases to be studied, assisted by the results from the specification of the variables and alternative hypotheses from previous steps. Fifth, the researcher should consider how to describe variance in the dependent variables, based on emerging data, considering not only individual variables but also types of cases, or combinations of variables, and the sequential pathways that characterize each type. Sixth, the researcher develops structured questions to be asked of each case in order to establish the values of the independent, intervening, and dependent variables. Finally, the researcher completes an analysis of the cases and makes a report of findings and conclusions.

VIII. Trustworthiness and Credibility

In this study validity – which determines whether the research truly measures what it was intended to measure (Lincoln & Guba, 1985) – was achieved by considering the following: (a) searching the literature on clusters and reporting in a balanced way on different aspects of the discourse around this subject; (b) looking within the literature to see if others asked or answered the research questions; (c) avoiding selection bias in selecting the case studies, which can lead confirmation bias, or to causal relationships being understated or overstated, or to deviant cases being overlooked; (d) managing the tension between parsimony and richness in selecting the number of variables and cases to be studied; (e) being cautious about making generalizations from case studies; (f) avoiding the 'degrees of freedom problem' which arises when there are more independent variables than cases; and recognizing that cases are not always independent because of learning and diffusion of knowledge, which compounds the challenges that come with case studies being 'small-n' samples, and limits the amount of new information each additional case study provides (Bennett, 2004; Levy, 2008). To ensure construct validity – which is the degree to which inferences can legitimately be made from the case study back to the theoretical framework on which the case is based– this study will employ multiple sources of evidence; to ensure internal validity – which is about inferences regarding cause-effect or causal relationships – this study will employ pattern-matching and explanation building; and to ensure external validity – which is the degree to which the conclusions in the case can be generalized to other persons, places or times – this study will use replication logic (Rowley, 2002; Yin, 2003). Reliability - which can be thought of as consistency, and involves using research methods that are considered to be robust and using those methods consistently (Lincoln & Guba, 1985) - will be achieved by doing the following the following: (a) consistently following the steps laid out in the procedures developed for each case, which will be guided by an overall conceptual framework and the case study questions; and clear field procedures for data collection supported by a well-developed case study database (Bennett, 2004; Levy, 2008). In general, the execution of a good case study requires good data collection which in turn is highly dependent upon the competence of the researcher who is an active agent in the process (Rowley, 2002). With case studies, random sampling is generally not appropriate. Random selection will often generate serious biases in small-n research, and the selection of a small number of cases requires the careful, theory-guided selection of nonrandom cases (Bennett, 2004; Levy, 2008). The challenge of case studies providing such a small sample size can, however, be offset by their usefulness in helping to examine the kinds of path-dependent learning and diffusion processes which take place within and between case studies (Bennett, 2004; Levy, 2008).

IX. Limitations & Delimitations

Limitations are shortcomings, conditions or influences that the researcher cannot control, that place restrictions on the methodology, and that might influence the conclusions or results (Babbie, 2007; Schutt, 2009; Rubin & Babbie, 2009). Limitations for this study include a time constraint to complete the case study, limits of knowledge of researcher of water technology innovation clusters, limited research on these clusters, a lack of representativeness of the sample, and a lack of independence between case studies (Bennett, 2004; Levy, 2008). Delimitations are choices made by the researcher which describe the boundaries that you have set for the study, and which the researcher has an ethical and academic responsibility to mention (Babbie, 2007; Schutt, 2009; Rubin & Babbie, 2009). Delimitations for this study include the following: size of the sample of documents for analysis; possible non-representation in selecting the literature and the cases to be studied; subjectivity in assessing instances that appear to contradict the frameworks; and subjectivity which can affect the selection and interpretation of data within cases, and cause different conclusions to be drawn from the same data by different people (Bennett, 2004; Levy, 2008).

PART B – CONCEPTUAL FRAMEWORK

I. Overview of Conceptual Framework

The conceptual framework which is employed in this study is built on several theories and concepts that are well established in the social sciences. The aim is to construct a framework in which the combined theories and concepts facilitates a comprehensive, interpretative explanation of the development and diffusion of water-related technologies in the social, economic, and political phenomena that is a water technology innovation cluster (Jabareen, 2009). A conceptual framework possesses ontological, epistemological, and methodological assumptions which are brought together in a coherent manner to play an integral and integrative role (Jabareen, 2009); and if constructed coherently "lays out the key factors, constructs, or variables, and presumes relationships among them" (Miles & Huberman, 1994: p. 440). The conceptual framework also presents actual practices that are related to the phenomenon to facilitate an understanding of what takes place in the real world beyond the confines of theory.

An underlying premise of this study is that the processes related to the development and diffusion of water-related technologies, and the phenomena of water technology innovation clusters, are complex, systemic, and linked to multiple bodies of knowledge that belong to different disciplines; and for a more comprehensive understanding of such processes and phenomena it is best to employ a multidisciplinary approach (Jabareen, 2009). This study also employs a largely qualitative approach which is designed to provide a set of tools for investigating complex phenomena – of which the water technology innovation clusters is an excellent example (Jabareen, 2009). In this study several case studies of water technology innovation clusters are employed to investigate the relationship between institutions and the development and diffusion of water-related technologies and how these impacts finding solutions to issues of water quality, availability, and cost (Baxter & Jack, 2008). Finally, this conceptual framework is designed to provide an internal structure that gives a starting point for conducting observations in the field, for writing interview questions, and for analysis of the phenomenon.

The conceptual framework for this dissertation is built around the theories of institutional economics – as advanced by Douglass North, Vincent Ostrom and Elinor Ostrom – theories of market and government failure – as advanced by Joseph Stiglitz – innovation and entrepreneurship – as advanced by Joseph Schumpeter and Peter Drucker – and competitiveness and clusters – as advanced by Michael Porter, Maryann Feldman and Johanna Francis – and diffusion of innovation – as advanced by Everett Rogers. A summary of the relevant ideas of each person is given below:

II. Market and Government Failure.

The water economy is organized under a framework of private and public institutions. Both set of institutions are subject to failure and this requires that policy makers find the optimal distribution of roles and responsibilities between the private and public sectors. Modern economies are primarily organized under a set of institutions called 'markets' which under ideal conditions - conditions which do not always exist – primarily uses price signals to supply information to ensure that the economy is Pareto efficient. Pareto efficiency is an economic state where resources are allocated in the most efficient manner, which means an economic state or economic strategy of allocation where one party's situation cannot be improved without making another party's situation worse (Stiglitz, 1989; Stiglitz & Rosengard, 2015). Pareto efficiency is a minimal economic notion of efficiency: it does not necessarily result in a socially desirable distribution of resources, it makes no statement about equality or justice, nor does it reflect an acceptable or desirable condition for the overall well-being of a society (Sen, 1993; Barr, 2012). Pareto efficient markets can only occur under stringent conditions: there must be perfect competition which requires that there must be a sufficiently large number of firms that each believes it has no effect on prices (Stiglitz, 1989; Stiglitz & Rosengard, 2015). The market economy is, however, dominated by a small number of large firms and most of these firms face downward-sloping demand and marginal revenue curves – thus actual competition generally deviates from the ideal of perfect competition - and much production and distribution is not mediated through markets, but occurs within large corporations (Stiglitz, 1989; Stiglitz & Rosengard, 2015). Markets therefore are not always Pareto optimal, nor socially optimal: markets often produce too much of some goods - air and water pollution are two good examples - and too little of other goods – fresh water, sanitation, and environmental sustainability are three good examples – which means that markets often ‘fail’ in relation to the theoretical ‘ideal’ market form of perfect competition (Stiglitz, 1989; Barr, 2012; Stiglitz & Rosengard, 2015).

The reality of how market economies actually function is therefore critical to understanding the circumstances under which markets yield efficient outcomes, and the circumstances in which they do not, so that appropriate government interventions can be designed to intervene in ‘economically inefficient’ markets to deliver higher levels of social and environmental outcomes while avoiding creating circumstances under which government failure arises (Stiglitz, 1989; Barr, 2012; Stiglitz & Rosengard, 2015). There is a widely accepted principle among economists that for modern markets to exist at all, and to work efficiently, there needs to be a government to provide the foundations upon which all market economies rest: the minimum necessary conditions would be of defining property rights and enforcing of contracts (Stiglitz, 1989; North, 1991; Barr, 2012; Stiglitz & Rosengard, 2015). Beyond this there are further possible justifications for governments to intervene in ‘economically efficient’ markets: one is to achieve a more equal or equitable distribution of income, which is not guaranteed by Pareto efficient markets, for example to ensure that everyone could afford a minimum supply of water in a situation where full-cost tariffs for water were applied; and another is because people may make sub-optimal judgments about their own welfare, such as not requiring everyone to connect to and pay for public sewerage (Barr, 2012; Stiglitz & Rosengard, 2015).

Stiglitz & Rosengard (2015) identify six conditions – or cases of market failure - under which markets are not Pareto efficient and which provide a rationale for government intervention:

1. Imperfect competition. This is a recognition that most economic activity takes place under conditions of monopolistic competition, oligopoly, and monopoly, to include the protection of intellectual property, and not under conditions of perfect competition. Many water utilities are monopolies and many water-enabled or intensive users are oligopolies or operate under conditions of monopolistic competition. Many water innovators have a vested interest in protecting the intellectual property of their technologies to secure a fair return on their investment.

2. Public goods. This is the recognition that some important goods, like environmental protection or drainage for storm water, will not be supplied by the market or, if supplied, will be supplied in insufficient quantity.

3. Externalities. This is where the actions of one party affects another party, the costs and benefits of that interaction are not property allocated between the parties, and the output and consumption decisions of the parties become suboptimal, with air and water pollution and the spillover effects of research being typical examples.

4. Incomplete markets. This is where private markets undersupply private goods because of high transaction costs and asymmetric information, leading to higher levels of risk, lower levels of innovation, the absence of complementary markets, and lower levels of investment. This is typical of water utilities that tend to be risk

averse, have high sunk infrastructure investment costs with long payback periods, and limited complementary markets.

5. Imperfect information. This is the recognition that economic actors sometimes have a private economic incentive to withhold information - such as about water quality – despite the public good nature of information, which justifies governments requiring public disclosure or investing in research and investment to expand knowledge.

6. Unemployment and other macroeconomic disturbances. This has become less dramatic under a managed economy but still helps to justify public investment in infrastructure for counter-cyclical macroeconomic benefits and to make the overall economy more efficient and productive. Private businesses are averse to investing in infrastructure which have investment-operational cycles measured in decades, without risk reducing institutional arrangements such as public-private partnerships,

The greatest degree of market imperfection is that associated with the production, dissemination, unequal distribution, and underutilization of knowledge and information: (a) firms may have a difficult time appropriating their returns to knowledge, resulting in an under-supply or under-utilization; (b) the capacity to learn and change is highly localized, so the ability to employ new technologies and increase productivity limits the benefits of the 'spillover effect'; (c) local events can have permanent effects that result in path-dependence, which creates the possibility of a 'low-level equilibrium trap'; (d) path-dependence prevents comparative advantages being the optimal basis for judgments about resource allocation and production; and (e) there may be too little entry of capital and new industries into the affected market, firms may not be able to divest themselves of risk, and hence they act in a more risk-averse manner, leading to a smaller market size and to under-performance (Stiglitz, 1989; North, 1991; Barr, 2012; Stiglitz & Rosengard, 2015). All these impediments to the efficient and effective development and diffusion of innovative water technologies are present in the water economy and prevent the emergence, or reduce the competitiveness, of water technology innovation clusters.

In some cases, market failures may be ameliorated by nonmarket institutions; however, issues related to the organizational form employed, and the roles and responsibilities of the two main categories of actors – firms engaged in production and distribution, and private or public entities engaged in regulation, facilitation, and intermediation – becomes extremely important (Stiglitz, 1989). The determinants of success involve more than just differences in the endowments of factors of production, the rate of capital accumulation, the level of technology, or the size of the market; they also involve basic aspects of the organization of the economy, including the functioning of markets, which is related to the ability of firms to acquire information about technology, and about what products can and should be produced, and how they should be produced (Stiglitz, 1989). Also, conditions need to be created whereby firms can reap sufficient benefits from undertaking the production of knowledge that produce spillover effects, thus reducing welfare losses from a reluctance by firms to produce knowledge from which they cannot appropriate all the gains from the returns on their investment (Stiglitz, 1989). Government therefore can play an instrumental role in institutional development providing they do not produce policies that encourage rent seeking nor government failure; however, this needs a government that can recognize both the limits and strengths of markets, as well as the strengths, and limits, of government interventions aimed at correcting market failures. Considering market and government failure in the case studies helps to answer the following research questions: Do governments intervene to facilitate the development and diffusion of water-related technologies and promote the development of industrial clusters for water technology firms? What public policies and strategies do governments employ to support the development or expansion of water technology innovation clusters? What are the roles and responsibilities – or the division of labor – between public and private partners in developing or expanding water technology innovation clusters?

III. Innovation and Entrepreneurship

Innovation and entrepreneurship are occupying an increasingly central role in facilitating change in socio-economic and socio-ecological systems as these systems become more complex, systemic and dynamic. This is especially true of the water economy generally and water technology innovation clusters specifically. Modern socio-economic and socio-ecological systems are characterized by increasing rates of interaction and greater degrees of integration. This process of change is being driven by emerging knowledge-based economies and societies that are dependent on technological progress that is broad both in scale and scope. The entrepreneur is the agent of change at the center of this process and the tool of the entrepreneur is innovation. For Schumpeter (1912, 1934, 1942) innovation is the fundamental instrument for achieving important structural change in human history; but, it was the entrepreneur who - as the technician with the cognitive and perceptual capacity - employs this instrument at the right time and place to initiate and steer change and bring about a new state in society. According to

Schumpeter, most members of society are passive 'consumers' with relatively stable preferences, who play a relatively passive role, who are predisposed to the status quo, and are thus not the primary cause of the socio-economic change; while the dynamic entrepreneur was placed in the middle of his analysis of change. For Druker (1998, 2014), entrepreneurs are agents committed to innovation who seek out and then seize opportunities and assemble resources to either produce new wealth creating resources, or enhancing existing wealth creating resources. Entrepreneurship can then be conceived as a purposeful and focused activity, that begins with a purposeful search for internal or external opportunities, that can be carried out by any organization, that can take place at any stage of the life cycle of a product or organization, that increases an organization's social and economic potential (Schumpeter, 1912, 1934, 1942; Drucker, 1998, 2014). Entrepreneurs can come from both the public and private sectors; entrepreneurship can exist at many scales from individuals, to groups, to entire countries; and the entrepreneur does not have to directly profit from innovation as the benefits can accrue to the society at large. While innovation can take place in any part of society or sector of the economy, the generation of innovation no longer depends on individual personalities but increasingly involves the cooperation of many different actors connected through collaborative networks that even reach across the globe. Spontaneous innovation, though dominant in popular culture is the exception rather than the rule. Schumpeter (1912, 1934, 1942) pointed out that entrepreneurs innovate not just by figuring out how to use inventions, but also by introducing new means of production, new products, and new forms of organization. These innovations, he argued, take just as much skill and daring as does the process of invention. Perfectly competitive firms and markets operating in equilibrium lack innovation and fail to spark the entrepreneurial behavior that is necessary for social and economic progress.

Schumpeter (1912) divided the innovation process into four dimensions: invention, innovation, diffusion and imitation. For him the invention and innovation dimensions have the least impact on society, while the diffusion and imitation dimensions have a much greater impact - invention and innovation often take years, and often require the convergence of multiple streams of knowledge before they become socially acceptable or commercially viable, making the entrepreneur central to implementation. Drucker identified seven sources of innovation, all of which are relevant to the water economy: (1) unexpected occurrences, such as climate change which represents an opportunity, a failure or crisis; (2) incongruities, such as below-cost pricing of water which represents a misalignment in the system and which requires a shift in perspective about the business model to be employed; (3) process needs, such as a greater role for the private sector which is driven by the requirement for greater efficiency; (4) industry and market change, such as deregulation which is a response to structural changes in the water sector; (5) demographic changes, which are impacting demand for water through changes in household size, age or income; (6) changes in perception, such as viewing water as a commodity which does not alter facts but changes their meaning; and (7) new knowledge, such as new treatment technology. New knowledge is the most high-profile source of innovation; however, it is also the most costly and risky type of innovation, with the longest time to market, which requires the convergence of multiple sources of knowledge, and which is very dependent on the capacity of the users and their actual needs. Drucker also offers three principles of innovation: (1) it must be purposeful, which means that innovation is systematic and begins with the analysis of new opportunities; (2) the process of analysis is both conceptual and perceptual and should be understood from the user's perspective; and (3) innovation should be simple and user friendly, and often takes place in small and incremental steps. According to Drucker innovation is built on hard work rather than genius. Considering the role of innovation and entrepreneurship in the case studies helps to answer the following research question: Do individual or organizational champions enhance the competitiveness of water technology innovation clusters?

IV. Institutional Economics, Economic Change and Economic Performance.

Douglass North argued that the tools of neoclassical economics provide an incomplete understanding of long-term economic change and he gave institutions a central place within economics through an extension of neoclassical economics. North challenged the notion of the rational and optimizing actor posited by neoclassical economics and instead argued that agents act intentionally but perceive the world through cognitive lenses that are part inherited from their culture and part derived from their own experience – the drivers of change are thus far more subjective than would be suggested by the neoclassical economics (North, 1991). The actions of agents are also governed by interests and incentives shaped by relative prices, endowments, and institutional constraints, as well as by subjective perceptions of the agent about how the world works (North, 1991). Social and economic outcomes are the sum of individual actions, but the summation process is not a simple adding up of outcomes - interactions between agents whose actions are based on decisions and beliefs critically influence the behavior of everyone so collective outcomes are far more systemic and dynamic and unpredictable than would be suggested by traditional neoclassical economics (North, 1991). Like a complex adaptive system, North's institutional economics is characterized by path dependence and emergence; and, unlike the world posited by traditional neoclassical economics, actors operate in a social and economic reality shaped by non-zero transaction costs, incomplete or asymmetric information, unequal endowments, and institutions that provide economies of scale that incentivize and reward certain actions by agents that may be individually rewarding but collectively sub-optimal (North, 1991). The economy described by North is very reflective of the structure and function of the water economy described earlier in the literature review.

North defines institutions as both the 'rules of the game' and 'means of enforcement,' and separates the rules from the organizations that actually 'play the game'. Institutions are the humanly devised constraints that structure political, economic and social interaction; institutions evolve incrementally; and institutions create order and reduce uncertainty in exchange (North, 1991). This conceptualization makes it possible to have a dynamic relationship between institutions and organizations - as the structure of the rules determines the interests and incentives facing the organizations – and, in some societies, the interaction of institutions and organizations produces a series of institutional changes that incrementally improves the performance of the system (North, 1991). This theory of institutional development explains differences in economic performance: why some organization or societies flourish and grow while others stagnate or decline?

The idea that institutions are the humanly devised constraints that structure political, economic and social interaction is also found in the work of Vincent and Elinor Ostrom. The Ostroms were pioneers in advancing our understanding about how institutions allowed people to gather information and make decisions to creatively solve collective human problems; and, equally importantly, how alternative institutional arrangements could be devised that overcome failures in key institutional regimes, namely the market system and a centralized, hierarchical state. The Ostroms employed the tools of public choice and game theory - linked these to theories about constitutional and institutional design, federalism, and polycentric orders - and applied these epistemological frameworks to the concepts of self-governing as this existed in the real world, especially in relation to water resource management (Ostrom, 2007, 2010, 2015).

The Ostroms saw social and economic problems as existing within a complex, systemic environment and sought to avoid oversimplification and compartmentalization in their analysis of these problems. Thus they employed multiple epistemological frameworks and multiple methodological approaches to understand the problems of social interaction and decision-making at the heart of policy analysis and design, and their body of work can be summarized as seeking to understand how society at different scales of governance employs information gathering and decision-making processes to balance the needs of groups and individuals which are driven by various combinations of shared, competing and conflicting interests, behavior that would be found in a market economy or in an industrial cluster. The contributions of the Ostroms that are relevant to this dissertation, which support the ideas of North (1991), fall under the following: (a) decision-making processes, (b) group versus individual interests, (c) institutional structures and institutional rules versus human behavior, (d) centralized versus decentralized approaches to governance, (e) institutional change, and (f) institutional analysis and design.

A. Decision-making processes. Probably the most important philosophical tenet of the Ostroms was the belief that humans can solve most collective problems without the intervention of a centralized, coercive and hierarchical authority, and that self-governance is the optimal mechanism for selecting decision outcomes, which is the ideal outcome for a competitive and sustainable industrial cluster. The promotion and maintenance of a self-governing administration was more compatible with heterogeneous, 'bottom-up' decision-making regimes as opposed to homogeneous, 'top-down' decision-making regimes, which are again characteristic of industrial clusters. This perspective contrasts with the view of many social scientists that perceive the general citizenry as ignorant and uninformed on social and economic issues and incapable of making decisions to solve collective action problems. The Ostroms employed a methodological individualist approach – which puts causal accounts of social phenomena as flowing primarily from the motivations and actions of individual agents pursuing their own interests - which required the social scientist or analyst to consider how individuals or groups of citizens understood social problems, and then how they chose to act upon them (Mises, 1949; Arrow, 1994; Hodgson, 2007). Individuals, and groups of citizens who shared common interests and concerns, were best placed to judge of their own circumstances and conceive contextually appropriate solutions, such as the highly local issues that are found in local and regional water economies. The process of information gathering, problem framing, decision-making, and action might include contestation, even conflict; but it was also very likely to involve cooperation and compromise, which builds social capital between individuals within communities, stretching the time horizon to permit reciprocity and commitment, thus permitting communities to resolve serious conflicts. Another important position of the Ostroms was the rejection of the notion of a single and universal 'optimal' solution, as well as the tradition within the social sciences to search for and implement as policy that solution (Ostrom, 2005).

B. Institutional structures and institutional rules versus human behavior. A core tenet of the Ostroms was a belief that institutions matter and that an understanding of socio-economic systems requires a deep understanding of institutions. Human behavior is driven by both altruism and self-interest, as well as by the structure of institutions, and the formal and informal rules that they impose on individuals and groups. These structures and rules provide constraining and enabling conditions, which determines the set of potential choices that are available to people, and which create regularities in social processes that structure interactions between people in social settings. The design of institutions is therefore meant to facilitate communication, deliberation, and contestation among the members of a community, such as a water technology innovation cluster, to enable that community to solve challenging dilemmas and achieve shared goals. Effective institutions require buy-in and commitment from those who would be bound by the rules. External authorities can enhance or impede the development of self-governing institutions by the 'constitutional' rules they adopt to address collective problems, which accounts for the reason why the Ostroms sought to facilitate the process of self-governance and constitutional choice at the appropriate scale of governance, rather than advocate for expert solutions imposed by authorities situated at a distance. The Ostroms also believed that well designed institutions allowed members of a community to harness nature in a sustainable and equitable way and overcome the 'tragedy of the commons' which is a potential dilemma of common pool resources or resources for which there are unclear property rights (Harding, 1968; Ostrom, 1990).

C. Centralized versus decentralized approaches to governance. Ostrom, Tiebout and Warren (1961) refined the concept of 'polycentric' governance which has been applied extensively to considerations of water resource management. Polycentric governance conceptualizes a system of government with multiple, formally independent decision-making centers – functioning under quasi-market conditions – as being more flexible and responsive to citizens' needs than a hierarchical governance regime. Polycentrism is a decentralized approach to governance which removes government as the focal point of ultimate knowledge and authority and it is designed to change how people think about shared resources, public services, centralized authority, collective decision-making, and property rights. Polycentrism suggests that governance should take place at multiple scales - because decision-making should be context specific - which permits a greater variety of policy approaches to meet diverse needs and conditions. Polycentrism provides a closer connection between taxes and benefits, reduces the chances for free-riding associated with large anonymous groups, and increases the likelihood of consensus which naturally comes with smaller, self-selected groups (Ostrom et al, 1961; Olson, 1965). Polycentrism has multiple centers of power - with jurisdictions that sometimes overlap, and at other times have different roles and responsibilities – that creates a check on power and allows citizens to seek justice elsewhere, thus advancing human welfare and creating a more stable, responsive and accountable political order. The conceptual framework of polycentric governance is that of a complex and adaptive system that mirrors the workings of an ecosystem in nature. The Ostroms believed that traditional neoclassical economic and political models designed to explain decision-making in complex policy arenas were too simplistic to capture the variety of institutional forms people had created (Ostrom, 2007).

D. Institutional change. Institutions are not always static and, ideally, they should be able to adapt to changing circumstances, and adapt with evolving sets of rules for managing emerging social, economic, and environmental dilemmas, such as those faced by the emerging water economy. Institutions influence human behavior but within that structure people can exercise agency and can transform institutions, potentially to better serve human needs or solve complex collective problems. Overall, these investigations show that - given the ability to communicate, experiment, and adapt institutional rules - people can develop various solutions to the sustainable management of the common pool resources (CPR), to which the 'tragedy of the commons' is supposed to apply, and to overcome both market and government failure to which the water economy is subject.

Many different institutional arrangements are feasible. The key to deciding which of the alternatives should be selected is found in the design the citizens would choose for themselves. Where others saw chaos, the Ostroms saw an underlying logic in which policy settled at varied levels consistent with the appropriate degree of social consensus. Not every issue had to be settled at the level of the state or even the metropolitan area. Instead, they predicted that simultaneous policy activities in distinct arenas could emerge without having to find a single consensus in the large scope decision settings. Elinor Ostrom and her research collaborators demonstrated that human communities have created a number of informal institutional arrangements for regulating access to common resources that succeed in creating a stable balance between resource use and renewal.

Institutions are rarely either private or public – 'the market' or 'the state'. Many successful CPR institutions are rich mixtures of 'private-like' and 'public-like' institutions defying classification in a sterile dichotomy. Here 'successful institutions' mean institutions that enable individuals to achieve productive outcomes in situations where temptations to free-ride and shirk are ever present. The water economies of many regions are now successfully employing public-private partnerships to optimally allocate technical, policy and regulatory responsibilities for water where these responsibilities were previously exclusively a government responsibility.

The competitive market - the epitome of a private institution - is itself a public good. The Ostroms also found the existence of path-dependence given that economic structures can crystallize around small events and lock-in, and this has raised awareness among policy makers that governments should avoid the two extremes of either coercing a desired outcome or keeping strict hands off, and instead seek to push the system gently toward favored structures that can grow and emerge naturally, as is the preferred strategy for building water technology innovation clusters . This is not a heavy hand, nor an invisible hand, but a nudging hand (Arthur, 1999). Policies succeed better by influencing the natural and evolving processes of the formation of economic structures, rather than by forcing static, inflexible and predetermined outcomes.

E. Institutional analysis and design. The Ostroms advanced that a systematic, comparative assessment of institutions required a framework supported by a family of theories that facilitates an analysis of institutional participants, structure, rules, and performance, which allows for theorists to predict likely socio-economic outcomes, but which also allows policy makers to improve collective choices through institutional reforms (Ostrom & Ostrom, 2003). Elinor Ostrom's framework for Institutional Analysis and Design will help to highlight the complex, interlocking nature of institutions and facilitate an understanding of institutional rules, and the impact of the costs and benefits that are the outcome of social interactions and institutional processes, as subjectively understood by institutional stakeholders. Institutional Analysis and Design has three analytic levels: the operational level, where day-to-day decisions are made; the collective choice level, that includes those decisions that set policies that govern the operational level; and the constitutional level, which establishes who will be involved and lays out the rules to be used at the collective choice level. Institutional Analysis and Design helps to understand the virtually endless number of institutional permutations that exist in the real world; and, also, to ensure that when designing or reforming institutions that the incentive systems of an institutional regime are aligned between these three levels, for without this alignment institutional arrangements for collective action will fail. Despite the complexity of institutions, the Ostroms believed that within the institutional framework patterns could be identified and a finite set of rules generated for generalization into a prescriptive framework to support well-performing collective choice processes.

Considering the relationship between institutions and economic performance in the case studies helps to answer the following research questions: What public policies and strategies do governments employ to support the development or expansion of water technology innovation clusters? and Does the institutional setting of a jurisdiction affect water technology policy outcomes?

V. Industrial Clusters & Competitiveness

A. Michael Porter's Diamond Model of Competitiveness

Developing and diffusing water technologies is an important activity within the emerging water economy, especially as technologies are important for ensuring a reliable supply of clean quality, protection of the environment from polluted water, and the production of fresh water with minimal energy inputs. Water technology innovation clusters are being promoted as the most effective and efficient structure for producing new cost-effective water technologies, supporting local economic development, and improving the quality of water infrastructure. Water technology innovation clusters are expected to fulfill this mission by supporting the development of new businesses and expanding products and services of existing businesses through the following: (1) by spurring innovation through sharing ideas and solutions to challenges in the water economy and by increasing access to finance for R&D and commercialization; (2) by accelerate the development of new technologies by building partnerships to facilitate easier access to test beds and for pilot studies; and (3) by increasing communication between technology firms, utilities and regulators to streamline the diffusion and adoption of new water technologies in the marketplace. Michael Porter's Diamond Model provides a framework for understanding how and why industrial clusters situated in local economies support the development of competitive water technology firms and a competitive water technology industry. Porter's economic theory explains that clusters with certain factors available to them have an increased likelihood of becoming internationally competitive and explains how proactive governments can act as catalysts to improve the conditions for competitiveness. Porter moves beyond the traditional economic notion that location, natural resources, labor and population size are the primary determinants in a country's comparative economic advantage: a company's ability to compete in the international arena is based mainly on an interrelated set of location advantages that certain industries in different nations possess:

1. Factor Conditions. The first element of the diamond is factor conditions. These are the human, physical, knowledge, capital and infrastructural resources whose efficient and effective deployment determines the competitiveness of any industry. Factors can be either basic – such as natural resources, unskilled or semi-skilled labor, or debt capital – which require little investment, or advanced – such as highly skilled labor,

modern telecommunications, or sophisticated financial products – which require large and often sustained investments for their development which delivers higher-order competitive advantage. Factors can also be generalized – which means they can be widely deployed across the economy – and can be easily duplicated, or specialized – which means that they have a narrow field of application – and cannot be easily duplicated, offers a unique competitive advantage, but which requires focused, high risk private and public investment. A country or industry with a generous endowment of basic factors tends to be put at a long-term disadvantage as industries seek to compete along cost or price, rather than quality or innovativeness, and cost and price advantages tend to be easily duplicated and unstable and unsustainable in the long run. Disadvantages in basic factors are often a stimulus to innovation as governments, industries and firms devote scarce resources to the creation of advanced and specialized factors to create a competitive advantage.

2. Related and Supporting Industries. Firm that are innovative and competitive do not succeed exclusively through their own efforts as few firms rely on internal markets to produce all the inputs and services they require to produce their own outputs. Firm that are innovative and competitive require relationships with other firms that are also innovative and competitive, and which can offer high quality, cost-effective inputs and services to support the production process. When those related and supporting industries are domestic a process of mutual innovation and

upgrading is possible as firms use contacts that extend through the entire value chain to engage in information sharing, mutual learning, and joint problem solving. Firms are also able to spread some of their costs through the sharing of common resources and R&D and pull through demand for complementary products and services that supports the entire industry value chain.

3. Demand Conditions. In a market economy what is produced and the price it can command is determined by the needs of buyers and their purchasing power, and without effective demand the other determinants of the 'diamond' offer only latent attributes. The composition of home demand, the size and pattern of growth of home demand, and the presence of foreign companies that operate in the domestic market and buy domestically are the three drivers that shape the rate and character of innovation by domestic firms, which in turn drives competitiveness. With the first driver the presence of sophisticated and demanding domestic buyers exert pressure on firms to offer goods and service of high quality that meet buyer needs. With the second driver a large and growing domestic market encourages large-scale facilities, technology development, and productivity improvement that deliver economies of scale and supports learning. With the third driver domestic firms create a point of access to international markets through foreign multinational firms as the needs of the domestic market get transmitted to or inculcated in foreign buyers which are then transmitted back to their home country.

4. Industry Structure and Rivalry. The political-economy context at national, regional, and local scales, and the industry context in relation to structure and rivalry, influence how firms are created, organized and managed. These contexts either constrain or expand the competitive possibilities available to the industry and the firm. The achievement by firms of competitive advantage depends on the degree to which the choices of firms with regards to goals, strategies, and ways of organizing and managing firms in industries, are aligned to the sources of competitive advantage present in a nation and in an industry. Firm strategy and structure at the macro level are affected by national priorities and a desire for national prestige; while at the micro level they are reflective of both company and individual goals. National priorities affect the sustained public commitment to ensuring that an industry has access to high quality human resources, capital, and infrastructure. Company goals, strategies and organizational choices are most strongly determined by ownership structure, the nature of corporate governance, the motivation of owners and holders of debt, and the incentive structure created to address the principal-agent problem with senior managers. Vigorous local rivalry can also stimulate productivity and competitiveness by creating a pressure to upgrade factors, innovate processes and products, and find new markets. Firms are therefore strongly influenced by the behavior of its competitors, and the presence of competitors in the domestic market forces firms to seek positions that are dependent on advanced factors created by and

unique to the firm, rather than basic factors available to all firms in the domestic market. Firms that have upgraded their competitive capacity in the domestic market are in a stronger position to upgrade their strategy to compete nationally and globally as they seek to expand their markets and increase profitability.

5. Government and Chance Events. The role of government and chance events are not as directly important as the four determinants in influencing the creation of a competitive advantage; however, they can be significant in shaping the direction and magnitude of each of the four determinants. Government policies can influence the entire system of determinants and their interaction and either undermine or enhance competitive advantage by acting as a catalyst or challenger for change. Government policies determine to a large degree the political, economic and social environment in which industries and firms must operate. Governments cannot create competitive industries and firms but they can be a positive influence in their creation and upgrading through health, safety and environmental regulations which raise product, process or performance standards, through public procurement which stimulates demand for advanced products, through support for education and training which promotes the creation of advanced and specialized factor creation, and through anti-trust and competition regulations which discourages the formation of monopolies and cartels and stimulates local rivalry. Chance events are developments beyond the control of firms that can play an important role

in shifting competitive advantage in many industries and include events such as pure inventions, breakthroughs in basic technologies, wars and conflicts, and natural disasters etc.

B. Maryann Feldman and Johanna Francis. Feldman and Francis examine clusters and explain how they emerge, grow and become embedded in the wider economic system. From their research they offer a three-phase model of cluster formation:

1. Phase one. In the first phase the initial entrepreneurial ventures have been sparked, possibly by some exogenous event, and the process of entrepreneurship undertakes a classic trial and error or learning-by-doing process as it seeks to adapt to the emerging crisis or opportunity. The learning process and the adaptation to new events and to the existing environment are important determinants in the development of the cluster. The cluster, its structure, its features, and its characteristics therefore emerge over time from the individual activities of the entrepreneurs and the organizations and institutions that co-evolve to support them.
2. Phase two. The second phase is dominated by increased entrepreneurial activity as entrepreneurs adapt to changes in the external environment and define and mobilize resources to promote and protect their interests. The independent actions of entrepreneurs are catalytic components of a self-organizing system and clusters self-organize around the entrepreneurial activities - the organization of the cluster and the entrepreneurial ventures evolve simultaneously, synergistically, and symbiotically. Once a critical

mass of start-ups is in place, supporting organizations are attracted and the cluster becomes self-sustaining: entrepreneurs are attracted by physical and human capital in the area, public and private networks build up to support and facilitate the ventures, relevant infrastructure is created through public and private initiatives, and services grow to support companies.

3. Phase three. The final stage is the establishment of a critical mass of resources: local resources developed within the region and external resources, such as venture capital, which locate to the area to benefit from the cluster. It is usually after the cluster becomes established that regional public sector financing and grant giving programs are established. Government policy creates further incentives for investment, incubators and other technology partnerships are created to promote growth of the industry, and mergers and acquisitions begin to thin out the companies.

Considering the relationship between clusters and competitiveness in the case studies helps to answer the following research questions: Do governments intervene to facilitate the development and diffusion of water-related technologies and promote the development of industrial clusters for water technology firms? What public policies and strategies do governments employ to support the development or expansion of water technology innovation clusters? What are examples of successful clusters in which specific strategies of government intervention can be used as good practices? and What are the roles and responsibilities – or the division of labor – between public and private partners in developing or expanding water technology innovation clusters?

VI. Diffusion of Innovation

Addressing the key challenges facing the emerging water economy will require both appropriate institutions and greater deployment of a wide range of water-related technologies. The water economy is, however, faced with key barriers to the development, diffusion, and adoption of water technologies such as insufficient access to financing for innovation, high capital-intensity, and built-in risk aversion of water utilities (EIP, 2014; Conway et al., 2015, Speight, 2015). Overcoming these barriers should therefore be a priority for public policy to ensure that water-related activities make a sustainable contribution to economic development, public health, and environmental preservation. The development of institutions that stimulate, strengthen and sustain research, development, diffusion and adoption of the water technologies that are essential for the successful management of water-related challenges must precede the development of water technologies.

The existence of substantial demand for water-related technologies must not lead to the assumption that the supply of water-related technologies to meet that demand will automatically follow, as the utility-optimizing, profit-maximizing theories of neo-classical economics would suggest. It must be recognized that technically inefficient and ineffective innovations can and do diffuse, while technically efficient and effective innovations fail to be adopted (Abrahamson, 1991), a pattern identified by Conway et al. (2015) with the innovation bias in supply-side over demand-side water technologies. Policy makers, innovators and entrepreneurs must therefore understand what facilitates diffusion of an innovation given the characteristics of an innovation and the characteristics of the social, political, and economic system in which the diffusion process will take place. Theories for the diffusion of innovations seek to explain how, why, and at what rate new ideas, policies, and technologies spread, are adopted, and become part of the fabric of social, political, economic and technological life. Diffusion of innovation theory complements economic theory related to market failure by offering explanations for why market forces sometimes fail to support the development or diffusion of water-related technologies - namely insufficient incentives for investment, the public goods nature of water, incomplete markets, or information asymmetries – which become bottlenecks during the diffusion process. Everett Rogers (1962, 2003) argues that diffusion is the process by which an innovation is communicated over time through a specific population or social system and, depending of the characteristics of that population or social system, the theory of diffusion explains how an innovation gains momentum, diffuses, and is adopted, or conversely is not adopted.

Rogers (1962, 2003) proposes that four main elements influence the spread of a new idea: the social system, rate of adoption, communication channels, and the innovation itself. This diffusion process also relies heavily on the quality of human capital, is strongly influenced by the decision-making processes, which people employ, and the innovation must be adopted by a critical mass of persons to be self-sustaining with a social system.

The adoption of an innovation, which involves series of stages people undergo from first hearing about a product to finally adopting it, is an individual process; the diffusion of an innovation, which is how an innovation spreads, is a group phenomenon. The structure and characteristics of a social system have a strong influence on the diffusion and adoption of innovations (North, 1962, 2003; Wear, 2012). First, innovations are often adopted within a social system through two types of innovation-decision processes: collective innovation decisions and authority innovation decisions. The collective decision is a bottom-up process which occurs when adoption is by consensus; while the authority decision is a top-down process which occurs when adoption is among very few individuals with high positions of power within an organization or hierarchical group. The development, diffusion and adoption of water-related technologies is often a top-down process driven by regulation and public investment rather than water scarcity or market demand, which is why Norway and Switzerland are leaders in water innovation (Conway et al., 2015). Second, communities with strong interpersonal networks, such as rural communities or clusters, have the capacity to be more innovative or have faster rates of diffusion-adoption. Third, opinion leaders, gatekeepers and change agents are very important in the diffusion-adoption process because of the influence they have on the diffusion-decision process, on the various categories of adopters, and at the various stages of the diffusion process. The water economy is considered a low innovation sector and a supportive culture is considered critical to stimulating innovation and supporting the diffusion-adoption process (Conway et al., 2015; Speight, 2015). Fourth, elites often have a vested interest in the status quo and are often not innovators, and innovations are often introduced by outsiders who push innovations up a hierarchy to the top decision makers: innovation is often a bottom-up and outside-in process (Rogers, 1962, 2003; North, 1991). The bottom-up and outside in influence is particularly strong in the water economy where water utilities generally rely on outside actors to identify solutions to problems, perform R&D, and deliver pre-tested technologies (Conway et al., 2015; Speight, 2015).

Communication-influence processes are important to the diffusion-adoption process and opinion leaders, gate keepers, and change agents tend to have special characteristics that make them important actors (Rogers, 1962, 2003). Opinion leaders have the most influence during the evaluation stage of the innovation-decision process and on getting late adopters on-board with an innovation. Opinion leaders typically have greater exposure to the mass media, are more cosmopolitan, have greater contact with change agents, have more social experience and exposure, have higher socioeconomic status, and are more innovative than others. Opinion leaders and change agents are also important in assembling the network or social system, which implements innovation. Change agents introduce innovations to a social system first through the gatekeepers, then through the opinion leaders, and then to the wider community. It found that direct word of mouth and example were far more influential than broadcast messages. Not all individuals exert an equal amount of influence over others. In this sense, opinion leaders are influential in spreading either positive or negative information about an innovation. Nevertheless, opinion leaders and change agents do not always fit neatly within the structure of a traditional hierarchy of influence based on official, bureaucratic, technocratic, political or economic status. In addition to the gatekeepers and opinion leaders that often exist within a given community, change agents may come from outside the community. Therefore, innovators are not necessarily members of the elite or insiders and much innovation is a bottom-up, or outside-in, process.

The rate of adoption that is present in a social system, which is the relative speed at which persons adopt an innovation, is significantly determined by an individual's adopter category (Rogers, 1962, 2003). The rate of adoption is usually measured by the length of time required for a certain percentage of the members of a social system to adopt an innovation. Rogers divides adopters into five categories: innovators, persons with a high threshold for risk who are willing to experiment with innovations; early adopters, who are leaders within a social system who are aware of the need for change and are willing to embrace innovations; the early majority, who are willing to adopt a successful innovation for which there is perceived evidence of a need; the late majority, who are risk averse persons who will adopt well-established innovations that offer established benefits; and laggards, who are conservative, bound by tradition, and resistant to change and will often require some form of pressure to adopt an innovation. In general, innovators and early adopters require a shorter adoption period when compared to late adopters and laggards.

Rogers (1962, 2003) also identifies several stages through which the innovation-diffusion process progresses. The rate and degree of adoption in this cycle is significantly influenced by the type of adopters present in the social system and innovation-decision process the adopters employ. At some point along the adoption curve, the innovation reaches a critical mass with enough individual adopters to ensure that the innovation is self-sustaining. Identifying the stage by which a person gains awareness of an innovation and the need for that innovation, tests the innovation, makes continued use of that innovation, and makes the decision to adopt (or reject) determines the rate and degree of diffusion and adoption. The diffusion-adoption cycle includes awareness of the need for an innovation, interest in the innovation, evaluation of the need for the innovation, trial of the innovation to test it, and the decision to adopt (or reject) the innovation (Rogers, 1962, 2003). The five stages of the diffusion-adoption cycle are: (1) knowledge, (2) persuasion, (3) decision, (4) implementation, and (5) confirmation. At any time during or after the adoption process a person might reject an innovation. Diffusion thus occurs through a decision-making process, which is a series of communication channels over a period that exists among the members of a similar social system.

Rogers (1962, 2003) also identified five main factors that influence adoption of an innovation, and each of these factors is at play to a different extent in the five adopter categories and during each of the five stages of the adoption cycle. The five factors are: (1) relative advantage, the degree to which an innovation is seen as better than the idea, program, or product it replaces; (2) compatibility, the degree of consistency of the innovation is with the values, experiences, and needs of the potential adopters; (3) complexity, the degree of difficulty in understanding how to use the innovation; (4) triability, the extent to which the innovation can be tested or experimented with before a commitment to adopt is made; and (5) servability, the extent to which the innovation provides tangible results. Rogers outlines several strategies to help an innovation reach this stage, including when an innovation is adopted by a highly respected individual within a social network thus creating an instinctive desire for a specific innovation. Another strategy includes injecting an innovation into a group of individuals who would readily use a technology, as well as providing positive reactions from and benefits for early adopters. Considering the processes for the diffusion and adoption of innovations in the case studies helps to answer the following research questions: Do individual or organizational champions facilitate the development and diffusion of water-related technologies and enhance the competitiveness of water technology innovation clusters?

In Table 3.1 a list of concepts, which have been identified as collectively constituting the theoretical framework of both the water economy and water technology innovative clusters, are presented.

Table 3.1. Conceptual framework for the water economy, water technology innovation clusters and selected sources of data that support these concepts

The Concept	*Inquiry Character*	*Selected Sources of Data*
Path Dependence	Epistemological Concept	Douglass North
Emergence	Epistemological Concept	Douglass North & Elinor Ostrom
Transaction Costs	Epistemological Concept	Douglass North
Institutional Analysis	Methodological Concept	Elinor Ostrom
Market Failure	Epistemological Concept	Joseph Stiglitz
Innovation & Entrepreneurship	Epistemological Concept	Joseph Schumpeter & Peter Drucker
Clusters & Competitiveness	Epistemological Concept	Michael Porter
Cluster Formation	Epistemological Concept	Maryann Feldman & Johanna Francis
Diffusion of Innovation	Epistemological Concept	Everett Rogers

CHAPTER 4

CLEAN WATER TECHNOLOGY PROGRAM: THE EPA INITIATIVE TO PROMOTE WATER TECHNOLOGY INNOVATION CLUSTERS IN USA

I. Introduction

Policymakers in the United States are increasingly linking two traditionally separate policy domains: the need to strengthen regional economies so that they remain competitive in the global economy, while providing good jobs for workers and a healthy tax base for local governments; and the need to upgrade water infrastructure to ensure an adequate supply of fresh water, to protect public and environmental health, and to support industry and agriculture. The historic approach was not only to address these policy domains separately but to see them as being in opposition – economic development came at the expense of environmental health. The current trend, however, is to approach water resource management and local economic development in an increasingly integrated and coordinated manner. There are several components to this policy logic. One is that public and environmental health can be improved through innovative water technologies that reduce or minimize pollution, increase the efficiency of water use, and reduce the amount of energy required to transport and treat fresh-and-waste water. A second is that the general competitiveness of the economy is supported by a reliable supply of fresh water. A third is that innovative water technology firms can form the basis of a competitive industrial clusters. A fourth is that innovative and competitive water technologies firms are most likely to emerge in business clusters or business ecosystems that exist within a well-developed local water economy with strong demand from water utilities, water-intensive industries, or water-enabled industries that demand cutting-edge water technologies. Finally, innovation and entrepreneurship within the cluster is facilitated by a well-developed local research and educational base that is particularly geared to developing cutting-edge science and engineering capabilities. Water technology innovation clusters (WTICs) are increasingly seen by U.S. policy makers as a potent source of innovation and entrepreneurship that will lead to increasing productivity and competitiveness while providing innovative solutions to both existing and emerging water resource management challenges. Governments and leaders in the water sector are increasingly supporting the development of these clusters through innovative policy measures, novel financing tools for startups, cross-sector partnerships that connect entrepreneurs with other stakeholders, and support for cutting-edge research to build economically stronger and environmentally more resilient communities.

This case study provides a background to the Environmental Protection Agency's (EPA) Clean Air and Clean Water Technology initiatives from which arises the EPA's support of Water Technology Innovation Clusters. This case study begins by showing how the federal government is attempting to shift from a fragmented policy framework to an integrated policy framework to jointly address environmental and economic challenges. It then recounts how the EPA and Small Business Administration (SBA) launched the Water Technology Innovation Cluster (WTIC) Program in Cincinnati. The case study then outlines the goals and objectives of the EPA with regards to the WTIC Program, the strategies employed by the EPA to roll out the WTIC Program, and how these strategies, through specific pieces of legislation and programs, fit into the larger federal policy framework to support innovation and entrepreneurship. Throughout the case study, specific examples of EPA projects are offered to demonstrate the Clean Water Technology Program in practice.

II. Background to the Federal Policy on Innovation & Clusters

Public policy at all political scales in the U.S. has long been involved in promoting clusters to support local and regional economic development; in regulating water resources to protect public and environmental health; and in supporting universities and federal laboratories which carry out research and develop technologies which protect the quality and quantity of water resources (Wessner 2012; Water Citizen, 2013). This long-standing commitment to economic development and to water resource management involves legislation and regulation going back decades. It has also involved the commitment of public resources to support research, development, technology transfer and the commercialization of innovative water technologies. The effectiveness of these policies and programs for both economic development and water resource management has, however, been criticized as being ad hoc and uncoordinated, for demonstrating a lack of understanding about both regional economic dynamics and the complexity of the water economy, for being under-resourced, for misdirecting those limited resources to the wrong sectors, and for a gap between the public rhetoric and the reality of the government's commitment to meeting water challenges (Rodgers 1993; Mills et al. 2008; Water Citizen, 2013). Several reports highlight these concerns. With respect to business clusters, a 2008 study by the Brookings Institute suggests that federal programs tended to target lagging or declining sectors rather emerging or growing sectors, support economic inputs or factor endowments rather than strengthening advanced or specialized factors, and channel only about one percent of economic development spending towards upgrading clusters (Mills et al. 2008). With respect to water resource management, a 2004 study by the National Research Council suggests the following: (1) that real levels of total spending by 10 federal agencies for water resources research, which were around $700 million in 2000 dollars, have remained relatively constant or may have even slightly declined over the previous 30 years; (2) that funding for water resources research has not paralleled the growth in either demographic and economic parameters, or the growth in federal budget outlays compared to other sectors; (3) that the actual federal water resources research portfolio is inconsistent with, and lags behind, the public policy priorities assigned for water resources; (4) that water research is traditionally conducted in a decentralized and uncoordinated manner; and (5) that the water resources research portfolio has a decidedly short-term focus when seeking solutions to water resource problems (National Research Council 2004). Also, with respect to water resource management, a 2012 study by the Congressional Research Service on selected federal water activities suggests that while water resources have historically received generally broad policy attention, the emphasis of federal research has been towards supporting regulation rather than innovation, and towards environmental protection rather linking water development with economic development (Cody 2012). In recent years, however, there appears to be a shift towards linking water development with economic development, and to shift the financial responsibility from the state towards the private sector, and this can be seen in part by the programs of the Small Business Administration (SBA) and Environmental Protection Agency (EPA) towards supporting clusters involved in the innovation and commercialization of water technologies (Water Citizen, 2013).

In the U.S. water economy some of the specific challenges that policy makers and water innovators at all scales must recognize and address include: (1) a highly fragmented or dis-aggregated fresh-storm-and-waste water industry with a few large utilities and a large number of small, financially-constrained community water utilities; (2) regulated water utilities and water businesses that have traditionally been highly risk averse; (3) an innovation diffusion process where the movement of technologies from idea to commercialization face points of dis-junction and a diffusion timeline measured in decades rather than months or years; (4) a water supply-demand imbalance than it very pronounced in some regions of the country; (5) a water resource management challenge that crosses geographical and jurisdictional boundaries; and (6) an unsustainable funding gap in maintaining and replacing aging infrastructure (Water Citizen, 2013; Earth & Water Group 2016; EPA Water Technology Cluster Leaders, n.d.). To the first challenge, a highly fragmented or dis-aggregated water industry creates challenges for water entrepreneurs and innovators to establish viable business strategies to support investments in new water technologies. To the second point, state-by-state regulation and technical standards for technology testing, certification and approval, limits market size and thus profitability; and developing a broad product range, building multiple distribution channels, and providing technical support to serve multiple, divergent markets raises the cost of, and risks associated with, commercialization (Water Citizen, 2013; Earth & Water Group 2016; EPA Water Technology Cluster Leaders n.d.). To the third point, a reduction in the efficiency and effectiveness of the process of innovation and diffusion of water technologies also raises the costs of, and risks associated with, commercialization. Small businesses lack the resources to wait for the decline in capital and operating costs, and improved learning, that comes with wide-spread adoption and economies of scale in production (Jaccard 2005). Addressing the intersection between the management and protection of water resources, the promotion of economic development, and the promotion of water technology clusters, requires a public policy framework that recognizes that the water economy exists in a complex social, economic and environmental context with competing interests and shifting priorities at multiple scales; it involves recognizing that water is a unique resource with unique properties; and it has to be addressed by multiple strategies (Water Citizen, 2013; Earth & Water Group 2016; EPA Water Technology Cluster Leaders n.d.).

The most recent set of federal responses to the water economy have involved a combination of strategies to strengthen business innovation ecosystems connected to water resources. This strategy has been implemented through programs and projects aimed at increasing the efficiency and effectiveness of the innovation-diffusion and innovation-commercialization processes. These processes involve innovations in a number of complementary areas: (a) in streamlining the development, testing, and adoption of better water technologies, (b) in developing models for the sustainable financing of water project, (c) in choosing appropriate structures for public-private partnerships, and (d) in regulations for protecting water quality and public and environmental health that stimulate innovation and entrepreneurship. For the Obama administration, the strategy has involved policies connected to the broader goals of promoting sustainable economic growth through innovation and entrepreneurship that strengthen competitiveness in key economic sectors, chief among these being 'advanced' and 'knowledge-driven' sectors such as 'clean' and 'green' technologies. These strategies of the Obama White House were articulated and communicated to the public and to policy makers through a series of presidential addresses, presidential memorandum, White House Summits, and legislation (The White House, 2009; The White House, 2011; The White House, 2015; The White House, 2016).

In 2009, President Obama issued the first 'Strategy for American Innovation' which articulated a vision that innovation is essential to developing competitive industries, sustaining long-term economic growth, and lifting incomes and standards-of-living; and that the private sector remained the engine of economic growth (The White House, 2009). Government should act as a facilitator for private-sector led innovation and government's facilitation role was best carried-out through a combination of incentives and regulations (The White House, 2009). The strategy emphasizes that the building blocks of American innovation rests in strengthening and broadening national advantages in R&D, better harnessing science and technology, building a knowledgeable and skilled world-class workforce, creating a national environment which supports entrepreneurship and risk taking, building and maintaining high quality public infrastructure, maintaining national advantages in information technology and knowledge management, and securing competitive advantages in emerging industries and their associated technologies (The White House, 2009). In both 2011 and 2015, the 'Strategy for American Innovation' was updated and expanded. In the 2011 version a 10-year, $150 billion commitment was made to public investment to support R&D, and piloting the commercialization of clean energy technologies, such as solar, wind, green buildings, efficient lighting, next-generation bio-fuels, proliferation-resistant nuclear reactors, energy storage, and carbon capture and storage (The White House, 2011a). The 2015 version set out the six key elements which would set the framework for the evolving innovation strategy: (1) investing in the building blocks of innovation, which include basic R&D, education, infrastructure, and immigration; (2) stimulating private-sector innovation through tax credits, policies to support innovators and entrepreneurs commercialize technologies, and through supporting local innovation ecosystem; (3) empowering innovators and entrepreneurs through prizes and grants; (4) supporting emerging industries, such as advanced manufacturing and 'clean' and green' technologies, to support long-term economic growth; (5) catalyzing breakthroughs in areas identified as national priorities, such as smart cities and infrastructure, clean technologies, and energy efficiency; and (6) delivering innovative government that is better integrated and which better serves citizens and businesses (The White House, 2015, pp. 3-9). In 2011, The White House also issued a Presidential Memorandum directing agencies with federal laboratories to improve the results from their technology transfer and commercialization activities (The White House, 2011b).

In addition to directives from the executive branch of government there are numerous pieces of legislation designed to promote innovation and entrepreneurship, encourage R&D collaborations between the federal government, universities and the private sector, and improve the process for the commercialization of technologies, including those related to water. Three of the most important pieces of legislation that relate to both water technologies and water technology innovation clusters are the United States Federal Technology Transfer Act (FTTA) of 1986, the Water Resources & Development Act (WRRD) of 2013, and the Water Resources Development Act (WRDA) of 2016. The FTTA was the second piece of legislation to address the transfer of technology from federal government agencies to the commercial sector (the first being The Stevenson-Wydler Technology Innovation Act of 1980), it formally chartered the Federal Laboratory Consortium (FLC) which was established in 1974, it enabled federal laboratories to enter into Cooperative Research and Development Agreements (CRADAs), and it allowed federal agencies to negotiate licenses for patented inventions made in federal laboratories. (The FLC is a national network of federal laboratories that provides the forum to develop strategies and opportunities to help transfer technologies developed in federal labs into commercial products for the global marketplace; and a CRADA is an agreement between a government agency and a private company or university to work together on R&D.)

Building on the FTTA are the Small Business Technology Transfer Act (SBTT) of 1992 and the Small Business Research and Development Enhancement Act (SBRDE) of 1992. The SBTT is designed to increase opportunities for small businesses and non-profit organizations to collaborate with federal research laboratories, and the Act also requires agencies with a R&D budget of more than $1 billion to reserve 0.3% of their research budget for Small Business Technology Transfer (STTR) awards. The SBRDE, which has been reauthorized several times, is designed to provide startups and small business with incentives to undertake R&D that carries high technical risk but have the potential to generate high commercial reward. The Water Resources Reform and Development Act (WRRD) of 2013 is a bill to authorize the United States Army Corps of Engineers to do various water related projects, such as improvements to ports or flood protection. The WRRD changes the way projects are planned, reviewed and authorized and it allows non-federal organizations and groups to provide funding for water projects. Despite being a water bill its main goal is economic development by improving the nation's competitiveness through better water related infrastructure (Kasperowicz, 2013). The Water Resources Development Act (WRDA) of 2016 is the latest in a series of bills going back to 1974, which were enacted by Congress to deal with various aspects of water resources, such as environmental protection, improved navigation, and flood protection. The WRDA also authorizes the EPA to provide grants and loans to state and local governments, public water systems, and nonprofit organizations to support a wide range of water quality projects and programs (EPA, 2016). These pieces of legislation collectively allow federal agencies, including the EPA, to conduct collaborative research with non-federal partners, broaden the scope of an agency's research by leveraging partner research resources, protect intellectual property that is developed during these collaborations, and license an agency's technologies (DOI, 2017; EPA, 2016). The EPA and the Confluence Water Technology Innovation Cluster, working under this framework between fiscal years 2011 and 2013, have supported technology innovation through the funding of 17 water technology collaborative research projects, to include joint research, patenting, new technology development, technology commercialization, workshops, and events. This framework has facilitated eight CRADAs for water-related technologies, with an additional six CRADAs proposed or in progress (NIST, 2016).

Current federal policy has evolved towards facilitating an integrated strategy designed to improve water resource management, public health, environmental protection, and local and regional economic development that is private-sector led. The policies are being implemented jointly by federal agencies and partners in regional innovation clusters that draw together private industry, university research, government agencies, and other public resources. The federal government has also promised to make substantial investments in R&D, in physical and technological infrastructure, in funding a process of collecting and bench-marking performance metrics, in providing financial and technical support for mentoring entrepreneurs and innovators, and in providing financial support for regional water cluster organizations. (The White House, 2009, 2011a, 2011b, 2015; Wessner, 2012).

Federal policy has evolved in this direction because of a growing recognition of the complexity of the water economy and the multiple barriers to innovation that exist in that sector to include the following: (1) the U.S. has been under-investing in the essential drivers of innovation and competitiveness, such as education and physical and technological infrastructure; (2) too many economic and environmental policies and strategies have had a short-term orientation; (3) innovation and entrepreneurship are essential drivers of competitiveness, economic growth, and job creation and need to be nurtured; and (4) the federal government plays an essential facilitation role but must itself evolve to also become innovative, entrepreneurial and joined-up if it is to solve important problems (White House, 2009, 2011a, 2011b, 2015; Wessner, 2012; EPA Water Technology Cluster Leaders, n.d.)

III. The EPA's Water Technology Innovation Cluster Program

A. Origins of the EPA's Water Technology Innovation Cluster Program

The policies and strategies of the federal government to boost economic development, protect the environmental, and safeguard water quality and quantity, have opened new challenges and opportunities for businesses and local governments and has placed new responsibilities on federal agencies to create the programs that facilitate implementation of these policies and strategies. The federal government has identified regional business clusters as the economic scale at which to intervene, and several federal agencies are engaged in supporting regional efforts to strengthen regional innovation ecosystems around targeted industries that can sustain economic growth and job creation while also improving environmental outcomes. Although about 10 federal agencies are involved in supporting regional clusters and regional innovation ecosystems, the US Small Business Administration (SBA), US Commercial Service of the Department of Commerce (USCS), and the Environmental Protection Agency (EPA) are key to efforts with respect to clean technologies, public health, and environmental protection.

In 2010, the EPA and the SBA began exploratory work with local businesses, academic institutions and communities in Ohio, northern Kentucky and southeast Indiana to establish the feasibility of creating an environmental technology innovation cluster focused initially on the commercialization of water technologies. The region was chosen for several reasons: (1) the Andrew W. Breidenbach Environmental Research Center in Cincinnati is one of the largest federal water R&D laboratories in the country with substantial research facilities and many federal and contract scientists; (2) the federal government has supported water research and water technology development in Cincinnati for over a century, particularly related to regulatory standards set by the EPA to protect human health and the environment; (3) several university and private-sector research facilities have developed in the region around the EPA lab; (4) the region's utilities have been leaders in fresh and waste water systems; and (5) the region has a large number of water-intensive and water-enabled industries (The White House, 2011). In January 2011, EPA Administrator Lisa P. Jackson and SBA Administrator Karen Mills traveled to Cincinnati to announce a new collaborative effort called the Water Technology Innovation Cluster (WTIC) program. The program consists of a network of small and large businesses, business incubators, investors, water utilities, manufacturers, technology developers, researchers and other stakeholders with an interest in fresh-storm-and-waste water and the commercialization of water technologies. In May 2012, the USCS also partnered with the EPA and SBA and announced efforts to launch an environmental technology initiative intended to support the export of U.S. water technologies that would help create jobs in the growing environmental industry.

The Cincinnati cluster was not the first water technology innovation cluster in the United States. It was, however, the first to officially receive such a designation and recognition by the federal government and its key environmental and economic development agencies. The WTIC in Cincinnati, later to be named Confluence, was conceived as a public-private partnership that would bring together private businesses, universities, and public utilities with a focus on, or interest in, the development of state-of-the-art technologies that would help maintain water quality and quantity, that would protect public and environmental health, and support economic development. The EPA and SBA see these clusters as the ideal business ecosystem to develop and commercialize innovative technologies to solve environmental and public health challenges, encourage sustainable economic development, and create jobs. The EPA and SBA facilitated the creation of a steering committee, made up of a cross-section of stakeholders from the Cincinnati metropolitan region, to develop a framework and operating structure for the industry association that would represent the water technology cluster, and to develop a business model that would enable the association to flourish independently of public support. After Confluence, the EPA and SBA began to explore similar relationships with the water industries in other regions of the country, and the EPA has officially identified and designated 14 regions as having ‘emerging’ or ‘established’ water technology innovation clusters (EPA, 2016). As of 2015 there are at least 56 federally funded clusters supported by the SBA and various other agencies of the federal government: 14 Pilot Contract-based Clusters supported by the SBA; 10 Jobs Accelerator Advanced Manufacturing clusters, involving the SBA, EDA, ETA, NIST, and DOE; 20 Jobs Accelerator Collaboration Clusters, involving the SBA, EDA and ETA; 13 Rural Jobs Accelerators, involving the DEA, USD, ADRA, ARC; and three emerging clusters which include the Confluence WTIC (SBA, 2017). Since 2010 these SBA-led or coordinated initiatives have provided over $27 million in support for clusters involved in clean technologies, food processing and agribusiness, aeronautics and aerospace, music and entertainment, wood products, biotechnology, and advanced materials and manufacturing, among others. The EDA also supports another 19 regional innovation projects that have been funded through the EDA’s i6 program. Although these programs have been criticized as being too small in scale and scope to have a meaningful national impact on the overall economy, Mark Muro of the Brookings Institute suggests that well-designed cluster and accelerator programs which pull in tangible local support in the form of industry champions and matching capital are “are a low-cost way to stimulate a significant amount of collaboration, innovation, and new economic activity in the local economic regions that are the ultimate source of national prosperity” (Muro, 2013).

B. Vision, Mission, Goals & Objectives of the Water Technology Innovation Cluster Program

The current federal policies on regional economic development and environmental protection suggest a vision, being pursued both jointly and independently by multiple agencies and their local and regional partners that environmental protection and economic progress can go together. This is a position also supported by Porter who argues that intelligent regulations for health, safety and environmental protection stimulates innovation and drives international competitiveness in regulated industries (Porter, 1990, 1998). The assumptions about clusters contained in economic development policy at all scales of government suggests the following: (1) that industry clusters within an economically connected region promote positive spillovers, labor market specialization, and the sharing of industry-specific inputs; (2) that thriving regional innovation ecosystems create institutions that build social capital and networks which improve communication and knowledge sharing; and (3) that the cumulative effect of these synergistic relationships are productivity growth, cost or technological advantages, and increased competitiveness (Porter, 1990, 1998, 2000; Porter & Kramer, 2011; Wessner, 2012). Studies of the economic and social impact of the Clean Air and Clean Water Acts seems to suggest that the resulting regulations have not reduced economic growth and have been a good economic investment for America. These Acts have reduced premature deaths and illnesses which means that Americans experience longer, better quality lives, have lower medical expenses, fewer school absences, and better worker productivity (DeMocker, 2003).

In 2012, the EPA released a document entitled *Technology Innovation for*

Environmental and Economic Progress: An EPA Road-map, which presented a vision in which the agency promotes technology innovation that eliminates or significantly reduces the use of toxic substances, reduces exposure to pollutants in the environment, and promotes the growth and competitiveness of the industries that develop and commercialize these technologies (EPA, 2012). The Road-map outlined a strategy that states that the EPA "will undertake policy, regulatory, financial, and voluntary actions, grounded in science, that will promote innovation along the entire continuum of technology development and deployment," and "will advocate more cost-effective, innovative solutions that eliminate, or significantly reduce, adverse impacts to natural resources in a manner that promotes healthy, productive communities" (EPA, 2012, p. 3). The Road-map gives four broad areas of strategic thrust where the EPA will focus initial efforts: (1) leveraging technology innovation through the design of policies, regulations, standards, and the system of permitting; (2) working with a broad coalition of stakeholders to improve the process by which water technology is commercialized and adopted; (3) working across agency boundaries to ensure that water technology is commercialized and adopted; and (4) building new relationships and improving communication with the private investment community to ensure funds are available to commercialize technologies (EPA, 2012, pp. 4-5). The EPA vision for WTICs is of an industrial system capable of the following: (1) the development of the technical and institutional capacity, and the human and financial resources, to develop, test, market, and deploy innovative processes and technologies that are economically and environmentally sustainable; (2) action on controlling a broad array of contaminants to improve public health and environmental protection; (3) increasing the efficient use of water and energy to reduce the environmental impact of human activity; (4) making the adoption of new technologies cost effective for both utilities and consumers; and (5) making investments capable of being financed by local governments and their private financial partners (EPA, 2012).

The EPA mission is to collaborate with internal and external stakeholders and partners – including businesses, academia, researchers, and public utilities - to develop a portfolio of policies, regulations, and financial instruments that, when taken together, will institutionalize and promote technology innovation along the entire continuum from technology development, to technology testing and validation, to technology deployment (EPA, 2012). The EPA is seeking to go beyond simple organizational boundaries, employ an increasingly open innovation framework, partner with diverse stakeholders to identify, develop and deploy innovative technological solutions, build on a strong record of successful technology transfer, and secure the greatest prospect for achieving multiple environmental and economic development goals (McMohan, 2011). The goals and objectives of the EPA, SBA, EDA and USCS include promoting innovation, entrepreneurship and investments in cutting-edge technology that will protect America's water, air and environment, protect public health, promote economic development and international competitiveness, commercialize new technologies, and expand national and international markets, and doing so in a way that is complementary and synergistic (Benson & Garmestani, 2011; Fieldsteel, 2013).

C. Strategy and Structure of the Water Technology Innovation Cluster Program

The strategy of the EPA for encouraging and supporting the growth and development of WTICs is outlined in two agency documents: *The Technology Innovation*

Roadmap published in 2012 and *Building a Successful Technology Cluster* published in 2013. This strategy follows the prevailing theoretical frameworks that are found in the literature of clusters, and it incorporates the experience of actual clusters (Smilor et al., 1989; Porter 1990, 1998; Saxenian, 1994; EPA, 2012; Fieldsteel, 2013). The strategy is articulated by a focus on the following areas: (1) the design and implementation of appropriate policies, regulations, and procedures by federal, state and local governments to encourage innovation and entrepreneurship and facilitate the commercialization and adoption of technologies; (2) the encouragement and leveraging of R&D by federal laboratories, universities or other research institutions; (3) the facilitation of technology transfer from the public to the private sector; (4) the creation of networks for facilitating communication and knowledge diffusion; (5) the facilitation of cross-agency cooperation; (6) the encouragement of more public-private partnerships; (7) the development of new relationships with the investment community and the leveraging of private capital from private capital markets; (8) the nurturing of technology start-ups; and (9) the partnering with established water-technology, water-intensive, and water-enabled businesses (EPA, 2012; Fieldsteel, 2013). Each of these strategies is outlined below in greater detail.

1. Policies, Regulations, and Procedures.

With this strategy the 'Roadmap' provides a framework for connecting and advancing a regime of policies, regulations and procedures that ensures that all stakeholders make sound environmental choices, which in turn promotes technology innovation in the water industry that protects public and environmental health while supporting regional economic development (EPA, 2012). Governments at the various scales play different but complementary roles (Fieldsteel, 2013). The role of the federal government is to set standards for water quality and provide the financial and technical resources, which would allow local and regional governments to meet those standards. The role of the local government is to provide physical, economic, and institutional infrastructure that supports entrepreneurship and innovation in both the public and private sectors. Physical infrastructure includes of transportation, telecommunications, water, and sewerage; economic infrastructure includes an educated and skilled workforce; and the institutional infrastructure requires a competitive rate structures for financing the ongoing operations of public services and utilities, financial mechanisms to meet the capital requirements to build and maintain infrastructure, and legal mechanisms to enable and support the public-private partnerships which allow roles and responsibilities to be optimally allocated among stakeholders (Porter, 1990, 1998, 2000; Fieldsteel, 2013).

Governments at all levels also need to collect information on existing social and economic assets that will indicate the state of the water economy at various scales, and the level of development of the industries that will identify the existence and strength of water technology clusters. Accurate information will allow for the design of better public policies, for the marshaling of limited public and private resources, and for the alignment of those policies and resources with the needs of the local cluster to better foster economic development. Accurate information also allows stakeholders to understand the unique mix of assets that each region possesses so that local clusters leverage and build on their unique assets to create an industry with unique capabilities that best serves local needs and is difficult for competitors to replicate. Regions should avoid copying the industrial focus of other successful clusters and instead focus on economic specialization to achieve increasing productivity growth and competitiveness (Porter, 2007; EPA, 2012; Fieldsteel, 2013).

2. Research and Development.

The EPA's experience suggests that both basic scientific research into environmental challenges and applied R&D into promising environmental technologies is critical to understanding the water cycle, protecting water quality, increasing the efficiency of water use, and reducing the energy associated with treating and moving fresh water and waste water (EPA, 2012; Fieldsteel, 2013). Here the strategy is to connect the considerable R&D capabilities in water that exists across the many federal research laboratories, especially the EPA, and bring them to bear to address water and environmental challenges. These public capabilities and public intellectual assets need to be leveraged and combined with similar capabilities to be found in academia and the private sector to help develop, test and validate new water technologies and bring them to the marketplace in a timely manner, and at the correct technical and economic scale. Providing universities with adequate financial resources is important to encouraging both undergraduate and graduate students to explore courses of study in the environmental sciences and water resource management, and deliberate public-private partnerships are necessary to the support the commercialization and adoption of the technologies (Fieldsteel, 2013).

The most successful business clusters possess locally-based R&D excellence in core products and processes, and co-locating R&D with production, marketing, and customer support can increase efficiency in sourcing and sharing knowledge among cluster members, which leads to cost savings, quicker time-to-market, and more responsive customer service (Porter, 1990, 1998, 2000; Fieldsteel, 2013). Beyond basic scientific research, the most successful business clusters are also associated with universities that are highly engaged with the clusters and offer a combination of academic, business, legal, workforce, and financial support that are aligned with the needs of that cluster (Paytas et al., 2004). The presence in a cluster of R&D capability, of physical and intellectual assets connected to R&D, of adequate funding to conduct R&D, and the patenting of technologies, does not, however, automatically translate into patents that are high quality or technologies that move through the entire commercialization process to adoption (Paytas et al., 2004; Fieldsteel, 2013). Cluster development therefore requires an audit of the R&D capabilities of nascent or emerging clusters, a mapping of existing patents granted, and an ongoing monitoring and evaluation of patents in the region to determine the patent's value, analyze on their impact on and relationship to the diffusion of technology, and their strategic fit in an industry (Fieldsteel, 2013). Research and development can be a potential driver of innovation in water technology, environmental protection, and local economic development, but developing a viable product or business from a patent requires capital, business support services, and a competent management team (Fieldsteel, 2013). The EPA is leveraging its R&D capability and agency science, policy and technology programs to catalyze the creation of environmental technology innovation clusters (EPA, 2012). In 2011, the EPA and the University of Cincinnati signed a memorandum of understanding (MOU) which strengthened the long-term partnership between these two organizations to conduct joint research and collaborate on innovative water technology development (Kunnen-Jones, 2011)

3. Supporting Technology Transfers.

This strategy supports the EPA's belief that successful transfer of technology or diffusion of innovation is vital for supporting an effective and efficient process of commercialization and adoption of water technology (Fieldsteel, 2013). The transfer of technology is the process of transferring or disseminating technology from its point of origin to a wider set of stakeholders who have an interest in that technology. It takes place between universities, businesses and government agencies to further development and commercialization; it occurs both formally, such as through technology transfer offices, and informally, such as through social or professional networks; and it involves a process which extends from the identification of technology to its transfer to its protection through patents and copyrights (IPP, 2013).

Despite social and economic incentives to move scientific research from the laboratory into the production of commercial products, the process is often more difficult in practice than in theory. The potential complexity of the technology transfer process requires organizational and institutional structures that are multidisciplinary and include economists, engineers, lawyers, marketers and scientists (Fieldsteel, 2013). The process of technology transfer has improved with the passage of legislation such as the Bayh-Dole Act of 1980, Stevenson-Wydler Technology Innovation Act of 1980, the Federal Technology Transfer Act (FTTA) of 1986, and other pieces of legislation and regulations, and guidelines such as the 'Green Book' (EPA, 2016). Because of the potential for positive social, economic and environmental impacts the federal government is encouraged to reach out to private industry, academic institutions, foundations, state and local governments, and international institutions to establish collaborations and partnerships (Fieldsteel, 2013).

The EPA, through the Office of Research and Development's Science to Achieve Results (STAR) program, has invested $5 million over a 3 to 5-year period to support cluster development and technology commercialization, especially in the Cincinnati region. These funds were used to conduct key studies of the environmental technology marketplace for drinking water; to acquiring the services of a cluster consultant; to conduct technology and knowledge mapping of the region to gauge its strengths; to fund, through a competitive application process, research grants and graduate fellowships in various environmental science and engineering disciplines; and to help start-ups and research facilities develop, test, and market innovative processes and technologies (Barry et al., 2014).

4. Facilitating Communication and Diffusing Knowledge.

EPA thinking about environmental protection and environmental technology is evolving. The emerging paradigm is more holistic, integrated and synergistic. It connects scientists, innovators, entrepreneurs, academics, and regulators into a more efficient and effective framework for protecting public and environmental health while promoting economic development (EPA, 2012). Key components of this strategy are increased networking, collaboration and information sharing that builds social capital and encourages organizations to be more adaptable and flexible (Fieldsteel, 2013). Clusters are not only driven by economic imperatives, they are also significantly influenced by non-economic imperatives that shape regional social structures and institutions, which in turn shape the regional corporate culture and influences the regional creative process (Saxenian, 1994). The organizations in a cluster that are at the heart of entrepreneurship and innovation therefore exist within a unique institutional and cultural context. Cluster institutions and culture determine the degree of openness to new ideas and innovation, the ways in which incentives are structured, the degree to which people work together towards a common purpose, the values and attitudes towards risk and failure, and the degree of strategic patience that stakeholders have towards investing the time and energy required to build a successful cluster and wait for a return on that investment (Fieldsteel, 2013). Openness to ideas requires high levels of mutual trust and cooperation, and a tolerance towards risk-taking and failure. Mutual trust and cooperation among stakeholders increases communication, leads to repeated transactions, reduces the effort in information processing, and reduces transaction costs, which should lead to a more productive and competitive cluster (Porter, 1990; North, 1990; Saxenian, 1994). Increased communication, collaboration and mutual trust are facilitated by an institutional arrangement that includes industry associations and public fora where valuable cluster attributes are actively fostered among the widest cross-section of stakeholders to includes law, marketing, venture capital, and technology firms, universities, public laboratories, and government regulators (Saxenian, 1994; Fieldsteel, 2013). Cincinnati's Confluence hosts the Regional Utility Network Conference, Milwaukee's Water Council hosts the annual Water Leaders Conference, and the EPA hosts the annual Cluster Leader's Conferences, which are examples of key organizations playing a central role in supporting communication and networking within and between clusters.

5. Cluster Champions

Closely linked to networking, communication and collaboration is the critical role of cluster champions. Cluster champions are critical to both cluster formation and long-term cluster success, and it is champions that often increase public awareness and the cluster profile, serve as cluster and industry advocates, drive communication and collaboration, coordinate efforts between researchers and universities, connect members to investors and commercialization partners, and offer general business advice (Fieldsteel, 2013). In Milwaukee the champions were two local businessmen – Rick Meeusen and Paul Jones – and in Cincinnati these included two members of the University of Cincinnati Foundation's Board of Trustees, Jerry Leamon and Jeffrey Williams (Fieldsteel, 2013).

Politicians and public officials have also played a role as champions to ensure that the resources and policies of the government align with the goals and objectives of the cluster, and because public officials have an interest in both local economic development and environmental protection. Politicians and public officials can ensure that the local state supports cluster development by providing high quality schools, modern infrastructure, high-quality amenities, and well-managed and well-financed local utilities that work closely with the cluster, especially with testing, validating and piloting new technologies and being an initial customer (Fieldsteel, 2013). The mayor of Milwaukee, Tom Barrett, has played a very proactive and supportive role with that city's cluster; Ohio Senator Rob Portman (R) has been actively involved in water-related legislation and in bringing legislative attention to water-related problems in Ohio and the Mid-West; and the staff at the EPA's Cincinnati, especially Sally Gutierrez, have actively served as a catalyst both for the Cincinnati cluster, for other water technology clusters across the U.S., and a focal point for inter-agency cluster coordination with other federal agencies such as the SBA and EDA (Fieldsteel, 2013).

6. Public-Private Partnerships.

The EPA views public-private partnerships (PPP) as an important vehicle for connecting water economy stakeholders with different capacities, capabilities and resources– such as regulators, businesses, investors, and researchers - to take a focused approach that facilitates entrepreneurship and innovation along the entire continuum of development, testing, validation, piloting, commercialization and deployment of environmental technologies (EPA, 2012; Fieldsteel, 2013). Public-private partnerships (PPPs) can be defined as agreements for collaborative governance between a diverse cross-section of public and private actors to achieve a set of goals and objectives that address policy problems. Public-private partnerships require the establishment of common norms and rules to facilitate decision-making and implementation. Public-private partnerships also institutionalize a hybrid type of authority which goes beyond the traditional forms of interaction between state and non-state actors - where roles, responsibilities and operational boundaries were clearly defined – to incorporate more flexible and adaptive governance and management regimes (Andonova, 2010). The EPA sees PPPs as a more effective and efficient mechanism for bringing scientific knowledge and innovative water technology to bear on solving complex and systemic environmental and economic development problems, especially those which require novel solutions or new organizational forms (Porter, 1998; EPA, 2012; Fieldsteel, 2013).

The many novel organizational forms offered by PPPs offer ways of structuring economic relationships beyond pure competition on one end of the spectrum and pure public provision on the other, offering relationships which fit better with the regional and global competitive realities of the modern economy (Porter, 1998; National Research Council, 2012, 2013). Public-private partnerships can bring together both public and private researchers, profit and non-profit sectors, and public water suppliers and private technology firms; they can bring into the water industry additional technical and management expertise and a wider choice of funding mechanisms; and they provide a balance between the private sector's greater ability to act quickly, boldly and flexibly, and the public sectors role to provide for the common good (Fieldsteel, 2013).

Many emerging water technologies are coming out of collaborations between federal, university, and private laboratories, which increasingly receive support from both federal grants and venture capital funding (Fieldsteel, 2013). The areas of common interest, mutual dependence or collective responsibility between these stakeholders create an incentive for them to forge alliances to solve problems or create collective goods (Porter 1998). Public-private partnerships can take the form of a for-profit business contracted to provide a service on behalf of the state – such as Veolia and the Milwaukee Metropolitan Sewerage District – or a non-profit – such as The Water Council in Milwaukee which represents the Milwaukee water industry. The Water Council and Confluence have become models for successful public-private partnerships.

7. The Investing Community and Private Capital Markets.

This strategy recognizes that the water utility industry is a capital-intensive sector, where capital projects take years to come to fruition, investments are long-term, and scale economies and available technologies traditionally favored large-scale infrastructure – which historically accounts for the high level of public sector involvement in the industry through much of the 19th and 20th Centuries (Rogers, 1993; Solomon, 2011; Siegel, 2015; EPA, 2017). Water utility infrastructure needs continuous monitoring, maintenance, repair or replacement, and its efficiency and effectiveness are affected by demographic and climatic change. Financing the rebuilding and upgrading of America's water infrastructure, much of which is nearly a century old, will require billions of dollars in the coming decades, and new and innovative ways of financing (Rogers, 1993; Solomon, 2011; AWWA, 2016). The way water infrastructure has been financed in the U.S. has evolved over the decades. Traditionally cities issued bonds to finance water projects, paying back these loans out of revenue for the services offered; in the post-war period the federal government offered municipalities grants of money to underwrite much of the cost of water infrastructure; later federal financial assistance was restructured to take the form of loans from revolving infrastructure funds (Rogers, 1993; Foss-Mollen, 2001; Christian-Smith & Gleick, 2012). The reliance of water utilities on long-term debt financing for infrastructure means that municipalities must find a balance between low-cost financing, offering investors a competitive rate of return, and keeping tariffs down, which usually means issuing tax-exempt bonds.

Water infrastructure has traditionally been a safe investment: the default rate on water projects, which is estimated to be less than 1%, is low; inelastic demand creates stable and inflation linked cash flows; and governments guarantees infrastructure loans (Clark et al., 2012; AWWA, 2017). Private-sector financing for water infrastructure has, however, often been difficult to raise even as the amount of potential financing from private sources has increased. The challenge is to get the private sector to help underwrite the cost of financing water infrastructure and water technology, but as an active rather than passive investment partner sharing both the risks and the rewards over the long-term. Raising private capital for water infrastructure is seen as necessary given the scale of the investment required over the coming decades, the fiscal constraints faced by governments at all scales, and the better financial and management discipline offered by the private sector. Global trends in private-sector funded infrastructure investment have, however, fallen well short of expectations, despite almost three decades of vigorous attempts at privatization. One solution is for institutional investors to develop the technical capacity to better manage infrastructure investing (Clark et al., 2012; Arezki et al., 2016).

In addition, the U.S. infrastructure market faces unique challenges related to lack of strategic vision and poor coordination, weak technical capacity in the public sector, and costly, complex, and fragmented procurement policies and practices (Puentes & Sabol, 2015). The involvement of private capital markets in water infrastructure requires a stable and predictable policy, regulatory, and governance environment that can attract investment in infrastructure (Bielenberg et al., 2016). Raising more venture capital for water technology startups is also considered to be desirable, but this has long been perceived as a challenge. Venture capital is not equitably distributed across the U.S., and while this distribution may reflect risk perceptions and information asymmetries in capital markets, it does not reflect the investment needs of many regions across the country (National Research Council, 2012). In 2011 California absorbed 51.5% of all U.S. venture capital investment, Massachusetts absorbed 10.4%, while New York, Texas and the next four states accounted for 21.7% of venture capital investment (Fieldsteel, 2013). Although there have been calls from many stakeholders for a greater role for the government in venture capital markets, there are many who caution against a direct role for the state, point to a mixed track record of the state as venture capitalist, and note that venture capital makes up only a small fraction of the overall capital market (Florida & Smith, 1993; Porter, 1990). The current strategy of the federal government is therefore to improve the ways federal agencies communicate with the private sector and private capital markets about the opportunities to earn market rate returns from helping technology firms commercialize environmental technologies and from financing environmental projects; and the government is encouraging private sector investment in the water utility industry as a way to expand product markets and increase profitability, help water utilities reduce costs and improve service, and help local governments grow their economies and create new jobs (McMohan, 2011; Fieldsteel, 2013).

An example of the ways the federal government is supporting the financing of water infrastructure is the Water Infrastructure Finance and Innovation Act (WIFIA) of 2014. WIFIA is a five-year pilot federal credit program administered by EPA to provide low-cost, long-term loan financing and loan guarantees for water projects that may be under-served by existing state revolving funds (SRFs) because of their size, cost, and purpose. WIFIA is designed to accelerate new investment in, or support major improvements to, regionally and nationally significant projects in drinking and wastewater systems, as well as water resources projects such as flood control and navigation. WIFIA it is open to a wide cross-section of eligible borrowers to include governments, partnerships, joint ventures, corporations, and trusts; and it promises to be budget neutral in the long run (AWWA, 2017). WIFIA is designed to fill an existing financing gap by funding large projects costing over $20 million, as these are unable to access funds from SRF programs, and small projects over $5 million for communities with under 25,000 residents who may be unable to access loans through traditional measures (AWWA, 2017). Borrowers have up to 35 years to repay the loans, with a maximum repayment deferral period of 5 years after substantial completion of the project; projects must be creditworthy and have a dedicated source of revenue; and the interest rate charged will be equal to or greater than the U.S. Treasury rate for projects of a similar maturity at the date of project closure. Each dollar authorized and appropriated by the EPA can support up to 50 times that amount in loans, and borrowers can fund up to 49% of a project through WIFIA while the remaining 51% can come from SRFs, which the program is meant to complement, and other sources such as private equity investments (AWWA, 2017). For the fiscal year 2017, the EPA-WIFIA program received 43 letters of interest from prospective borrowers across the country for $6 billion in WIFIA loans for water infrastructure projects that, when combined with other sources, such as SRF loans, private equity, and municipal bonds, will provide over $12 billion to implement projects (EPA, 2017). Seventeen of the letters of interest came from California and one each came from Wisconsin, Indiana, and Washington State. In 2017 the City of Milwaukee plans to utilize $25-27 million in SRF funds and seek $20 million in funding from the WIFIA program to maintain the financial balances of the Drinking Water State Revolving Loan Funds and the Water Infrastructure Improvements for the Nation Act (WIIN) (City of Milwaukee, 2017).

8. Nurturing Technology Startups.

This strategy recognizes that startups, whether high-technology or not, play an important role in economic growth and job creation, in bringing new and innovative ideas and products to the marketplace, and in potentially being the large corporations of the future. Although most startups fail, and others may be bought out by existing businesses with their founders returning to the role of being a serial innovator, those startups that survive still generate almost half of all new jobs and encourage subsequent employment growth in their related industries, helping to strengthen and deepen business ecosystems (Morelix et al., 2016). Startups face many challenges to commercializing their products or growing their businesses into successful and sustainable ventures (Feinleib, 2011; National Research Council, 2012). One challenge relates to the market, such as small size or fragmentation. A second challenge involves a failure to create a viable and sustainable business model, such as a cost-effective way to attract, win and retain customers that provides the business and the entrepreneur with a return on the time and resources invested. A third challenge relates to the problem of finding, building and retaining a good management team. A fourth challenge relates to having working capital at critical points in the commercialization life cycle, especially as venture capitalists and angel investors become more risk averse. A fifth challenge relates to the product, such as a failure to find the correct product-market mix. Finally, a sixth challenge often involves isolation and an inability to enter industry networks and meet organizations from other sectors that have the same technology focus.

The federal government, in seeking to stimulate the growth of both startups and industry clusters, is facilitating networking opportunities through conferences, workshops, and fora, and is encouraging the creation of cluster associations to support their respective industries by providing networking opportunities and advocacy services (Fieldsteel, 2013). To succeed as a startup, entrepreneurs also need to take the time to participate in the cluster, find mentors and coaches to provide business knowledge, have interactions with other organizations to gain market knowledge, and develop partnerships or collaborations to develop new research and business opportunities (Fieldsteel, 2013). Entrepreneurs flourish in a connected, dense, and diverse ecosystem where they can move quickly to take advantage of market opportunities, and that type of ecosystem exists when it is endowed with adequate human and financial resources and good research and technological infrastructure (National Research Council, 2012; Morelix et al., 2016).

An industry association such as Confluence and The Water Council can support startups by advocating with the state, universities, and established businesses to focus on policies and strategies that benefit new innovators and entrepreneurs. One set of strategies involves workforce development policies to increase college completion rates, lift educational standards, and build and sustain a skilled, educated, and technologically competent workforce that can contribute to growing firms (Porter, 1993; Fieldsteel, 2013; Kauffman, 2016). A second set of strategies would involve policies for attracting and supporting immigrant entrepreneurs and innovators, who often play a disproportionate role in founding startups, and foreign students who graduate from American universities with the skills both startups and mature firms require (Morelix et al., 2016). A third set of strategies would involve advocating for policies that limit the scope, duration, and enforcement of non-compete agreements so that former employees with industry knowledge, entrepreneurial ambitions, and potential innovations can more easily start new businesses within the cluster, as was the case in the more open innovation environment of Silicon Valley as opposed to the more closed innovation environment of Route 128 (Saxenian, 1994; Morelix et al., 2016). A final set of strategies involves mapping the industry cluster to include identifying and analyzing the companies and their areas of expertise, the technology present in the cluster, the number of patents awarded, and publications made and their impact. Equally important is establishing a performance management system backed by a set of metrics from which the performance of clusters can be measured and bench-marked (National Research Council, 2012;

Fieldsteel, 2013).

9. Partnering with Established Businesses & Universities.

This final strategy recognizes that large businesses play an important role in industry clusters (Porter, 1990, 1998, 2000; Markusen, 1996). At a minimum level, large businesses serve clusters by anchoring both the cluster and the local economy, by maintaining relationships with major research universities, and by nurturing talent that can lead to the growth of new businesses. In a cluster with a more open culture or a well-organized industry association, large businesses share their industry expertise, collaborate with the other businesses on projects of mutual interest, conduct research with the federal laboratories, universities and start-up companies to commercialize technologies and products, work with educational institutions to develop curriculum, provide apprenticeships to build the workforce, and provide essential guidance for the cluster organization (Fieldsteel, 2013; Morelix et al., 2016). In an era were government resources are limited and private venture capital for startups is geographically concentrated, large businesses are becoming more important in supporting startups. They do this in several ways: (1) by providing capital for research, testing and validation, and for scaling up production; (2) by raising the market profile of startups that will expand their customer base; (3) by providing a market for their products and services; (4) by supporting startups during the long gestation period that it sometimes takes for products to penetrate markets and begin to make a profit; and (5) in some cases by acquiring startups when they show promise, or spinning-off startups to form new and independent businesses (Porter, 1998; National Research Council, 2012; Fieldsteel, 2013; Morelix et al., 2016). In the contemporary economy, businesses increasingly depend more on outside firms, external support services, and local institutions that are better placed to provide specialized products and services than can be produced internally, and the culture and bureaucracy of large businesses often place constraints that stifle innovation making relationships with external innovators and entrepreneurs valuable (Saxenian, 1994; Porter, 1998; Fieldsteel, 2013; Morelix et al., 2016). These business realities provide startups with a potential market, and an incentive to locate within a strong cluster, through an opportunity to serve large, well-established firms and by being a source of innovative technologies and products for large businesses (Saxenian, 1994; Porter, 1998; Fieldsteel, 2013; Morelix et al., 2016).

Not all large businesses embrace an active role in clusters (Saxenian, 1994). Some large companies are reluctant to interact with their competitors in a cluster organization, some fail to recognize that competition and cooperation can and does coexist within clusters, and some fear a loss of control over intellectual property or propriety information (Fieldsteel, 2013). In the case of the Milwaukee cluster, Badger Meter and A.O. Smith Corporation served the role of anchor companies, worked to raise the profile of the cluster and its members, served as advocates with governments at all scales, worked with universities to stimulate research and improve workforce development, and provided essential guidance for the cluster organization (Fieldsteel, 2013).

Universities also play an important role in building and sustaining clusters largely by conducting research and development, by training and developing the next generation of scientists, innovators and entrepreneurs, and by nurturing or spinning-off startups (Porter, 1990, 1998, 2000; Boh, De-Haan & Strom, 2012; Fieldsteel, 2014). Silicon Valley and Boston are among the most famous and celebrated regions with well-endowed and prestigious research universities that have supported cluster development and nurtured generations of innovators and entrepreneurs who have concentrated themselves in these locations (Saxenian, 2000; Fieldsteel, 2014). While research universities are universally considered to be a key anchor institution in clusters, not all universities are equal to the task of supporting their respective clusters (Saxenian, 2000; Fieldsteel, 2014). To support their clusters universities need to carry out a wide variety of tasks: (1) support basic and applied research that leads to the discovery of technologies that can be utilized within the cluster; (2) develop curriculum that will prepare their students for employment in the cluster by giving them the relevant knowledge, skills and experience, and by fostering a mobile and flexible workforce; (3) offer mentoring programs, accelerator programs, entrepreneurship training for students and faculty, and interdisciplinary project-based classes that bring together teams of science, policy, law, and business students to write business plans and grant proposals to create strategies for the commercialization of technology; (4) offer sophisticated support for the process of registering and licensing patents, and the capability in technology analysis to determine how successful its research, invention, patenting and licensing process has been; (5) offer incentives to attract and retain high-quality professors and research students; and (6) maintain reasonable fees for startups and small businesses to access the research findings and facilities (National Research Council, 2012; Boh, De-Haan & Strom, 2012; Fieldstee,l 2014). The University of Wisconsin-Milwaukee, the University of Cincinnati, and the University of Washington-Tacoma are all attempting to fulfill these roles for their respective clusters. The EPA also awards research grants to, and enters into cooperative agreements with, universities through the National Center for Environmental Research's (NCER) Science to Achieve Results (STAR) Program; and the NCER also manages the EPA's Small Business Innovative Research (SBIR) Program. The EPA's STAR program, through grants and graduate fellowships, engages some of the nation's best scientists and engineers in targeted research projects across several scientific disciplines that complement the agency's own intramural research program which is designed to protect human health and the environment. STAR research is funded through a competitive solicitation process, or request for applications (RFAs), that attracts nearly 2000-2500 proposals every year; and of the applications, more than 200 research grants and graduate fellowships are awarded (EPA, 2017).

IV. Other Supporting Federal Policies and Programs

A. Cooperative Research and Development Agreement (CRADA)

There are several federal policies and programs that the EPA uses to specifically support both innovation and entrepreneurship in the water economy and, indirectly, business cluster development. First, it is important to understand the federal government's role in R&D. The U.S. federal government invests a considerable amount of public funds in R&D through both federal research facilities and grants to external organizations. These funds reflect important, but often shifting, policy priorities for the federal government which during the Obama Administration included advanced manufacturing, clean energy technology, climate change research, neurological science and medicine, STEM education, and a permanent R&D tax credit (Steward & Springs, 2015; Hourihan & Parkes, 2017). The outlay for R&D in FY 2016 was budgeted at $145.2 billion, which represents about 3.6% of a $4 trillion budget, 12.4% of discretionary expenditure, and about one-third of all R&D expenditure in the U.S. (Steward & Springs, 2015; Hourihan & Parkes, 2017). In nominal, non-inflation adjusted dollars, this allocation for R&D in FY 2016 represents an increase of about 6.4% above FY 2015. In terms of priorities the DOC received an increase of 40.4% while the EPA received an increase of only 1.3%, suggesting that local economic development, industry support, and job-creation were relative priorities (Hourihan & Parkes, 2017). In terms of 'character,' about 53% of R&D expenditure goes to defense related R&D, and the remainder to civilian, non-defense

R&D which includes health, space, energy, agriculture, environment, and social science research. Research and Development 'character' can also be divided into roughly five classes which includes basic research, applied research, development, facilities construction, and R&D equipment (Hourihan & Parkes, 2017). The heavy emphasis on defense related R&D which, unlike civilian R&D, is heavily skewed to development, is a source of concern in some quarters among those who worry that it may crowd out valuable civilian R&D, erode long-term U.S. productivity and competitiveness, and put at risk the quality of public and environmental health (Porter, 1993; Hourihan & Parkes, 2017). The scale and scope of the federal research system is considerable with over 700 research facilities spread across the country, many of which work with civilian researchers, innovators and entrepreneurs to solve many of the country's important problems. These research facilities are a rich source of scientific and technological R&D, but they have traditionally had difficulties commercializing their technologies and reaching their full potential as catalysts for local and regional economic development. Since the 1980s, Congress through legislation has been encouraging these facilities to partner with non-government organizations to commercialize their technologies and better support local and regional growth (National Research Council, 2012).

The commercialization of the technologies which result from these partnerships requires a formal mechanism, and a Cooperative Research and Development Agreement (CRADA) is the main vehicle for enabling these partners to work together, to allocate roles and responsibilities, and distribute benefits and burdens (National Research Council, 2012; EPA, 2017) A CRADA is an agreement between a federal government agency and one or more external, non-government partners to pursue joint R&D projects, to share research materials, to create new intellectual property, and to commercialize new technologies (EPA, 2017). This type of agreement was designated under the Federal Technology Transfer Act (FTTA) of 1986 and is intended to speed the commercialization of technology, optimize resources, and protect the propriety rights of all the parties involved. A CRADA enables a federal agency and its outside partners to leverage their respective resources and technical capabilities, reduce a duplication of effort, expand their competencies and skills through increased collaborations, and make patented technologies available for licensing by outside parties (EPA, 2017). The range of potential non-government partners in a CRADA is considerable and includes businesses, universities, state and local governments, trade associations, foreign governments, and individuals.

A recent study by the Association of University Technology Managers (AUTM) of university technology-transfer programs since 1991, reveals a mixed record of success. This is despite a dramatic increase in the number of university inventions, licensing revenue, expenditure on full-time technology-transfer specialists, patent applications, and the number of start-ups launched by AUTM members (National Research Council, 2012). The 'productivity' of university technology-transfer programs, and the 'quality' of the patents and inventions, lags behind the impressive increase in raw output: 'successful' patent applications and the number of licenses have remained flat; 59% of invention disclosures by universities resulted in U.S. patent applications; 26% led to signed licenses; 16% resulted in U.S. patents issued; 3% of those inventions led to the formation of start-up companies; 52% of technology-transfer programs lose money for their universities; only 16% technology-transfer programs are financially self-sustaining; and most universities lack sufficient staff and funds to help startups navigate the commercialization process (National Research Council, 2012; Fieldsteel, 2014). Despite the challenges, the EPA believes the collaborations which the FTTA and CRADAs facilitate can lead to improved research outcomes, the creation of new intellectual property, and an improvement in the rate of commercialization of environmental technologies that lead to better protection of human health and the environment (EPA, 2017).

The collaborations that take place at the EPA's Cincinnati facility are a concrete realization of federal policy. In 2012 the EPA and its researchers began a collaboration with Urbanalta, a Cincinnati-based small business, and the Metropolitan Sewer District of Greater Cincinnati (MSDGC), to develop novel technologies and measurement methods for monitoring sewer flows during heavy rains and detecting the location of the resulting combined sewer overflows (Connair, 2014). The EPA developed a CRADA with Urbanalta which let the EPA take the lead on a joint patent for which Urbanalta was granted an exclusive first commercial license to use the technology (FLC, 2017). Under the CRADA, the EPA and Urbanalta contributed to cost sharing for the research, development, and demonstration of the flow monitoring technology; and royalties from the license will be returned to the EPA laboratory, and the researchers involved in developing the technology, thereby providing an incentive for future technology transfer (FLC, 2017). Urbanalta and the EPA developed several prototypes before eventually developing and designing a final, commercially viable sensor platform. Urbanalta's low-cost networked sensors have the potential to revolutionize flow monitoring and management for municipal utilities and reducing one of the most important threats to water quality (FLC, 2017).

B. Regional Innovation Cluster Award Program.

The U.S. economy has faced challenges in evenly and equitable delivering growth in productivity, output, and jobs across the country, a problem exacerbated by the Great Recession of 2008. Certain cities and regions have consistently outperformed, and others consistently under-performed, the national average (Shearer et al., 2017). Uneven and inequitable economic performance is correlated to the economic character of the contemporary U.S. economy. Cities and regions that specialize in R&D-intensive and advanced industries saw the fastest growth in output and productivity, but productivity declined in cities and regions where the economy depended on retail, hospitality, or health care. Cities and regions that were strong in hospitality, construction, and professional services, saw the greatest increases in hiring by young firms, suggesting that prosperity is not necessarily linked to the growth in employment (Shearer et al., 2017). Uneven economic performance is nothing new and the shifts in the structure of the national economy that were exacerbated and reinforced by the Great Recession are part of an historic pattern of continually evolving and shifting economic development connected to location and industry specializations. Early concerns about regional development led to the Public Works and Economic Development Act of 1965 and the creation of the Economic Development Agency (EDA) to facilitate job creation, increase private-sector investment, promote innovation, and accelerate long-term sustainable economic growth. The Stevenson-Wydler Technology Innovation Act of 1980 - which is part of a federal effort to actively foster innovation and better coordinate federal support for scientific and technological research and development, technology transfer, and commercialization - is connected to more recent concerns about U.S. global competitiveness (Federal Register, 2017). Support for clusters was one of the founding justifications for the establishment of the U.S. EDA in the 1960s (CREC, 2015). Policy makers at all scales of government have increasingly come to see regional innovation clusters as significant catalysts of local economic development; and there also is the widespread belief that without federal support some local communities would struggle to effectively support cluster development, especially in certain industries (Federal Register, 2017). Subsequent amendments to the Stevenson-Wydler Technology Innovation Act led to Regional Innovation Strategies (RIS) and the implementation of the Regional Innovation Program, which is managed by the EDA's Office of Innovation and Entrepreneurship (OIE). Under the Regional Innovation Program, the EDA currently awards grants designed to support innovation and entrepreneurship through proof-of-concept and commercialization assistance, operational support for organizations, and early-stage risk capital which are in turn designed to translate into local economic growth and jobs (Federal Register, 2017).

In 2010, the EDA became the lead agency in cluster development; however, since FY 2011 there are at least five federal agencies directly involved in the promotion of innovation and entrepreneurship in regional clusters: the EDA, SBA, DOE, USDA, and NSF. The policy of the Obama Administration is to expand federal support for clusters and regional development through multiple federal programs - embedded in multiple federal agencies, targeting several priority areas of the economy, but which complement each other - rather than anchoring them in a single discrete program or agency (Muro & Katz, 2011). The U.S. Small Business Administration Administrator (SBA) currently supports a portfolio of 14 Regional Innovation Clusters through its national infrastructure of financing and consulting networks as part of the federal strategy of supporting American global competitiveness by creating support systems for emerging small businesses in targeted industries (Muro & Katz, 2011). In 2014, the Milwaukee water technology innovation cluster was one of four Regional Innovation Cluster awardees to receive a grant of $500,000 from a pool of more than 40 applicants representing a wide range of diverse geographic areas and industries (SBA, 2014). Clusters supported through the program are awarded $500,000 for the base year of the contract, with four option years to be exercised at the SBA's discretion, for up to a total of $2.5 million per cluster initiative over five years. The SBA’s funding will be provided to each cluster's organizing entity, in this case The Water Council, to strengthen opportunities for small businesses within the cluster by providing mentoring and counseling services, teaming with partners for research and commercialization, providing fora to pitch their businesses to prospective investors, and opportunities to showcase their products and services to public and private sector adopters of new technology. The Water Council intends to utilize this SBA grant to establish a Center of Excellence for Freshwater Innovation and Small Business Development (The Water Council, 2014).

C. Small Business Innovation Research Program (SBIR).

The U.S. economy faces challenges with small businesses commercializing their technologies and products; and challenges with U.S. businesses in general maintaining their technological and innovative edge in the face of global competition from other advanced or emerging economies that have been upgrading their specialized factors (Porter 1990, 1998, 2000). The Small Business Innovation Research (SBIR) program was established by the Small Business Innovation Development Act of 1982 to build a strong national economy by using federal research funds to encourage scientific excellence, stimulate technological innovation and support entrepreneurship – especially among socially and economically disadvantaged persons - in priority areas identified by policy makers as critical to America's security, economy, environment, public health, or management of information and data (SBA, 2017). The SBIR is targeted at small businesses – defined for purposes of this award as businesses not exceeding 500 employees, including its affiliates – that engage in R&D, that have technologies with the potential for commercialization, and that meet specific U.S. government R&D needs (SBA, 2017). The program funds projects that are considered too risky for traditional sources of investment capital, where the risk and expense of conducting serious R&D efforts are often beyond the means of many small businesses, but where the wider public interest may be served. The SBIR is supposed to help promising small technology companies compete on a more level playing field with larger, better resourced, and better networked businesses (SBA, 2017).

Currently 11 federal agencies participate in the SBIR Program and approximately $2.5 billion is awarded through this program each year - the United States Department of Defense (DoD) is the largest agency in this program with annual grants totaling approximately $1 billion. The participating federal agencies are those with extramural R&D budgets that annually exceed $100 million, which are required to allocate 3.2% of their R&D budget to SBIR programs, which they individually administer within guidelines established by Congress (SBA, 2017). These agencies designate R&D priorities, according to their mandated missions, in their solicitations for proposals and awards which take the form of highly competitive contracts or grant which are subject to rigorous evaluations. The SBIR Program is structured in three phases (SBA, 2017). The first phase is designed to establish the technical merit, feasibility, and commercial potential of the proposed R&D efforts, award a contract or grant not exceeding $150,000 to successful applicants for a project period of 6 months, and evaluate the awardee to determine the quality of performance of the small business prior to providing further federal support in Phase II. The second phase seeks to continue the R&D efforts initiated in Phase I and funding – which does not exceed $1,000,000 over a 2-year period - is based on the results achieved in Phase I, the scientific and technical merit, and the commercial potential of the R&D project proposed in Phase II. The third phase is designed to help the business pursue commercialization of the technology or product; however, although the SBIR program does not fund Phase III, non-SBIR funded R&D or production contracts may be available for products, processes or services intended for use by the U.S. Government. Since its enactment in 1982, thousands of small businesses have received SBIR awards; and annually about a quarter of the companies receiving grants are receiving them for the first-time. Five federal agencies with extramural R&D budgets over $1 billion also operate a similar program to the SBIR, the Small Business Technology Transfer Program (STTR), which is used to expand public-private sector partnerships between small businesses and nonprofit U.S. research institutions (SBA, 2017). The STTR program requires the successful business to have a partnering research institution, which must be awarded a minimum of 30% of the total grant funds. These five federal agencies are required to fund STTR programs using an annual set-aside of 0.40% of their R&D budgets. The SBA serves as the coordinating agency for both the

SBIR and STTR programs (SBA, 2017).

The U.S. EPA is one of the 11 federal agencies that participates in the SBIR Program and the projects that it funds align with the agency's mission of ensuring clean air and water, increasing resilience to climate change, reducing the impact of waste, promoting clean and green manufacturing, and ensuring water security (Fieldsteel, 2014; EPA, 2017). In recent years the EPA's SBIR Program has supported the development of technologies from environmental monitoring devices to pollution clean-up systems and processes. In 2016 the agency announced that 13 small businesses nationwide would receive Phase I contracts totaling $1.3 million to advance 'proofs-of-concept' which would lead to the development and commercialization of technologies to help solve current environmental issues ranging from greener manufacturing of plastics to low-cost air sensors (EPA, 2017). If successful in their Phase I contracts, these businesses will be eligible to apply in 2017 for Phase II contracts of up to $300,000 each to develop and commercialize their technologies for the marketplace. One such business is Faraday Technology, Inc. which was awarded $100,000 to develop a technology to mitigate some of the impacts of animal agriculture on the environment via recovery of phosphorus and nitrogen from waste. Faraday, in collaboration with the University of Illinois, will seek to demonstrate the potential for an economically-viable, sustainable, industrial-scale nutrient extraction process that reduces agricultural costs while co-generating hydrogen. Faraday's technology employs a chemical free, energy efficient method of extracting nutrients from wastewater, while generating renewable energy sources, that represents improvements over current extraction methods based on aeration and chemical additions (EPA, 2016; Mibourn, 2016). The wastes from industrial-scale agriculture, to include concentrated animal feeding, is a significant source of pollution that impacts the quality of both surface and groundwater, increases the cost of water treatment, threatens environmental health, and creates significant amounts of manure with an annually cost of disposal is about $1.6 billion.

D. Networking: Cluster Leader's Conferences & Water Technology Market Summit.

Innovation, entrepreneurship and the success of a business cluster all depend in part on the quality and frequency of information sharing; and information sharing depends on opportunities for networking and the presence and degree of trust between agents in a cluster (Porter, 1990, 1998, 2000; Alves et al., 2004; Fieldsteel, 2014). Innovation and entrepreneurship are highly complex processes which require a high level of trust-based interactions and cooperation between a diverse set of economic and social agents. These trust-based networks facilitate peer-based learning and the sharing and creation of complementary knowledge, which in turn reduces the uncertainty surrounding a wide variety of risks, helps to identify emerging trends and technologies, improves the quality of policy and government action, and stimulates and reinforces innovative attitudes within firms (Drucker, 1985; Alves et al., 2004; Fieldsteel, 2014). Innovation and entrepreneurship are increasingly a collaborative process involving diverse economic and social agents who bring to the table complementary skills and interests (Drucker, 1985; Porter, 1990, 1998, 2000; Alves et al., 2004; Fieldsteel, 2014). Innovators and entrepreneurs who are embedded in reciprocal networks with other innovators and entrepreneurs tend to outperform those who are not embedded, and firms that innovate in isolation tend to have an innovation process that is inefficient and unsustainable (Enright

& Ffowcs-Williams, 2000; Alves et al., 2004).

Cluster networks do not always emerge organically nor are they automatically sustained. Cluster networking produces the greatest benefits if it is sustained over the long-term, and if it is facilitated by neutral parties representing the widest cross-section of stakeholders. Cluster networking can be both formal and informal. Formal mechanisms, however, create an important point for positive, proactive intervention for cluster associations and state agencies for economic development where the state can motivate, facilitate, and provide incentives for collective action by the private sector which is best placed to understand its own challenges and meet emerging opportunities (Porter, 1990, 1998, 2000; Enright & Ffowcs-Williams, 2000). Robust, trust-based, reciprocal networks of communication therefore offer a number of benefits for clusters and their members: (1) they reduce transaction costs by making the transfer of information easier and less costly; (2) they facilitate the access to strategic information and knowledge as cluster members have preferred access; (3) they facilitate easier and less-costly bench-marking and performance monitoring and measurement with similar firms with the cluster; and (4) they facilitate a rationalization of production by sharing quasi-public goods, supply chains, marketing channels (North, 1990; Porter, 1990, 1998, 2000; Alves et al., 2004).

The EPA, in supporting the agency's clean environmental technology program, recognizes that networking and good communication among cluster stakeholders is key to encouraging technological innovation and entrepreneurship (EPA, 2012; Fieldsteel, 2014). To achieve this the EPA has instituted several initiatives. One of the first was a Water Technology Market Summit in 2012, which was co-sponsored with American University and which brought together 150 representatives of government, industry, investment and academia (EPA, 2012). The goals of the Water Technology Market Summit were: (1) to begin a dialogue among stakeholders to identify strategies to stimulate and accelerate innovation and the adoption of environmental technologies, (2) to expand the environmental technology market to support economic growth and create jobs through environmental protection, (3) to protect environment and human health and develop partnerships among key environmental stakeholders, (4) to identify concrete actions that the public and private sectors would take to increase investment in technology clusters, and (5) to broaden business opportunities in commercializing innovative environmental technologies (EPA, 2012).

Another initiative to support networking has been the annual Water Technology Innovation Cluster Leaders Meetings. The first meeting was held in 2013 in Cincinnati, Ohio and was entitled *Technologies and Innovative Solutions for Harvesting and Non-potable Use of Rain and Stormwater in Urban Settings* and it was attended by approximately 100 stakeholders. This meeting discussed innovative ways to capture and use rain and storm water while monitoring water quality and protecting public health (Lye & Waits, 2013). The second meeting was held in 2014 in Cincinnati, Ohio and was entitled *Successfully Supporting Early-Stage Companies: The Role of Technology Testing* and it was attended by approximately 60 stakeholders. This meeting discussed the challenges relating to the testing of technologies that must be addressed before a new water technology can go to market (Waits, 2014). The third meeting was held in 2015 in Pittsburgh, Pennsylvania and it was entitled *Federal Funding Opportunities for Early-Stage Water Companies* and it was attended by approximately 75 stakeholders. This meeting, which was held in partnership with the Water Economy Network, discussed federal funding opportunities for early-stage water technology companies, the role of water cluster anchor companies, and the benefits of belonging to a water cluster (Waits, 2015).

V. Conclusion

The U.S. faces economic and environmental challenges that include stressed water resources and the declining global competitiveness of its high-technology industrial base. Both challenges threaten the quality of life of the American people. These challenges are not new – they have been emerging for several decades and have been subject to continual policy intervention at all political scales. The limitations to the efficiency and effectiveness of traditional public policy is partially connected to the fact that these policy problems, though connected, have been addressed in an ad hoc and fragmented manner, and that the resources committed to address these problems have not always been sufficient to the task. Over time, however, federal policy has been evolving to adopt a more joined-up approach to both planning and implementation. The EPA's Clean Air and Clean Water Technology initiatives are an example of a more integrated approach to federal policy towards both regional economic development and environmental protection. With this new approach, the goal of the federal government is to improve both economic and environmental outcomes by strengthening regional business clusters build around the water industry and water technology firms. The EPA and SBA, which have partnered to implement this policy, have given these regional business clusters the designation Water Technology Innovation Clusters. The idea behind the policy is to identify where clusters exist and support their growth and development with resources such as federal funds for both basic and applied R&D, increased networking such as through conferences and industry associations, increased collaborations such as those that support innovators to develop pilot projects and field test their technologies, and by streamlining regulations and regulatory processes which speeds up and simplifies the permitting process for water technologies. All these efforts collectively improve the process by which technological and institutional innovations diffuse and become available to meet America's growing and evolving water, economic, environmental, and public health needs.

CHAPTER 5

WATER TECHNOLOGY CLUSTER IN CINCINNATI, USA

I. Introduction

This case study examines Confluence, the water technology innovation cluster based in Cincinnati, Ohio. Cincinnati was one of the first cities in the U.S. to be designated as a water technology cluster by the SBA and EPA under the federal government's efforts to promote both regional clusters and clean technologies. The case study begins with a brief look at the historical relationship between water, economic development and environmental impacts in Ohio over the last 200 years. It then moves on to the establishment of Confluence, which is the industry association representing the water technology sector in the Greater Cincinnati Metropolitan Region. Several specific examples of the efforts of Confluence and its stakeholders are examined: the attempt by the Greater Cincinnati Water Works (GCWW) and the Metropolitan Sewer District of Greater Cincinnati to spur local economic development; the creation of a Regional Utilities Network; the establishment of a tristate regime to simplify the approval of water technologies and to speed their commercialization; the partnership with the business incubator and accelerator, The Hamilton Mill, to support several water technology startups; the efforts to support two technology startups, Citilogics and Pilus Energy; and the multi-stakeholder project to respond to toxic algal blooms in Ohio waterways. Interviews with several key stakeholders were conducted: Sally Gutierrez and Teresa Harten of the EPA, Melinda Kruyer of Confluence, and Anthony Seppi of The Hamilton

Mill. Finally, Confluence is analyzed using Porter's Diamond to gain insights into its competitiveness as a water technology cluster.

II. Background and Context to Cincinnati Water Cluster

A. Early History

Ohio has an important and historic relationship with its water resources. Rivers and lakes were important for communication and trade in the 18th and 19th centuries, and reliable supplies of water became an important input in manufacturing from the late 19th century onwards (Herdendorf, 1996). Rich soils, relatively smooth topography over much of the state, nearly 70,000 kilometers of rivers and streams, and adequate rainfall provided fertile farmland. The hilly south-east of the state was rich in timber (Herdendorf, 1996). Ohio sits on top of the 1.5-trillion-gallon Great Miami aquifer, one of the country's largest sources of fresh groundwater. Ohio is home to some of the country's largest and most important urban and industrial centers and all are situated near a source of water - whether it is Lake Eire in the case of Cleveland, Sandusky, and Toledo, the Ohio River in the case of Cincinnati, or one of the rivers that feed the Ohio River as in Dayton and Columbus. Water resources were not always managed with the care they deserved, with the most infamous example being the badly polluted Cuyahoga River which caught on fire of 1969. The state of Ohio and its regional partners are now striving to sustainably manage its water resources and leverage this local asset.

The economy and innovation have had an important and historic relationship in Ohio. Great Ohio inventors included Charles F. Brush, Thomas A. Edison, Martin Hall, Charles F. Kettering, Thomas Midglet, Jr., and Orville and Wilber Wright. Great entrepreneurs included John D. Rockefeller, Marcus A. Hanna, Samuel L. Mather, Harvey S. Firestone, and Frank A. Seiberling. Ohio was the nation's leading agricultural state at the end of the Civil War and in 1880 there were nearly 250,000 farms in Ohio. The state maintained this position until overtaken by farms in Western states at the end of the 19th century. With the rise of manufacturing Ohio also became a major producer of farm machinery, but agriculture remained an important industry supported by the creation of the Ohio Agricultural and Mechanical University, the 4-H movement, the Ohio Agricultural Experiment Station at Wooster, and the establishment of the Ohio Cooperative Extension Service with agents in every Ohio County (Herdendorf, 1996). Building upon is rich natural resource factors Ohio became a major industrial region in the emerging steel, oil and rubber industries, all of which require access to a reliable supply of water.

Research and development have been a well-established activity since the late 19th century. Ohio researchers, colleges and universities have been making significant scientific and technological advances in many fields that have been an important support to Ohio’s industry and economy, and this has kept the state’s economy among the most important in the United States (Herdendorf, 1996). Ohio colleges and universities have strong curricula supported by cutting-edge laboratories in the fields of science, technology and engineering. In 1913 Ohio State University established the Engineering Experiment Station, which was also sponsored by industry and government, to carry out research associated with the development, utilization and conservation of the state's natural resources and the promotion of economic development. By 1950, there were approximately 300 industrial research laboratories in the state, employing more than 33,000 persons; and today the state has more than 6,000 scientists involved in implementing nearly $4 billion worth of research annually, of which about 1,000 are doing research associated with water and sanitation. Ohio's economic growth in general, and particularly its industrial growth, has always been closely linked to scientific and technological advancement and this is being translated into supporting innovation and technological development in the water economy.

B. Recent History

Cincinnati, which is the home base for the Confluence Water Technology Innovation Cluster, is the 24th largest metropolitan area in the United States with a population of more than 2 million people, a rich and diverse workforce, and a diversified economy of both manufacturing and services. The Cincinnati metropolitan area is also home to several educational institutions, such as The University of Cincinnati, Xavier University, Northern Kentucky University, Thomas More College and Cincinnati State; the U.S. Environmental Protection Agency's (EPA) internationally respected Andrew W. Breidenbach Environmental Research Center, a leader in water research, bio-remediation and pollution prevention; and the U.S. Air Force Research Laboratory in Fairborn, which applies leading-edge aerospace research to water needs. The Cincinnati metropolitan area was one of three locations identified by the EPA and Village Capital as a water technology innovation cluster, the other two locations being San Diego and Milwaukee. A 2010 study found that Greater Cincinnati has more water-technology patents per person than any region of the country; and it is also a major source of scientific publications in drinking water, waste water and storm water. Many of these patents and publications are connected to the EPA's Cincinnati Research Center, and to private companies such as Procter and Gamble, Shell Oil, Eli Lilly, Zoeller, General Electric, and

Aspen Technologies. With 80 percent of their products containing or relying on water, Procter & Gamble was one of the early and ongoing firms conducting research and developing technologies related to water. Many private companies and public utilities therefore contribute to the water research field. The tristate region identified as being associated with the Cincinnati cluster is home to about 90 public water utilities to include the drinking-water utilities in Cincinnati and Dayton, Cincinnati's Metropolitan Sewer District and Northern Kentucky's Sanitation District.

Cincinnati is considered the birthplace of federal government water research (Verbeten, 2016) when in 1913 the United States Public Health Service established a Field Investigation Station to oversee the first federally funded water research studying the relationship between water-borne diseases in drinking water, pollution in streams, and wastewater treatment technologies. These studies led to the introduction by the federal government of safe drinking water standards and to standards for the maximum acceptable contaminant levels in water. The federal government's actions were largely a response to Ohio being a pioneer in freshwater supply, water softening and wastewater treatment. The first public fresh water system in Ohio was constructed in 1821 in Cincinnati, by 1870 there were 11 public systems serving 2.7 million people, and by 1970 there were 680 plants serving over 80% of the state's population (Cosgrove & Hushak, 1972). Ohio opened the country's second rapid sand filtration plant in the city of Warren, Ohio in 1895, which was followed by further major water treatment facilities in Lorain, Cleveland, Columbus and Cincinnati and the establishment by Ohio State Board of Health of the first systematic investigation of the efficiencies of the filtration plants in the years 1908-08 (Burges, 1916). At the time of its opening in 1907, the Cincinnati treatment plant was the second largest of its kind in the world and these investments paid off with a dramatic reduction in water-borne illness, such as typhoid, among the Ohio population. The Cincinnati's Field Investigation Station remained at the forefront of federal water research when in 1948 the United States Congress enacted the first Water Pollution Control Act which authorized the Public Health Service to protect water quality for fish and aquatic life and the facilities in Cincinnati to conduct research on water pollution and train personnel in pollution control. The United States Public Health Service and the Greater Cincinnati Water Works (GCWW) had been collaborating since the early 1900's (Thompson, 2013). In 1970, the newly created EPA took over Cincinnati's Field Investigation Station which has grown into the 22-acre Andrew W. Breidenbach Environmental Research Center. It is the second largest EPA research and development facility in the country.

Major Ohio utilities continue to be pioneers in the provision of fresh and waste water services to both industry and consumers, as well as in the protection of public and environmental health. The population of the state, the levels of urbanization, the requirements of agriculture and industry, the cooling requirements of thermoelectric power, and the need to sustainably exploit the hydrologic cycle are all drivers of water management in the state. Companies like Cincinnati based Procter & Gamble are intensive users of water with 80 percent of their products containing or relying on water. In 1970 Ohio ranked sixth in total water use among the 50 states, the only other eastern state to use more was Pennsylvania, and its industrial use of water was the highest in the nation (Cosgrove & Hushak, 1972). In 2010, its total water use of the Cincinnati area was twelfth among the 50 states and its industrial use of water was tenth in the nation. Most of the other leading states either had larger populations or heavy demands for irrigation (Maupin et al., 2014). Ohio utilities such as the GCWW and Cincinnati Metropolitan Sewer District (MSD) continue to be leaders in the use of rapid-sand filtration, chlorine and granular activated carbon (GAC), and ultraviolet (UV) disinfection technologies; and the MSD is regarded as a national leader in the development of sustainable storm water management solutions and asset management and a Wet Weather Strategy designed to reduce combined sewer overflows as mandated by the federal government. This innovative environment in water technology is why Melinda Kruyer, Executive Director of Confluence, is confident that the region will be a national and global leader in fresh, storm and waste water technologies and services (M. Kruyer, personal communication March 11, 2017).

III. Confluence Water Technology Innovation Cluster

A. Creation of Confluence Water Technology Innovation Cluster

The idea to formally designate the Greater Cincinnati Metropolitan Region as a water technology innovation cluster and to encourage the formation of an industry association what would eventually become Confluence rests on a recognition of the following: the region's water assets, the long local tradition of water research and innovation, a unique concentration of labs and testing facilities, and the long presence of the EPA's research center. The cluster's geographic scope includes the Dayton and Cincinnati metro regions, Northern Kentucky and Southeastern Indiana. The joint EPA and Small Business Administration (SBA) initiatives attempts to harness regional expertise in public utilities, public and private research facilities, and innovative businesses to achieve what were traditionally seen as discrete goals of their respective agencies. These goals are the encouragement of local economic development and the protection of environmental and human health and they are now seen as complementary and interrelated.

In April 2010, EPA Cincinnati was charged with launching the development of a public-private partnership focused on the commercialization of innovative environmental technologies for clean air and water. The EPA Cincinnati initiated several studies and organized several briefings with regional leaders in the water industry to investigate the potential for forming a technology innovation cluster in the Greater Cincinnati Metropolitan Region focused on water. The response the EPA received during these briefings was overwhelmingly positive and the region quickly formed a steering committee to spearhead the effort. This committee drafted an initial vision and mission for the cluster and developed agendas for two stakeholder meetings, which EPA hosted at its facility in October 2010 and January 2011. Approximately 60 stakeholders from regional universities, large corporations, emerging companies, all three levels of government, and economic development agencies attended each of these meetings. A market analysis was produced by the 2010 U.S. Drinking Water Innovation Vendor Outlook Report on the companies and market trends shaping innovation the U.S. drinking water sector; and there was a Mapping Report on Proposed Water Cluster in Cincinnati Region which mapped the regional output of research publications and patents. These reports were presented to the stakeholders.

During these two meetings, the stakeholders concluded that the region did possess unique strengths in water resources and water technologies and would provide a viable base on which to formally build a water technology innovation cluster to competitively meet present and emerging needs in regional, national and global water markets. The stakeholders agreed to proceed with the development of an industry association, to be named Confluence. Based on the draft framework and operating structure developed by the steering committee it was determined that the steering committee would serve as the basis for the initial Confluence Board of Directors. On 18th January 2011, the EPA and SBA announced the start of the Water Technology Innovation Cluster for the Ohio River Valley Region. The EPA provided $5 million of seed money for research to help attract companies to the cluster for public-private collaborations, while the SBA provided website support. Confluence was one of three initial clusters identified by the EPA and SBA – the others being in San Diego and Milwaukee – and the number of clusters has grown to 14 nationwide.

B. Vision, Mission, Goals and Objectives of Confluence

Confluence is a 501(c)(3) non-profit which was established in 2011 as a regional partnership between the private sector, local, state and federal governments, public utilities, non-profits, economic development agencies, the EPA, universities, and research facilities. The Confluence region includes southwest Ohio, northern Kentucky, and southeast Indiana. Confluence coordinates scientific, technological, and financial resources from the stakeholders to aid the development and diffusion of promising water technologies; and it promotes leveraging water resources to support local economic development, build and maintain a vibrant, technology-driven economy, and protect environmental and public health. To achieve these goals Confluence focuses on five distinct objectives that supports innovators and entrepreneurs by matching existing and emerging technology companies with the appropriate resources and potential markets: (1)

increased networking between stakeholders, (2) speeding up technology testing, (3) improving public policy and regulation, (4) linking entrepreneurs with sources of funding, and (5) assisting with the commercialization and marketing of technologies and products. These objectives ultimately enable water technology innovators and entrepreneurs to successfully market their technologies and solve in unique and creative ways some of the most challenging issues facing the water economy. The cluster focuses particularly on developing technologies that facilitate sustainable water resource management, improve water and energy efficiency, reduce costs for utilities and consumers, address a broad array of contaminants, and improve public health.

Confluence states that its vision is "to identify, test, develop and commercialize innovative technologies to solve environmental challenges and spur sustainable economic development and job creation, by: (1) attracting the best and brightest scientists and entrepreneurs, (2) promoting economic development through the creation and attraction of jobs and investment, and (3) becoming the world's source for practical and affordable solutions and sustainable practices." Confluence's mission is to "collaborate to establish the region as a global leader in sustainable environmental technology innovation, with an initial emphasis on water." To facilitate the vision and mission, Confluence has employed a number of strategies: (1) host an annual water symposium that brings together stakeholders to network and share perspectives on regional, national, and global water challenges; (2) market the cluster to attract more innovators and entrepreneurs to the region; (3) support local innovators and entrepreneurs; (4) work to remove barriers and expedite approval processes through the multi-jurisdiction agreement between Ohio, Kentucky and Indiana; and (5) align the efforts and increase the interactions of different organizations in the water industry. Alan Vicory, Confluence's former board chairman, states that:

> "We help facilitate the efficiency of the ecosystem—in this case, toward the development and deployment of new technologies—and in doing that, you create economic development by growing indigenous businesses and attracting new ones from the outside. Our vision is to help businesses identify markets and test, develop, and commercialize innovative technologies to solve environmental challenges and, at the same time, spur sustainable economic development and job creation locally. The cluster is all about economic development -- bringing jobs to our region. That's why we're here -- to capitalize on these assets that we have. We want to bring manufacturing here, and we want to bring the best and brightest minds (Cunneff, 2014)."

Confluence also focuses on five distinct objectives that many of these entrepreneurial companies are looking to meet: (1) networking, (2) testing, (3) policy and regulation, (4) funding, and (5) purchasing. Through this approach Confluence serves as the focal water networking hub of the Greater Cincinnati area, offering an exclusive point of contact with other important entities and matching technology companies with the appropriate resources and accommodations to establish an all-encompassing foundation that considers all aspects of the development process.

C. Structure and Leadership of Confluence

Confluence is a geographically concentrated network of interconnected public, private and non-profit organizations that voluntarily work together to leverage regional water resources to promote regional economic growth and technological innovation in the water industry. The leadership of Confluence comes from these organizations and represents a variety of interests and perspectives, offers a range of knowledge and skills, promotes relationships and networks that cross organizational and disciplinary boundaries, and facilitates access to resources.

The board membership is made up of persons from the private sector, the public sector and academia as follows: Reese Johnson, Vice President, CH2MHill (Confluence President); William Scheyer, President, Skyward (Confluence Vice President); Verna Arnette, Deputy Director, Greater Cincinnati Water Works (Confluence Secretary); John Menninger, Principal, Stantech (Confluence Treasurer); Michele Simmons, Environmental Manager, City of Dayton Water Department (Member); Dr. Patrick Limbach, Vice President for Research, University of Cincinnati (Member); and Jim Uber, CEO, CitiLogics (Member). The management team consists of Melinda Kruyer, Executive Director, and Roger Smith, Finance Director, and office space is on Kellogg Avenue near the Greater Cincinnati Water Works.

Confluence's paid up membership of 20 companies includes startup companies, such as CitiLogics, Lagoon, Green Forward Technologies, Searen, Pilus Energy, Urban Alta, and Aquionics, major corporations such as Procter & Gamble Co. and General Electric, federal water laboratories, major research universities, and water industry experts. Stantec, as one of the largest water consultancies in the world, provides critical resources of technological knowledge and industry connections. As a Sustaining Member of Confluence, Stantec's roles include strategic planning and advisor to the board and members. Procter and Gamble put up seed money to get the group an office and provides international connections. Confluence is also targeting around 250 more companies and about 90 utilities around the region to participate in the program.

D. Partnerships and Activities of The Water Council

1. Regional Utility Network

The utility industry is the United States is highly fragmented and the Confluence cluster has over 90 utilities in a 100-mile radius of Cincinnati. These utilities face a range of challenges to include replacing aging and crumbling infrastructure, a lack of funding for capital improvement projects, difficulty implementing full-cost recovery for providing services, the declining quality of water, planning for and responding to water scarcity, drought and climate change, replacing a retiring workforce, meeting government regulations for water quality, reducing energy usage and costs, planning and responding to emergencies and threats to security, a public with a lack of building appreciation for the value of water, and building relationships with customers that communicates the challenges of water stewardship and develops public support for local utilities (AWWA, 2016; M. Kruyer, personal correspondence, March 11, 2017). In 2015 Confluence responded with the creation of the Confluence Regional Utility Network (RUN), which represents a complete cross-section of the region's public utility industry from fresh to storm to waste water. Confluence is attempting to create a network of utilities, which would be linked to scientists, technologists, innovators and entrepreneurs within the Confluence cluster. The RUN is designed to provide a platform where stakeholders could collaboratively find customized, forward-thinking solutions to the challenges faced by utilities, promote scale efficiencies, which would conserve scarce resources, and create markets for technologies from the cluster (M. Kruyer, personal correspondence, March 11, 2017).

Confluence and RUN host annual conferences to discuss and address the challenges facing its members and recognize innovation in the field. The first conference was held in November 2015 and the membership created a created a prioritized list of 21 urgent challenges that they faced which included protecting source water, the real-time monitoring for contaminants, incorporating information and communication technology into operations, and the risks posed by lead service lines. A workshop to specifically address lead was held in June 2017. Confluence also hosts the Reverse Pitch Conference which gives potential solution providers an opportunity to hear about water challenges directly from regional utilities and submit abstracts on their technologies that would be applicable to the specific needs of these utilities. Reverse Pitch allows stakeholders to share detailed information on technology specifications, project plans, and budget constraints which act as constraints to addressing water challenges (M. Kruyer, personal correspondence, March 11, 2017).

Confluence has also created the W Prize out of its Confluence Innovation Fund as a challenge-based competition to stimulate and recognize innovation in the water technology sector. The specific challenges for this W Prize were developed by the 2016 Confluence Regional Utility Network and presented at the Reverse Pitch Conference in July of that same year. In December 2016, twenty-four companies at the Confluence Tech Showcase were selected to participate and after an evaluation process and voting by the Technical Committee and Confluence board, four companies were selected for W Prizes which was awarded in February 2017. The Confluence Innovation Fund and the W Prize are both designed to support innovation in the water technology sector by supporting the process by which technologies that address real-world water challenges are identified, developed and commercialized of specific innovative technologies that will address today's unprecedented water challenges (Verbeten, 2016).

2. Tri-State EPA Agreement

To simplify and expedite the commercialization process of water technologies, Confluence in 2013 brokered a multistate memorandum of understanding between regulators from Ohio, Kentucky and Indiana, which would allow startups and firms to get water technologies approved by all three states at once. The three state environmental agencies have agreed to work together to simultaneously develop water technologies and expedite testing. According to Kruyer, there are many obstacles firms face converting water-technology ideas into commercial projects, and field testing and regulatory approval are among the most significant (M. Kruyer, personal correspondence, March 11, 2017). Even if a firm receives approval for its technology from the EPA the technology must still be approved by state environmental regulators; and water technologies traditionally can take 12-15 years to move from the laboratory to commercialization. Confluence is working to take down barriers to technology commercialization and to expedite the regulatory approval process. On January 16, 2013, Confluence brokered the landmark signing of a multi-state agreement with the EPAs of Ohio, Kentucky and Indiana to help streamline and harmonize the approval process of emerging drinking and waste water treatment technologies. In both the Chesapeake region and the Midwestern states of Ohio, Kentucky and Indiana, regional water clusters have helped to remove these barriers, by enabling collaboration between state regulators to develop cooperative agreements, allowing for reciprocity of new technology testing across multiple states. Innovation in regulation at the regional level will substantially increase market attractiveness and accelerate innovation through increased market-pull. Many pressing water quality and related environmental and public health problems – such as lead in pipes and algal blooms – cannot and should not wait 12-15 years to be addressed when, over the past 20 years, an expanding range of potentially viable technologies have become more commonly available than most users realize or can quickly be brought on stream (Najm & Trussell, 1999). The ongoing discovery of new contaminants, the promulgation of new water quality standards, and the increasing cost of providing utility services have stimulated the development of new water technologies; however, the state processes for small-scale pilot testing, and subsequently approving and implementing at full-scale the new technologies, has lagged both technological advances and consumer demand. According to

Ringenberg et. al. (2017), obtaining state regulatory agency approval for the implementation of new water technologies is a long-standing national problem, especially in small drinking water systems. The state regulatory approval process is a barrier because of the following: (1) state regulators lack time, specialized training for their staff, and pilot test data from vendors; (2) it is difficult to obtain independent verification or certification of water technologies; and (3) there is insufficient networking between state regulators and local water utilities that would facilitate - for both existing and emerging technologies - the collection, evaluation and sharing of performance data (Ringenberg et. al., 2017). Confluence is convinced that a simpler and faster approval process will encourage more water technology companies to locate in the Confluence cluster, where they could leverage the region as a domestic market for their technologies. A simpler and faster approval process would also allow more utilities to employ technologies to improve water quality, improve the reliability of their service, simplify operations and service delivery, reduce capital and operations and maintenance costs, and reduce non-revenue water losses. Having a three-state coordinated testing protocol, allows a successful demonstration to immediately create a market for deployment in three states instead of one.

3. Ohio Algal Blooms

In 2014 Lake Erie was affected by an algal bloom that covered several hundred square miles and extended the 120 miles from Toledo to Cleveland. Part of that bloom formed directly over the water intake for Toledo's municipal water supply and caused a disruption in that city's fresh water supply that lasted several days affecting almost 400,000 residents. In 2015 the Ohio River was affected by an algal bloom that extended 600 miles along the river from Pittsburg to Illinois, which affected the operations of more than 14 municipal waste utilities along the river and closed the river to recreational activities. These blooms were so severe that they could be observed from space. Algal blooms, once a severe problem in Ohio waters in the 1950s and 1960s, but largely resolved by the 1980s, have once again become more noticeable in Ohio's lakes, streams and rivers during the first decades of the 21st century (Wines, 2013, 2015; Smith et al., 2015).

Although most blooms in waterways are green algae and are not harmful, there are some types of cyanobacteria that have the ability to produce toxins called harmful algal blooms (HABs). Algal blooms have been recorded for centuries but with urbanization, industrialization, modern agriculture and poor sewerage practices that dump nutrient loaded wastewater into lakes, rivers and oceans their frequency and severity have increased. One of the most celebrated cases took place in June 1969 when parts of Lake Erie near Cleveland caught on fire. This brought the problem to national attention and prompted Congress to pass the Clean Water Act of 1972 – later supported by a separate Great Lakes phosphorus reduction agreement between the United States and Canada - which largely restored Lake Eire over the next decade by improving water quality and restoring aquatic life to the Lake. Lake Erie was particularly susceptible to pollution because it is the warmest and shallowest of the Great Lakes and its shores are home to more than 11 million people, several of the largest cities in

North America, and the location of a significant concentration of North American industry (Wines, 2013, 2015; Smith et al., 2015).

Lake Erie is again sick and so are many other bodies of water in and around Ohio. The Clean Water Act of 1972 redressed point sources of pollution but not non-point sources of pollution. The current phase of pollution of water is driven by urbanization and industrial agriculture that have spawned new and potent sources of runoff from fertilized farms, cattle feedlots, and leaky septic systems whose origin cannot easily be identified. There are some 250,000 farms in the Ohio River watershed which makes regulation and monitoring more difficult than when regulators must monitor the discharges from a few hundred sewerage plants and factories. The consequences of algal blooms include not only threats to public and environmental health, but it also raises the cost of treating municipal water. The water plant in Huntington spent $700,000 to deal with one outbreak on the Ohio in 2015. Toledo saw its budget for chemicals double between 2010 and 2014 to $4 million annually to address this problem (Wines, 2013, 2015; Smith et al., 2015).

Algal blooms, which have been increasing in frequency and severity around the world, are caused by a combination of the discharge of additional nutrients into bodies of water, warm weather, and sunlight. Algal blooms reduce the oxygen levels in water which can reduce aquatic life and when the algae die they can produce toxins that can cause skin rashes and burns if touched, and diarrhea vomiting, liver damage, and even death if ingested (EPA, 2017). The amount of toxin needed to kill animals is remarkably small. Beyond the dangers to people and animals, the cost of algae on commercial fishing and on recreation runs into the tens of billions (Wines, 2013, 2015; Smith et al., 2015). The only effective and efficient way to control cyanobacteria blooms is to control the release of excess nutrients into bodies of water; however, the protection of public health also requires sophisticated technologies to predict their occurrence and monitor water quality. Until recently the EPA was not required to regulate toxic algae leaving the problems to be managed by individual states (Wines, 2013, 2015; Smith et al., 2015).

Confluence has contributed to addressing algal blooms in Ohio by convening two Algal Toxin Summits in 2014 and 2015, which sought to raise public awareness about the problem and focus attention on solutions. Confluence did this by bringing together leading experts in water technology, utility water treatment, water quality and water monitoring to share information and ideas regarding the algal toxin challenge to safe drinking water. During the 2015 bloom on the Ohio, Confluence brought together a project team which included 2 researchers from the Ohio River Valley Water Sanitation Commission, one from Bowling Green State University, another from YSI (a company that makes high-tech water quality meters), and NASA researchers from NASA's John H. Glenn Research Center in Cleveland. NASA had been providing information to water utility in northern Ohio, but this was their first-time assisting people in southern Ohio (Smith, 2015). Confluence is confident that its network of scientists, engineers, technologists, public utilities, public and private research facilities, and local, state and federal agencies uniquely positions the industry association to facilitate this critical and timely discussions of this continuing and growing problem (M. Kruyer, personal correspondence, March 11, 2017).

Although in 2009 the EPA and state water authorities issued a joint report on the problem of pollution of the nation's waterways by phosphorus and other nutrients, titled *An Urgent Call to Action*, measures at the federal level to address algal blooms have only recently come one step closer to reality with the Drinking Water Protection Act of 2015, which was authored by Senator (R-OH) Rob Portman. After the bloom on Lake Erie in 2014, Portman convened a panel of regional experts from state and federal agencies, universities and utilities, which resulted in an ongoing collaboration which worked toward finding solutions to the algal bloom problem. The 2015 legislation will direct the EPA to do the following: (1) develop and report to Congress a strategic Algal Toxin Risk Assessment and Management Plan, which will evaluate the risk to human health from drinking water provided by public water systems contaminated with algal toxins; (2) recommend feasible treatment options to mitigate any adverse public health effects associated with harmful algal blooms; and (3) recommend source water procedures and protection practices (portman.senate.gov., 2017).

IV. Other Contributors to the Confluence Water Cluster

A. MetroWest Commerce Park

Water is an important component of local economic development (Addams et al., 2009; OECD 2011; Goldman Sachs 2013) and even in the water rich U.S. regional disparities in water supply, climate change, and pollution are driving up risks associated with water quality and quantity. The city of Cincinnati, through the Greater Cincinnati

Water Works (GCWW) and the Metropolitan Sewer District of Greater Cincinnati (MSD), are launching a nationwide marketing effort to attract high-volume, high-quality water users to the MetroWest Commerce Park in Cincinnati's Lower Price Hill neighborhood (MSDGC& GCWW, 2013). The 18-acre site - which is targeted at specialty users such as food and beverage processing, light industrial manufacturing, high-tech applications – offers up to 50 million gallons daily of any quality water at what it claims to be significantly lower rates than other communities around the country, and that close proximity to the MSD processing facility will also reduce discharge rates. The GCWW and MSD also claim that the ability to supply customers with reclaimed water allows firms to meet their sustainability targets and environmental goals, and that their services go beyond the supply of water and collection of sewerage to include water technology expertise. This type of initiative is part of the efforts of the MSD to reduce the 180 million gallons a day of treated wastewater which is discharged into the Ohio River by offering non-potable, reclaimed water for irrigation, cooling and other industrial needs at reduced rates. To make the MetroWest Commerce Park more attractive to potential investors, state and local financial incentives may also be available to qualified parties, representing the collaborative and cross-functional nature of emerging local economic development practices.

B. Pipeline H2O

Business incubation and acceleration is an important component in building water technology innovation clusters. Business incubators are designed to increase the success-rate of new businesses and accelerators are designed to jumpstart more developed businesses. Most sophisticated incubators or accelerators offer entrepreneurs rigorous professional development programs, coaching and networking, professional guidance in areas such as accounting and law, administrative support, and seed funding to move their ventures forward and to allow them to focus on core commercialization issues (Pettersen et al., 2015). Confluence is supporting business incubation in water technology through an initiative called Pipeline H_2O with the mission to identify the world's leading water-based startups and commercialize their technologies (A. Seppi, personal conversation, July 6, 2017). Pipeline H_2O is managed by and based at The Hamilton Mill, a business incubator in Hamilton, Ohio which specializes in advanced manufacturing and clean technologies. Pipeline H_2O, the Greater Cincinnati region's first water technology accelerator program, is a partnership between the cities of Hamilton and Cincinnati, local public utilities, local universities, non-profits in economic development, venture capital, and universities involved in education and research. An important partner for Pipeline H_2O is Village Capital, which The Hamilton Mill brought into the Pipeline program. Village Capital is a community network that is dedicated to innovation which operates business development programs for early-stage entrepreneurs in agriculture, education, energy, health and water and which facilitates entrepreneurs to work together across the boundaries of other organizations. Over the past five years, Village Capital program graduates have reached 6 million customers, created over 7,000 jobs, and raised more than $110 million in follow-on capital. Greater Cincinnati is one of five Village Capital communities dedicated to innovation around water technologies, and therefore is an important resource on which Pipeline H_2O can draw.

The program plans to utilize The Hamilton Mill's existing "City as a Lab" approach which enables startups to have access to municipal utilities to help test their technologies and get market validation for their projects in a few weeks instead of the years which have been typical for water technologies (A. Seppi, personal conversation, July 6, 2017). In addition to utilities throughout the region, startups will potentially be able to test their ideas and water technologies at local universities and at the EPA test beds in Cincinnati. Hamilton, Ohio is considered to have high quality municipal water and the municipality owns three hydroelectric plants in its network of water, sewage, electric and gas utilities. Pipeline H_2O public-private collaboration which Confluence facilitates. The Executive Director of Pipeline H_2O, Anthony Seppi, is a city-paid employee who is on loan to The Hamilton Mill. Pipeline thus offers startups access to mentorship, professional support, venture capital, and, most importantly, access to companies and utilities that are willing to beta-test their technologies. These companies and utilities which serve as test facilities will likely become the first customers for these technologies.

Pipeline is hoping to attract eight-ten startups a year who will be competitively chosen from a field of global applications and then put through a 15-week commercialization program that connects the startups which important organizations in the water-tech industry, which will assist them in the commercialization process (A. Seppi, personal conversation, July 6, 2017). During their participation in the program the startups will be peer evaluated using 20 criteria in six categories - team structure, product, finances, validation, scalability, and return on investment – and this process will determine which two startup from the cohort receives funding to support full commercialization. The first cohort of Pipeline H_2O began their commercialization program in February 2017 and consists of eight startups from across the United States who were selected from a competitive field of sixty-six applications. They represented 14 different countries from five continents to include two from Africa, 11 from Asia, one from Australia, three from Europe and 49 from North America. The call for applications to participate in the 2017 program was initiated on September 2016 and the final selection was made in November 2016.

The eight startups in the first cohort were: AguaClara, which is designing non-electric municipal scale water treatment technologies that are sustainable in traditionally underserved communities; ANDalyze, which is developing DNA-enzyme sensors to bring real-time water testing to the field; kW River Hydroelectric, which is developing technologies to extract renewable energy from low-level dams using a micro-turbine which they patented; PowerTech Water, which is developing a disruptive technology platform to clean and purify water; Searen, which is using vacuum air-lift technology to streamline water treatment; WaterStep International, which is developing a mobile unit to provide a rapid response mini-water treatment solution for emergencies or disasters; Slipstream ZLD, which is developing a low-cost and extremely efficient wastewater crystallization system which would completely eliminate wastewater from low-volume industrial producers; and WEL Enterprise, which is developing the first ever system to handle all treatment and reclamation of wastewater on one platform which would reduce water consumption, wastewater production, and thus costs of production. Three of the startups are from the Greater Cincinnati area: kW River Hydroelectric of Hamilton; Searen of Cincinnati, and WEL Enterprise of Covington, Kentucky. The culmination of the 2017 Pipeline H_2O program will be a demonstration day by the participating startups at the Water and Energy Exchange Summit to be held in Cincinnati in November 2017.

Pipeline H_2O is thus designed to identify and help startups working on water technologies that will help solve some of the world's most pressing water challenges which include water reuse and recycling technologies, waste-and-storm water treatment, metering and monitoring of water usage, infrastructure management, and data analytics (A. Seppi, personal conversation, July 6, 2017). These technologies in turn will improve water quality and quantity and reduce the energy associated with the collection, conveyance and treatment of water. The project will help technology startups overcome one of the most important and challenging aspects of the commercialization process, which is piloting technology projects before scaling-up and deploying them nationally or globally.

C. Startups: CitiLogics & Pilus Energy

Confluence has helped several startups move through the commercialization process, one of which is CitiLogics whose co-founder Jim Uber is a professor of environmental engineering at the University of Cincinnati. CitiLogics developed a predictive-analytical software called Polaris which helps municipal water companies more efficiently analyze and monitor water pipes and pinpoint leaks and ruptures in aging water infrastructure. The ability to integrate data from multiple sources allows for more accurate forecasts of how complicated water systems behave which will improve the management of risks, minimize damages to infrastructure, and reduce operating costs. There is almost one million miles of water pipe in the United States supplying drinking water to 90% of the population, they break about 240,000 times a year, and lose almost 6 billion gallons a day to leaks, which represents waste of 14% to 18% of the water which is treated each day (AWWA 2017). Most of the water pipes were laid down in the first half of the 20th Century - and so are reaching the end of their 75-100-year lifespan – yet are being replaced at about half the rate that is required (AWWA, 2012, 2016). This suggests that if CitiLogics can get its technology to market there is potentially significant demand.

With the support of Confluence and its network of partners, including the EPA, CitiLogics was able to fast-track product development and beta-test its software at the Northern Kentucky Water District (NKWD) and the Greater Cincinnati Waterworks (GCWW), demonstrate its technology at various Kentucky and Ohio water utilities, signed its first contract with the GCWW, and hired its first employee. Both the NKWD and the GCWW are active partners in Confluence. At this was accomplished in 2 years rather than the 12-15 years that the commercialization of water technology usually takes. In 2013 the Covington, Kentucky-based water-technology startup recently received a $150,000 federal Small Business Innovation Research (SBIR) grant which will be matched from Kentucky's Small Business Innovation Research (SBIR) Matching Fund Program; and the company will be eligible for a follow-up $750,000 SBIR grant and another $500,000 in matching funds from Kentucky (May 2013). CitiLogics has so far been successful in generating $300,000 in research grants in 2013, $500,000 in 2014 and an expected $2.5 million in 2015 (FLC, 2015).

Another startup which Confluence has helped is Pilus Energy of Cincinnati, Ohio. Pilus and University of Cincinnati microbiology professor Daniel Hassett has developed genetically engineered bacterial robots that turns sewage into electricity and has the potential to disrupt the wastewater industry and impact the important water-energy nexus. With increasing urbanization and industrial agriculture, the amount of sewerage generated is increasing beyond the current capacity of the world to treat, and the current treatment technologies require a considerable amount of fresh water. Waste water has the potential to generate electricity and produce biogas using a combination of synthetic biology and fuel cell technology.

Pilus Energy has, however, struggled to find funding from Cincinnati investors as there is a reluctance to invest in clean technologies because of the high risk and long time to earn a return (Globe News Wire, 2014). While Cincinnati has much to offer water innovation technology companies, funding remains a weakness. In 2014 Tauriga Science of Danbury, Connecticut, acquired Pilus Energy for $2,000,000. The EPA, after learning about the company through Confluence, has entered into an agreement to let Tauriga use their test and evaluation facility, which it runs in partnership with the Metropolitan Sewer District of Greater Cincinnati, to conduct a five-phase, $1.7 million commercial pilot test of this technology at commercial scale (Globe News Wire, 2014). This joint project offers the potential to provide commercial validation for the technology and allow access to the global wastewater-to-value market which is currently estimated at $10 billion and is projected to grow to $27 billion by the year 2021 (Globe News Wire, 2014).

V. Application of Porter's Diamond

A. Factor Conditions

Confluence recognizes the fact that the Cincinnati Metropolitan Region is geographically central between the U.S. East Coast and Midwest and has access to large, reliable supplies of fresh water from the Miami aquifer, thousands of miles of streams and rivers, the Ohio River, and Lake Erie. Confluence explicitly states that it intends to support the water industry by leveraging these natural resources and sees the state's fresh water as one of the industry's premier assets (M. Kruyer, personal conversation, March 11, 2017). The local economic development community is promoting the state's access to water when attracting investors and cites as a success the recent decision of Abbott Laboratories to invest $240 million, and hire hundreds of people, for a new nutritional drink manufacturing facility (Thompson, 2013). This basic factor is, however, not unique to Confluence's region as most Eastern states also have access to large, reliable supply of fresh water. The challenge for Confluence is to help is stakeholders maintain the quality of the region's water as urbanization, manufacturing and industrial agriculture threaten the supply.

A more important factor advantage for Confluence is industry access to a large pool of scientists, engineers, and technologists, to public and private research facilities, to high quality institutions of higher education, and a 100-year history of regional, water-related ingenuity and innovation (M. Kruyer, personal conversation, March 11, 2017). The region's universities are heavily involved in water technology projects, such as NKU's College of Informatics and the Biology Field Station at Thomas More College, which brings students into partnerships with the Northern Kentucky Sanitation District, Duke Energy, and other local agencies to find solution to regional, national and global water challenges. Confluence also has access to 4 networked business incubators and accelerators, including The Hamilton Mill, and beta-site testing facilities to include the EPA's facilities in Cincinnati, local universities, and local public utilities. Ohio is also home to the U.S. Air Force Research Laboratory at Wright-Patterson Air Force Base. These are collectively all advanced and specialized factors. There are, however, concerns with the rate of entry of young people into science, engineering and technology fields, especially environmental disciplines (M. Kruyer, personal conversation, March 11, 2017; T. Harten, personal conversation, March 11, 2017).

Ohio has access to venture capital at a per capita rate of about US$6 (Clustermapping.us, 2017) – which is low by national standards, but which must also be balanced by the state's population of about 11.6 million which is 7th overall nationally. Massachusetts has the highest amount of venture capital per capita at US$109, but a smaller population. Ohio's R&D expenditure is at a per capita rate of about US$946 – which is about the middle range among states with the highest being US$4,137 in Massachusetts - while federal R&D is at a per capita rate of about US$114 – which is also in the middle range among states with the highest being US$469 in Maryland (Clustermapping.us, 2017). Venture capital and R&D expenditure are advanced and specialized factors and Confluence needs to improve these for its industry, especially to support public projects to upgrade public utilities and protect public and environmental health which puts the focus especially on public R&D. From the Harvard Cluster Mapping Program, Ohio receives an innovation score of 8.04 – which is an average score compared to California which scores 27.01 – and an annual patent count of 3,370 – which is a slightly above average count but far behind the leader, California, with a count of 33,343 patents (Clustermapping.us, 2017).

B. Related and Supporting Industries

Confluence has identified, and is actively recruiting, many interconnected firms and supporting institutions which have the potential to support the water cluster provided they work together in a coordinated manner to promote economic growth and technological innovation (M. Kruyer, personal conversation, March 11, 2017). Access to financial resources is usually an important need for technology startups. A wide range of financing programs to help small businesses start and grow their operations are available from federal, state and local governments and these offer a wide range of benefits to include low-interest loans, venture capital, and scientific and economic development grants; however, only a small number of startups will qualify for these funds. Water technology startups have a particularly hard time finding investors, however, investors are far more willing to invest in water utilities which are offering stable long-term regulates rates that are inflation protected and largely immune to economic cycles (Goldman Sachs, 2013). Startups also require business support. To help address the financing and business support needs of startups, Confluence has partnered with four regional incubators and accelerators: The Entrepreneur Center in Dayton, Hamilton Mills in Hamilton, Hamilton County, the Business Center in Cincinnati, and UpTech Accelerator in the city of Covington, Kentucky.

Facilities to test and validate water technologies are an important resource for technology startups and a critical step that must be achieved if the technology is to be commercialized. The cluster has access to some of the best laboratories and test facilities in the United States, such as at the EPA and with local utilities who are members of Confluence. Some of the major universities are actively working to support the cluster, particularly with water research and development, to include the Universities of Cincinnati, Dayton, and Northern Kentucky. The University of Cincinnati has made 'water clusters' one of five targeted areas of research over the next five years and is investing between $12 and $15 million and hiring six new faculty members in support of the Confluence cluster (Federal Laboratories Consortium, 2017).

The Confluence board of directors and membership, which is critically involved in networking, is drawn from across the tri-state region and is composed of a variety of leaders and experts from industry, government and academia. Confluence has also formed several working groups helping to advance the agenda of Confluence: the Three-State Protocol and Test Bed Development Work Group, the Water Policy & Water Event Work Group, the Confluence Business Advisory Council, the Confluence Partnerships Work Group, and the Communications & Marketing Work Group. One of the key roles of a cluster association is to facilitate the creation of networks and communication channels that better integrate the technology supply chain and facilitates technology commercialization (S. Gutierrez, personal conversation, March 11, 2017); and clusters associations connect key stakeholders across organizational and disciplinary boundaries to create synergies that increases the economic potential of the entire water industry (Haddaway, 2015).

C. Demand Conditions

The water industry is facing one of the most promising markets with good prospects for growth and profit, for stimulating local economic development, for meeting the need for sanitation and hygiene, and for supporting the competitiveness of other industries which are heavy water users. The annual global demand for water technology is estimated at about US$500 billion, and about US$100 billion in the United States, with annual growth estimated at about six-eight percent a year; and the estimate for investment in water infrastructure up to 2050 are about US$9 trillion globally, and about US$ one trillion for the United States (Addams et al., 2009; OECD, 2011; Goldman Sachs, 2013). The annual regional market for water technology in the Ohio, Indiana, and Kentucky tri-state area is estimated at about US$2.1 billion, with growth prospects of six to seven percent every year; and the Confluence cluster is also situated within 600 miles of more than 40% of the United States population and economy, positioning it to compete in a large and dynamic market of both water utilities and water intensive industries (Haddaway, 2015; M. Kruyer, personal conversation, March 11, 2017). The cluster has also started to attract considerable interest from overseas investors, especially from other water clusters in Israel and Canada, which are attracted to Cincinnati because of its pool of scientists, technologists and engineers, because of its world-class public and private research facilities, and because of its large local market (Strauss, 2013). This interest from foreign investors bodes well for stimulating greater rivalry, increasing the flow of knowledge, increasing the pool of sophisticated local buyers, and offering local technology firms access to foreign markets.

D. Firm Strategy, Structure and Rivalry

Confluence has identified roughly 250 regional companies whose work is related to water. These companies range from large water intensive industries - like Cincinnti's Procter and Gamble - to small water technology firms - like Newport, Kentucky’s CitiLogic and Cincinnati’s Pilus Energy - to larger technology firms - like Dayton, Ohio’s 40-year-old UES Inc., a 220-employee research and development defense contractor which has developed several technologies to include a portable sensor for detecting bacterial contaminants in water (May, 2013). Firms in the water technology industry therefore operate on several scales but do not have the same structure and level of regional domestic rivalry that is present in other industry clusters, especially those that produce more homogeneous products. Water technologies are often highly specialized and subject to intense intellectual property protection. The industry is also dominated by water utilities, who are its largest customers by far (GWI, 2015), and this influences the structure of the industry and the nature of rivalry because of the long life-cycle of many utility investment, the conservative nature of utility management, and highly restrictive nature of regulation and technology verification which affects the commercialization of water technologies. Despite these challenges, however, the utility sector potentially provides water technology firms a large guaranteed regional and national market. Interfirm rivalry is thus more likely to come from other water technology firms at the national and global level, which is precisely why the efforts of Confluence at networking and attracting outside investors to Cincinnati are so important to expose the water industry to greater rivalry which will stimulate competition and thus industry upgrading and innovation.

E. Role of Government and Chance Events

Confluence was established in January 2011 by public and private leaders of the Cincinnati water industry as a direct result of a concerted effort between the SBA and EPA to achieve two complementary goals: promote local economic development by strengthening the competitiveness of a key regional industry; and promote the development of clean water technologies that would help to protect the quality of water either supplied to the public or discharge to the environment. The EPA, through its Cincinnati office, has continued to support the Confluence cluster on two levels: through public relations channels, by publicly encouraging and promoting the work of organization; and through technical support, by allowing Confluence members access to scientists and research facilities at the EPA's Cincinnati Test and Evaluation Facility

(TEF) to support testing and validation of new technologies. The partnership between the TEF and local utilities is designed to facilitate the commercialization of technologies - by making it easier for companies to try out their innovations in controlled, government-approved settings – and the streamlining of regulatory approvals in the tri-state area. The EPA also carries out several research projects and market analysis studies which would be of technical and commercial value to innovators and entrepreneurs.

According to the Brookings Institute good economic development policies would strengthen regional clusters, stimulate innovation, and attract both local and foreign investments; would focus on important emerging industries, such as clean water technology; and would achieve this through targeted public investment in infrastructure, basic R&D, and workforce skills that are required to support the new knowledge-based, high-technology, and environmentally sustainable economy of the 21st Century (Saha et al., 2014). The government therefore has an important a role to play in building strong industry clusters by securing the basic drivers of innovation, economic growth, and competitiveness that would secure the country's long-term prosperity. The track record and the commitment of the federal government in supporting these drivers generally is, however, open to challenge: public investment in R&D has been weak or declining, having fallen in 2014 to its lowest levels since the Second World War, and tends to favor defense over civilian technologies; the federal government's present priority seems to be on regulation rather than innovation and R&D; the workforce skills gap in the United States between what is produced by the public education system and what is required by the emerging knowledge-based economy continues to grow; and current United States immigration policy continues to reinforce this skills gap by allowing a disproportionate number to low-skilled immigrants to enter the country (Drucker, 1985; Porter, 1990; Saha et al., 2014). The track record and the commitment of the federal government in supporting research into water is even more open to challenge as the federal government spends 50 times as much on R&D for clean energy as for clean water; and federal spending on water infrastructure has been declining since 2010, with the financial burden being increasingly shifted to state and local governments (Eskaf, 2015; Musick & Petz, 2015; Fishman, 2016).

State and local governments also have an important role to play is supporting the water technology industry through infrastructure investment, as the largest purchaser of water technologies are public utilities (GWI, 2016); however, water utilities are hampered by the tariffs that are set for water that do not cover the cost of providing water services (Goldman Sachs, 2013). Low tariffs constrain capital flows and slows the rate at which water utilities can adopt new technologies. Despite these challenges facing the Confluence cluster, the Brookings Institute has identified Cincinnati as having an out-sized global foreign direct investment profile in high-technology areas, such as chemicals and general-purpose machinery manufacturing (Saha et al., 2014); and Israeli high technology companies have been investigating investing in the Greater Cincinnati region (Thompson, 2013; Rutledge, 2016). This is reflective of the relatively high technical capacity of many of the region's larger utilities, the high quality of the water infrastructure, and the scientific, technical, and engineering base of the cluster.

Chance also plays an important role in the water industry with disruptive events coming from advances in 'big data', membranes, and sensors dramatically changing what was possible in fresh and waste water management and treatment; from climate change which will require better technologies which helps society to use less water and produce less waste; from disasters that can unexpectedly disrupt sources and infrastructure; and from political, legal and regulatory shifts that affect how water is collected, stored, conveyed, treated and returned to the environment. An example of a political shift with important ramifications for water management was the 2008 signing by President Bush of the Great Lakes Compact which bars new diversions beyond the Great Lakes Basin, with few exceptions. This compact affects how new or expanding communities in the Great Lakes region will access fresh water, and largely guarantees that regional water exploitation will have to be worked out in the courts for many years to come (The Economist, 2010).

V. Conclusion

The water technology innovation cluster centered in Cincinnati, Ohio has the ingredients to be considered an emerging cluster (Tichy, 1998); but, it will require time and continued concerted effort, or external intervention, on the part of key cluster stakeholders if the cluster is to become self-sustaining, and the region is to realize the long-term economic benefits that can be derived from a successful cluster made up of globally competitive firms (Brusco, 1990). Smilor et al. (1989) and Phillips, (2006) laid down several prerequisites for a successful cluster: for Smilor these were scientific preeminence; new technologies for emerging industries; the attraction of major technology companies, and the creation of home-grown technology companies; and for Phillips there needed to be a high degree the interaction and collaboration between major sectors in the cluster to solve complex problems and achieve joint goals. These prerequisites can emerge and be sustained if the region has well-resourced, high quality research universities; has a network of champions and support organizations; has support in critical areas from all scales of government; has an environment conducive to supporting startup companies; and has large corporations willing to use their resources in a catalytic role to support and sustain the cluster (Smilor et al., 1989).

The Confluence cluster boasts 'scientific preeminence' in water technology due to the presence of the Andrew W Breidenbach Environmental Research Center, which is one of the largest EPA research facilities, and the University of Cincinnati, for which water research has always been an important element in its academic and environmental portfolio, and several companies which are intimately connected to water technology innovation. The region's industries, universities and innovators have also registered many patents, and published numerous articles related to drinking, waste and storm water which also supports the existence of 'scientific preeminence' (McMillan, 2011). The sources of these patents and articles are, however, currently concentrated in three organizations - Procter and Gamble, the EPA and the University of Cincinnati (McMillan, 2011) – and most of the rest distributed largely among a few medium-to-large corporations in the water industry. Nevertheless, while a steady stream of new technologies is emerging from home-grown technology sources, most of these are from established companies, the EPA and the University of Cincinnati. Confluence has been working hard to attract major technology companies, with some interest shown from Israel; however, to date, no major successes have been recorded. There has been some interest from startups from around the world to utilize the emerging resources of Confluence, and this can be seen among the startups which have applied to join the incubator at The Hamilton Mill. This 'scientific preeminence' could be considered a strength of the Confluence cluster; however, the concentration of this activity in a few organizations could also be a weakness suggesting a low level of entrepreneurship and innovation in this industry.

Confluence has had several strong local champions, however, most support has come from the EPA and the University of Cincinnati, more than from the private sector. This could be connected to the fact the most of the private sector stakeholders are water-intensive or water-enabled industries rather than water technology companies. Strong support has come from all scales of government, particularly the EPA and SBA at the federal level, and from local governments through their economic development agencies and local utilities. This is borne out by the Regional Utility network, the Tri-State EPA agreement, and the collaboration between Confluence, The Hamilton Mill, and the City of Hamilton. These limitations are to be expected in an emerging cluster where initial progress is slow as stakeholders build social and economic networks in a small but fragmented industry; where the cluster's infrastructure and capacity is being built; where the technological fruits of innovation is not yet profitable, and the main attention of existing businesses is elsewhere; and the cluster is working out where its core competencies will lie (Tichy, 1998). The dependence on the state and research universities for external intervention should be considered a long-term weakness of this cluster (Porter, 1990).

Utilizing Porter's Diamond Model (1990), Confluence is well endowed with basic factors, such as fresh water, advanced factors, such as large pool of highly skilled labor, and specialized factors such as the Andrew W Breidenbach Environmental Research Center and the University of Cincinnati. These advanced and specialized factors are a potential source of competitive advantage for both startups and existing firms and a strength of the Confluence Cluster. Confluence is well endowed with related and supporting industries - to include public utilities, water-intensive and water-enabled industries – to provide inputs and services to support the process of research, development and commercialization of water technologies, and mutual innovation and upgrading. The regional utilities have been supportive of water technology firms in the testing, validating, and commercialization emerging technologies, and this collaboration is supportive of the process of mutual innovation and upgrading which is vital to protecting water quality and reducing water use. These relationships be a strength of the Confluence cluster.

No industry can survive without effective demand and sophisticated and demanding buyers push firms to upgrade quality and become more competitive. The demand for water technologies is considerable, especially from utilities, and the government's regulatory requirements for water quality and environmental protection are driving innovation in the water technology industry. The market for water technologies from utilities should be an opportunity for the Confluence cluster; however, the challenges of finding a sustainable model to finance capital projects and maintenance is a threat to the industry. The main challenge facing water technology firms, especially startups, is the length of time it takes to test, validate and approve technologies to meet regulatory requirements; however, industry associations such as Confluence are ideally positioned to support the industry in this regard. The presence of an industry association is a strength of the Confluence cluster; however, the absence of a sustainable business model to adequately finance the association is an important weakness.

Local industry rivalry among water technology firms is limited as firms within the region tend to produce heterogeneous products; however, when taken at the national or global scale there is considerable competitive pressure and customers have the option to source technologies from all over the globe. Israeli firms have been particularly active in exploring opportunities in the Ohio region and they have expertise in waste water treatment and data analytics that could be useful in the Ohio region. The absence of intense local rivalry is a potential weakness of the Cluster; however, the presence of national and global rivals should reduce this problem. Finally, the state is a key player in the water technology industry: it provides grants and seed capital to support startups and research, it sets regulatory standards, and it is the major customer for water technology through its water utilities. Confluence as a water technology innovation cluster did not emerge as a result of spontaneous generation but through a process of external intervention; and governments at all scales and the local research universities must continue to support entrepreneurship and innovation, and themselves be innovative and entrepreneurial, until the critical mass of private technology firms is created to take the lead which is necessary for the long-term viability of a mature cluster (Brusco, 1990; Porter, 1990). This dependence on state support, which is subject to shifts in policy priorities, is a potential threat which Confluence must address as its number one priority if it to reach maturity.

CHAPTER 6

WATER TECHNOLOGY CLUSTER IN MILWAUKEE, USA

I. Introduction

This case study examines The Water Council, which is the industry association representing the water technology innovation cluster based in Milwaukee, Wisconsin. Milwaukee is being aggressively promoted by The Water Council, and a wide cross-section of city leaders, as one of the world's leading clusters for innovation and entrepreneurship in water technology, a bold claim, which has been challenged is some quarters. The case study begins with a brief look at the historical relationship between water, economic development and environmental impacts in Milwaukee over the last 150 years. It then moves on to the establishment of The Water Council, which is the industry association representing the water technology sector in the Greater Milwaukee Region. Several specific examples of the efforts of the Council and its stakeholders are examined: the establishment of a Global Water Center, which houses The Water Council and several of its partners in industry and academia; the establishment of an incubator and accelerator at the Global Water Center; the establishment of the Innovation Commercialization Exchange (ICE), which is water technology database; and the networking efforts of the Council through such events as the annual Water Summit. At The Water Council Dean Amhaus, President and Chief Executive Officer, and Isaiah Perez, Membership Manager, were interviewed.

The work of three important partner organizations is also examined: the Milwaukee Metropolitan Sewerage District (MMSD), which overseas sewerage for the city; Veoila Water, which operates the city's two sewerage treatment plants on behalf of MMSD; and the University of Wisconsin – Milwaukee School of Freshwater Science, a global center for freshwater research. Key stakeholders interviewed included Kevin Shafer and Matthew McGruber of the MMSD, Joyce Harms of Veolia, and Elizabeth Sutton of the School Freshwater Science.

Finally, the Milwaukee water technology cluster is analyzed using Porter's Diamond, which is a well-established framework for analyzing competitive advantage. The four determinants of Porter's Diamond – factor conditions, domestic demand, firms structure and strategy, and related and supporting industries - and two additional factors – government and chance - interact as a system whose structure and behavior supports entrepreneurship and fosters innovation which can stimulate firms to increase productivity and improve business. The structure and behavior of the Milwaukee's water technology cluster historically arose from the region's ample supply of fresh water and the presence of numerous water-intensive and water-enabled industries; however, this case will show that public and private entrepreneurs and innovators have been actively using public policy and private initiative to upgrade the regions water cluster with moderate success.

II. Background and Context to Milwaukee Water Cluster

The economy of Milwaukee has been significantly shaped for more than one and a half centuries by its relationship to water. The city is located on the western shore of Lake Michigan and at the confluence of the Milwaukee, the Menomonee and the

Kinnickinnic rivers. The Great Lakes are the largest fresh water system on the planet and hold about 20% of the world's fresh water (EPA 2017). The city's water intensive industries have included at various times in its history fur-trading, meatpacking and food processing, tanning, brewing, pulp and paper production, power generation, and shipping. As a port city, it has access to both Lakes Michigan and Huron and it became a center for collecting, distributing, and processing raw materials produced in the city's hinterland. For a time in the second half of the 19th Century, Wisconsin was the second ranked wheat-growing state in the U.S. and Milwaukee shipped more wheat than any place in the world. The state's production of barley and hops, and the presence of German immigrants, helped to support a major brewing industry, making Milwaukee the largest beer producing city in the world with the four largest breweries in the world

While the 19th Century economy was dominated by flour-mills, packing plants, breweries, brick-works, railways and stockyards, bulk commodity storage, and tanneries, the 20th Century economy became dominated by heavy industry and machining. Like so many traditional U.S. industrial cities the post-war period witnessed a long and painful industrial decline which saw industries close, or move to lower-wage regions, and several corporate headquarters relocate to other parts of the U.S. (Wisconsin Economic Development Corporation, 2017). While the top 10 Milwaukee employers in 1970 were all manufacturing firms, 9 of the top 10 employers in 2004 were service firms. Although Milwaukee is now dominated by services, and has seen growth in finance and banking, publishing and printing, and healthcare, there remains a residual presence of traditional manufacturing and some growth in more advanced manufacturing (Mattoon & Wang, 2014). Manufacturing remains the single largest employment category, with 17% of the workforce, and maintains the second highest location quotient, at 1.58 (Mattoon & Wang, 2014). Milwaukee remains the international headquarters of six Fortune 500 companies: Johnson Controls, Northwestern Mutual, Manpower, Rockwell Automation, Harley-Davidson, and Joy Global (Newman, 2013).

Wisconsin is still home to more than 200 companies that depend on water as a key input. These companies together employ nearly 250,000 people and generate $56 billion in annual sales (Wisconsin Economic Development Corporation, 2017). The skills and knowledge associated with Milwaukee's traditional water-intensive and water-enabled industrial base still exists and are now employed manufacturing water meters, water heaters, pumps and plumbing fixtures; and recently, the city has made a large investment to upgrade and leverage its strengths in water technology. The region is estimated to be home to possibly 150 -200 water-technology companies such as A.O. Smith, manufacturing water heaters, Badger Meter, manufacturing water meters, Kohler, manufacturing faucets and toilets, Siemens, manufacturing filtration, Pentair, manufacturing flow management and filtration systems, and Veolia Water, managing sewage and water treatment. These water-based companies are estimated to employ nearly 37,000 people and generate $5.7 billion in annual sales (FDI Alliance, 2017). Efforts are being made by a partnership of private firms, public utilities, universities, and government to attract water technology firms to Milwaukee to establish the city as a leading center for freshwater expertise and technologies (Muller, 2013). Developing the water and wastewater technology industry has been identified in the 2013 Milwaukee 7 Regional Economic Development Partnership strategy plan as one of nine strategies that are focused on improving regional productivity and competitiveness.

III. The Water Council

A. Origins of the Water Council

The idea to form The Water Council to represent the water technology industry emerged from a 2006 meeting between two local chief executive officers, Rick Meeusen of Badger Meter, which makes water meters, and Paul Jones of A.O. Smith, which produces water heaters and filters. Meeusen and Jones convened a meeting of 80 local businesses and civic leaders representing the region's water technology companies and universities to formulate a vision, work out a strategy, identify resources, and prepare a plan to make Milwaukee into a regional and global 'water hub' (Muller, 2013; Daigneau, 2013). In 2007 local water leaders held their first Water Summit, which has been an annual feature since then, and convened quarterly meetings to steer the establishment of the association. In 2008, what was at that time called the Milwaukee 7 Water Council, established a paid membership structure and the first members of the association were welcomed. In 2009 The Council was formally established as a collaboration between industry, utilities, and academia and registered as an industry-led non-profit 501(c)(3) organization (Muller, 2013). In 2012, the Milwaukee 7 Water Council was renamed The Water Council. Under The Water Council's leadership, the Global Water Center opened at the renamed Freshwater Way, across from the Milwaukee Metropolitan Water District (MMWD), helping spur interest in the redevelopment of what has become known as Milwaukee's Water Technology District. The District attracted more than $211 million worth of development between 2010 and 2015, including The Water Council's Water Tech One and the University of Wisconsin-Milwaukee School of Freshwater Science at Freshwater Plaza, which is located a few blocks to the south.

The efforts of Meeusen and Jones to promote the Milwaukee water technology industry first received support from the Milwaukee 7 Regional Economic Development Partnership because of the publication in 2007 of a landmark Economic Asset and Opportunity Analysis (Milwaukee 7, 2007). This analysis identified the water technology industry as a sector with growth potential and a natural evolution for the Milwaukee economy. The Milwaukee 7, which was launched in September 2005, is the regional cooperative economic development platform for the seven contiguous counties of southeastern Wisconsin - Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington and Waukesha counties. The Milwaukee 7 mission is to attract, retain and grow diverse businesses and talent in the seven counties in the greater Milwaukee region and it remains a partner with The Water Council (mke7.com 2017). The idea of a cluster was not original but no one before Richard Meeusen and Julia Taylor, head of the Greater Milwaukee Committee, formally initiated the studies, consultations and surveys to gather evidence, nor drove the process to marshal the human and material resources to support organizational development (Miner, 2010).

B. Vision, Mission, Goals, and Objectives of The Water Council

The vision of The Water Council is to position Milwaukee as the premier location in the world for research and development, education, manufacturing, and the commercialization of technologies related to fresh water. The Council's vision statement, as laid out in the 2016 annual report, is to "Be the globally connected epicenter of water research, innovation, education, and business development" (The Water Council, 2016). The Water Council positions itself as both a unique industry association and a unique industrial community in the North American setting, and a national model from which other water technology clusters can learn and which other clusters can model (D. Amhaus, personal correspondence, May 17, 2017). Levine (2009) describes The Water Council as the world's first collaboration between business and academia for integrating academic water research and water technology commercialization in one facility. Although it works closely with and seeks moral and material support from government and non-profits, it is ultimately an industry-led initiative to create an industry-focused association with the incentives and flexibility to drive the interests of a specific segment of the water industry (Muller, 2013). By aligning the interests and coordinating the efforts of water technology businesses of different scales, water-intensive and water-enabled industries, nonprofit organizations, and academic institutions, the Council hopes to identify, research, develop, and serve new market opportunities in water technologies, and in the process create jobs, attract capital and talent, and have a long-term, positive economic impact on the Milwaukee region.

The Water Council's broad goals are three-fold: support economic growth in the region, attract new talent, and develop the technology to solve the world's water problems (Muller, 2013). The Water Council's specific goals are to create a global water hub that helps grow innovators, entrepreneurs and firms focused on developing cutting-edge technologies for both industrial and domestic markets - technologies that improve the efficiency of water use, protect water quality, and ensure the availability of water supplies (Daigneau, 2013). For its efforts, the Council received an important enforcement when Michael Porter suggested that The Water Council is "best-in-class with its water technology development," that the Council is an industry association global leader in supporting its cluster, and that it is an example of a cluster helping to drive regional development initiatives (Harvard Business School, 2014; Leitz, 2016). MIT and Harvard have announced the launch of a study of the Milwaukee cluster and hope to use what they learn to develop a model of cluster development for use in other cities (Harvard Business School, 2014; Leitz, 2016).

The Water Council has also begun to receive national and global recognition and awards for its efforts. In 2009, Milwaukee was designated as a U.N. Global Compact City for its work on water quality and is hoping to use this award to enhance the city's image and reputation and build its brand as a global hub of water technology. Milwaukee is one of 13 cities given this designation and is only the second such U.S. city, the other being San Francisco, which has a Silicon Valley supported Business Council on Climate Change which promotes low-carbon environmental practices. Milwaukee is also only the second city to focus on water, the other being Jamshedpur in India, where Tata Steel works on industrial sewage treatment projects. Global Compact cities must commit to align their governance regimes with 10 universally accepted principles in the areas of human rights, labor, environment and anti-corruption, and work with partners to progress social equality and justice, environmental sustainability and good governance in the urban environment. In 2011, The Water Council received one of four inaugural U.S. Water Prizes from the Clean Water America Alliance, a Washington, D.C.-based advocacy group, in recognition for efforts to advance water "as a finite, reusable and sustainable resource" (Schmid, 2011). In 2015, the State Science & Technology Institute (SSTI), a highly respected national organization focused on technology-based economic development which supports initiatives to create a better future through science, technology, innovation and entrepreneurship recognized The Water Council with its award for ‘Improving the Competitiveness for Existing Industry’ (The Water Council, 2017). In 2016, CoreNet Global, a non-profit association representing executives from across the globe with strategic responsibility for the real estate assets of large corporations, recognized the Council for ‘Water Technology Cluster Leadership’ when it received its Economic Development Leadership Award, which celebrates the successful implementation of innovative and economically promising projects in a community or region (The Water Council, 2017).

The vision of The Water Council has evolved over the years and its ambitions have grown. Like so many other clusters around the world, The Water Council specifically invokes a comparison with Silicon Valley (Muller, 2013); however, this rhetoric has not gone unchallenged (Levine, 2009). Initially The Water Council promoted the water cluster as a core driver of job creation and economic growth in the region (Schmid, 2012; Muller, 2013; Daigneau, 2013). Now the Council has adopted a global perspective and is branding Milwaukee as a Global Water Hub. The Water Council believes that Milwaukee has a rightful claim to be considered a global water technology cluster because of its historic industrial, public utility, and academic traditions in addressing water quality and water management; and because of a strong, existing base of water technology companies with considerable experience serving regional utilities and water-intensive and water-enabled industries (Schmid, 2012; Muller, 2013; Daigneau, 2013). The Harvard-based US Cluster Mapping Project suggests that the efforts of The Water Council have positioned Milwaukee as a Global Water Hub - like Leeuwarden in The Netherlands, Israel, and Singapore – and one of the world’s most significant places for water research, for water technology businesses, and for water intensive industries because of its established and extensive history of engagement in the study, treatment, movement, and storage of water. (Clustermapping.org, 2017)

C. Structure, Leadership, and Strategy of The Water Council

To achieve its vision and mission The Water Council has worked aggressively to promote the water technology industry and a network of related and supporting industries (D. Amhaus, personal correspondence, May 17, 2017). This has been done through the selection of strategies that align with the Milwaukee 7 Framework for Economic Growth which consist of nine mutually reinforcing strategies designed to increase the number of firms, the overall size, and the productivity and competitiveness of the traded sectors of the Milwaukee economy, as well as restructure the economy within the paradigm of the 'new-economy' which is 'information-driven,' 'lean,' and 'green' (Milwaukee 7, 2014). The strategies of The Water Council in general address the promotion and branding of Milwaukee as a 'Global Water Hub,' the building of strategic partnerships, the support of local educational institutions and the creation of talent, the support of research and development related to water technology at local through to global scales, and the facilitation of startups through coaching, mentoring and access to capital (D. Amhaus, personal correspondence, May 17, 2017; I. Perez, personal correspondence, May 17, 2017). The strategies also reflect the conventional wisdom that clusters usually emerge organically and are built on and leverage unique local factors. These unique local factors include (1) natural resources, in this case an abundance of fresh water; (2) logistical advantages, such as access to both a port and a hinterland; (3) human capital advantages, the historic presence of skilled immigrant workers and a strong university system with a history of water research; (4) economic history, the city's long history with water-related industries such as brewing, water heating components, and wastewater treatment; and (5) chance, such as the fact that de-industrialization, the pollution of rivers and lakes by industry and urbanization, and the requirements of the Clean Water Act have all converged to create an historic window of opportunity to promote local water technology firms and position Milwaukee as a 'Global Water Hub' (Porter, 1993; Foss-Mullan, 2001; D. Amhaus, personal correspondence, May 17, 2017).

The first strategy, the promotion and branding of Milwaukee as a 'Global Water Hub,' aligns with both the second, sixth and seventh strategies of the Milwaukee 7 Framework which are to “become a global hub for innovation and startup activity in the water technology industry,” to “foster a dynamic, richly networked innovation and entrepreneurship ecosystem, building on existing nascent, but fragmented activities,” and to “catalyze 'economic place-making'” (Milwaukee 7, 2014, p. 61-3). Both the Milwaukee 7 and The Water Council identify water and wastewater technology as a viable industry in a rapidly growing global water market; and both believe that the region’s water cluster is a potential source for innovation and entrepreneurship (D. Amhaus, personal correspondence, May 17, 2017). The promotion and branding of Milwaukee as a 'Global Water Hub' received an early endorsement from a study paid for by The Water Council but carried out by Sammis White, Associate Dean, School of Continuing Education and Professor of Urban Planning at UWM. Professor White claimed to have found 120 firms involved in water and declared Milwaukee had a window of opportunity to build a water cluster provided that sufficient public and private funds could be raised to build the organizational infrastructure to develop and support the cluster (Miner, 2010).

The second strategy, the building of strategic partnerships aligns with the sixth and ninth strategies of the Milwaukee 7 Framework which are to "cultivate a densely networked, integrated and dynamic ecosystem of regional actors driving innovation and entrepreneurship," and to "enhance inter-jurisdictional cooperation and collaboration for economic growth" (Milwaukee 7, 2014, p. 62-67). Both competition and cooperation are features of successful clusters; and cooperation allows an industry to create and share public goods and infrastructure, spread certain costs, share information, solve common problems, and achieve economies of scale externally rather than internally (Porter, 1993). The Water Council has been highly successful in bringing people together around a common vision and this is beginning to have a direct impact on the efficiency and effectiveness of the innovation to the commercialization process (D. Amhaus, personal correspondence, May 17, 2017). Probably the most important strategic partnerships were the early support Richard Meeusen received from Julia Taylor, head of the Greater Milwaukee Committee, and from the Milwaukee 7, the regional economic council spearheaded by the Metropolitan Milwaukee Association of Commerce (Miner, 2010).

The third strategy, the support of local educational institutions and the creation of talent, aligns with the fifth strategy of the Milwaukee 7 Framework which is to "align workforce development with growth opportunities in targeted, high-potential industry clusters" (Milwaukee 7, 2014, p. 62). The success of water technology firms depends on Milwaukee being able to both retain and grow a skilled workforce, support cluster-specific career pathways, and create industry recognized certification and credentialing related to water technology (D. Amhaus, personal correspondence, May 17, 2017).

The fourth strategy, the support of research and development related to water technology, aligns with the sixth strategy of the Milwaukee 7 Framework which is to "strengthen industry-academic partnerships... to better align institutional R&D agendas," to "stimulate university technology transfer to bring more institutional R&D to market through commercialization," and to "accelerate adoption of new technologies, processes and business models in more mature industries" (Milwaukee 7, 2014, p. 62-3). Research and development and the innovation to commercialization process is vital to the success of water technology firms. Traditionally, the slow pace of adoption of new water technologies by utilities, of between 12 to 15 years, has made it more challenging for innovators and entrepreneurs to create viable businesses, increases the cost of operating utilities, increases the time needed to comply with water quality regulations, and puts the environment at risk (D. Amhaus, personal correspondence, May 17, 2017; K. Schafer, personal correspondence, May 17, 2017).

Finally, the facilitation of startups through coaching, mentoring and access to capital aligns with the fourth and sixth strategies of the Milwaukee 7 Framework which are to "enhance the export capacity and capability of the region's firms, focusing on small-and-medium-sized enterprises," to "enrich the array of technical support, funding and other resources available to emerging innovators and entrepreneurs," and to "augment capital resources available to regional entrepreneurs" (Milwaukee 7, 2014, p. 62-3). While large firms and utilities might be the main consumers of water technologies, much of the innovation in water technology comes from startups and small small-and-medium-sized enterprises (D. Amhaus, personal correspondence, May 17, 2017).

The Water Council is led by a Board of Directors consisting of 20 leaders from across the spectrum of industry, academia, public utilities, and conservation. The co-chairs are Rich Meeusen of Badger Meter, Inc., and Paul Jones formerly of A.O. Smith Corporation, who were the original innovators of the idea of a developing a formal water cluster in Milwaukee and supporting this cluster with an industry association in the form of The Water Council. The executive team is led by Dean Amhaus who has served as the President and CEO of The Water Council since March 2010. Other members of the executive leadership team includes a VP of Business Development who is responsible for program development, implementation and oversight of the U.S. Small Business Administration's Regional Innovation Cluster Contract; a Chief Technical Officer who is responsible for research and commercialization initiatives, while also continuing his role as Associate Vice Chancellor for water technology research and development at the University of Wisconsin-Milwaukee (UWM); a VP for Sustainability and Stewardship initiatives whose focus is on rolling out the Alliance for Water Stewardship's International Water Stewardship Standard in North America; a VP for Marketing & Communications who leads the strategic marketing for the Council including branding, public relations, global communications, the annual Summit, events, and membership; and a Director of Entrepreneurship & Talent who leads the BREW Accelerator, the Pilot Program, the Talent Campaign, and the overall mission of growing the water generation. The executive team is also supported by a support staff of about 30 people.

The current membership of The Water Council consists of about 191 public, private and non-profit organizations with an interest in water, which represents considerable growth from the five initial members. The Water Council is housed in a refurbished 100-year-old box factory which was opened in 2013 and which serves as a head office, as a research hub, as a business incubator and accelerator for emerging water technology companies and promising startups, and as the focal point for industry networking. The building was named The Global Water Center, and it represents a shift for The Water Council from a regional focus to a re-positioning as a globally-focused water technology center of excellence. The seven-story building, at the renamed 247 Freshwater Way in what is now called the Milwaukee Water Technology District, has approximately 40 tenants in its 98,000 square feet which includes universities, water-related companies, municipal utilities, startups, and others. Here, industry experts, academics, graduate students, lawyers, accountants, and entrepreneurs share facilities that includes a state-of-the-art water flow lab, board and conference rooms, and an auditorium (I. Perez, personal correspondence, May 17, 2017). The Global Water Center is modeled on Kinrot in Israel, the world's largest incubator focused solely on water, which was started by the government of Israel in 1993 but privatized in 2006 (Siegel, 2015; K. Shafer, personal correspondence, May 17, 2017).

D. Partnerships and Activities of The Water Council

The Water Council’s rapid evolution in Milwaukee, supported by vigorous public-private partnerships, is creating a powerful and unique international success story, with far-reaching effects for the city, the state, the region and the global water industry. The Council brings together research entities, existing businesses, start-ups, and government agencies to commercialize technology, promote water entrepreneurship, and increase access to capital. From the start, the initiative has been driven by the private sector and most stakeholders seem to agree that this governance arrangement works best for the industry, and that it should stay that way (D. Amhaus, personal correspondence, May 17, 2017). The Mayor of Milwaukee,Tom Barrett, was quoted in *Forbes* magazine as saying that “if it had started at the public end, we would be hustling to get private-sector involvement” (Daigneau, 2013). Nevertheless, both city and state governments has been a very supportive partner which has enabled the Council to be more aggressive, flexible and innovative (Daigneau, 2013; D. Amhaus, personal correspondence, May 17, 2017). The Water Council has also been connecting to other water technology clusters internationally and has signed memorandums of understanding to share expertise with water technology clusters in Leeuwarden, Netherlands, Montpelier, France and Tianjin, China (Murphy, 2015). The building of partnerships is the second strategy of The Water Council.

One of the most important partnership which The Water Council has developed is with the Alliance for Water Stewardship (AWS), an international multi-stakeholder organization dedicated to enhancing water stewardship through the development of global water standards. In 2014, The Water Council become the official North American regional partner for AWS, thus making a commitment to help this organization brings together leading organizations from around the globe who are committed to advancing the responsible use of freshwater (Schmid, 2012). The AWS also named Milwaukee as its North American headquarters and regularly conducts training in water stewardship at the Global Water Center. In line with their second strategy, The Water Council is aggressively working to build new partnerships and expand its network. The International Water Association (IWA) is global network of over 9,000 water professionals in 130 countries, with offices in London, The Hague, Nairobi, Dakar, Bangkok, Beijing, Singapore and now Milwaukee. Its membership – which includes scientists and researchers, water utilities, large water-enabled and water-intensive industries, nonprofits, and water technology providers - works across the full spectrum of the water cycle and water economy (IWA, 2017).

1. Business Research Entrepreneurship in Wisconsin (BREW) Accelerator

Technology startups face numerous challenges to include barriers to entry for their innovations and technologies, lack of capital, an inappropriate business model, a lack of general business expertise, a deficiency or even absence of administrative support, and difficulty finding talent to help grow the business (Feinleib, 2011). Technology startups also have a very high rate of failure, even when they offer sophisticated technology the market may present a challenge to commercialization. Technology innovators and entrepreneurs might have great ideas and technically impressive products; however, they must solve the dilemma of the product-market fit and deliver value to customers with products that meet needs, fit with their systems, are reliable and economical, and are user friendly (Feinleib, 2011). This often requires user feedback and field testing or pilot projects that are capable of being scaled up (D. Amhaus, personal correspondence, May 17, 2017; K. Schafer, personal correspondence, May 17, 2017). Wisconsin faces a struggle in producing startups and, when compared against other states, traditionally scores low in this regard (Schmid, 2017). In line with their fifth strategy, The Water Council is working to create a startup pipeline to support a steady stream of innovators and entrepreneurs (Muller, 2013; Daigneau, 2013).

To address the challenges faced by water technology startups The Water Council has created an initiative called The BREW Accelerator (Business, Research, Entrepreneurship, in Wisconsin). This accelerator is designed to support water innovators and entrepreneurs with wide ranging business and technical support from the World Water Hub, to integrate them into a collaborative network of technologists, innovators, and entrepreneurs, and to fund water technology startups with commercialization potential (I. Perez, personal correspondence, May 17, 2017). Water startups with commercialization potential will receive up to $50,000 in investments from the Council in exchange for a small percent of equity. The BREW accepts up to six water technology startups for a six months program which includes: a lease of office space; access to research facilities and the Global Water Center's Flow Lab; access to faculty and students from the University of Wisconsin-Milwaukee (UWM) School for Freshwater Sciences; business training from the University of Wisconsin-Whitewater (UWW) through the Institute for Water Business; coaching and mentoring from business and water technology experts; participation in the activities and events of The Water Council; and opportunities to make pitches and presentations (I. Perez, personal correspondence, May 17, 2017). The first BREW cohort graduated in June 2014 and included:

H_2O Score, which developed software to track water usage and encourage conservation; Microbe Detectives, which developed a DNA sequencing process to provide comprehensive microbial evaluations for water quality and disease management that would go undetected under traditional tests; New Works, which offers hands-on training for water management professionals and water technology experts using state-of-the-art lab equipment; Noah Technologies, which developed a monitoring system to warn against basement flooding which could save millions in property damage; and Vegetal Innovation & Development, a French startup which is a global leader green roof technology. To date BREW has graduated 24 startups to include one from France, one from Ireland, and two from Canada. The current cohort of six startups also includes one from Canada which is working to improve urban resilience through technologies to harvest and hold rainwater.

Further support for water technology startups comes from various public and private resources which are channeled through the The Water Council. The Council in 2015 became one of the U.S. Small Business Administration's (SBA) Regional Innovative Cluster Participants; and in 2015 also became part of the U.S. Department of Commerce (DOC)/Economic Development Administration's (EDA) Regional Innovation Strategies Program (Verbeten, 2016). The SBA Regional Innovative Cluster Participant program is a national partnership that has established a Small Business Channel to support small-and-medium-sized water technology businesses become globally competitive by linking them to regional networks of research institutions, supply chains, skilled workers, commercialization tools, and sources of financing. This award is for $500,000 and will be channeled through the Council's Center of Excellence (CoE) for Freshwater Innovation and the Small Business Development program. The Water Council was one of four organizations selected from 40 applicants from across the United States. As for the Regional Innovation Strategies Program, this has been used to support the establishment of a Water Seed Fund which will let the Council provide seed-stage investments to promising water technology startups. The $71,625 cluster grant will receive matching funds from the Council as part of a fund-raising effort to create the $5 million Wisconsin Water Cluster Seed Capital Fund (BizTimes, 2015). In 2014, The Water Council was one of 10 organizations nationally to receive from JPMorgan Chase & Co. a one-year grant of $225,000, which was followed up in 2015 by a second grant of $230,000. These two grants were awarded to help identify potential water technology investors and connect them with innovators and entrepreneurs and their emerging businesses (Gallagher,, 2014; Schuyler, 2015; Murphy, 2015). These grants are from of JPMorgan Chase's 'Small Business Forward' program, which is providing a number of organizations access to $30 million over the next five years to boost high-performing small business clusters. These funds are being used to complement the work of The BREW (Verbeten, 2016).

While not all BREW startups have gone on to be successful, several have gone on to commercialize their technologies and services or have been acquired by larger firms (Schmid, 2017). Ireland-based OxyMem Ltd. which is a designer of wastewater treatment reactors has attracted an investment stake from Dow Chemical. Wellntel Inc. which supplies real-time systems that monitor wells and groundwater sources for homeowners, farmers and communities moved out of the Global Water Center and established its own headquarters in Milwaukee. CORNCOB Inc. which developed a new, more energy-efficient, lower maintenance, and more reliable system to run contaminated water through membrane filters now operates out of suburban Waukesha. Solar Water Works - which supplies portable, solar-powered water treatment systems – has secured an initial contract to supply units that will be utilized to improve water quality at two Milwaukee area beaches. And Radom Corp. which manufactures portable instruments that detect toxic trace metals in water, wastewater and industrial processes maintains offices in the Global Water Center but has added a production site in suburban Hales Corners and has licensed its patents to larger, established multinationals.

2. The Water Summit

In 2007, The Water Council convened the first Water Summit in Milwaukee to discuss creating an industry association to promote and develop the region's water technology cluster. Sixty individuals from business, government and academia attended this participatory forum, agreed that the region had the elements and potential to develop into a water technology cluster, and collectively agreed to an agenda to make it a reality (Miner, 2010). The participants came to the conclusion that Milwaukee had the natural and human resources, the academic and research institutions, and a sufficient concentration of businesses, to constitute a nascent cluster; that the water technology industry was capable of making a contribution to local economic development, research related to fresh water, and education and talent development of water technologists, innovators and entrepreneurs; and that an industry association would play an important role in raising public awareness, building support from a wide cross-section of stakeholders, and assisting innovators and entrepreneurs commercialize cutting-edge water technologies (Miner, 2010; The Water Council, 2017). Since that inaugural 2007 event, the Water Summit has grown into a two-day event which is attended by about 400 of the world's water industry thought-leaders and decision-makers, innovators and entrepreneurs, potential investors, economic development specialists, water technologists, and students. The building of partnerships is part of the second strategy of The Water Council.

The summits have adopted different themes each year to reflect emerging issues and trends and to promote the work of the Council and the Milwaukee cluster. In 2008, it was the "Water Innovation Economy: Growing a Blue Business in a Green World," and the keynote speaker was the Senior Adviser to the United Nations Global Compact Program; in 2008 the theme was “The True Costs and Opportunities of Water,” and the Council celebrated Milwaukee being named a 'Global Compact City'; in 2010 the theme was the “Blue Footprint” which recognizes the huge amounts of energy required to move and treat water and wastewater; in 2011 the summit was expanded from one to two days and featured three tracks, “The Global Water/Energy Nexus,” “Urban Watersheds: Striking the Balance” and “Making Urban Agriculture Work”; in 2012 the theme was “Building the Water Centric City” which looks at the financial and engineering challenges of aging water infrastructure; in 2013 the summit showcased The BREW and the new World Water Center; in 2014 the theme was “Thriving in the Global Water Economy” which examined water innovation and sustainability, financing and investment, and operating in the global water market; in 2015 the theme was “Creating a One Water Region,” which considered a model that connects and enhances the performance of the historically fragmented water economy; in 2016 the theme was “Establishing a Water Resilient City,” which considered urban planning and environmental strategies to overcome risks to water quality and quantity; and finally in 2017 the theme was “A Secure Future Needs Water,” which considers water security and threats to water supplies.

3. Innovation Commercialization Exchange Institute

The Innovation Commercialization Exchange (ICE) Institute is an initiative of The Water Council designed to aggregate and evaluate promising and emerging water technologies from across the research and development community of university, private sector and federal laboratories and connect these technologies to water related industries - including utilities, agriculture, and manufacturers. Industry experts will act as technology scouts to seek out these new innovations and bring these back to the Council where they will be vetted, cataloged and stored in a database powered by IBM Watson which has the capacity to help match technology to industry needs (Chawaga, 2016). A key component of the ICE Institute is the partnership with the Federal Laboratory Consortium for Technology Transfer (FLC) which represents 300 federal labs across the United States. A key challenge facing the water technology industry is the difficulty of commercializing emerging technologies, and university and government laboratories doing water and water-related research have traditionally faced a difficult commercialization process (Thomas & Ford, 2016). The Water Council has appointed Dr. David Garman - Associate Vice Chancellor for water technology, research, and development for UWM - as the new Chief Technology Officer for The Water Council with responsibility to lead the ICE Institute. The partnership with the FLC fulfills a commitment The Water Council made during the 2016 White House Water Summit to develop a channel between federal laboratories and water industries (White House, 2016). Only members of The Water Council can utilize the services of the ICE Institute. Development of the ICE project was supported by a $75,000 grant from WEDC through the agency's Targeted Industry Projects program which was instituted to support industry cluster and sector development in the state of Wisconsin. The creation of a data base is in line with the fourth strategy of The Water Council.

IV. Other Contributors to the Milwaukee Water Cluster

A. University of Wisconsin, Milwaukee: School of Freshwater Science

In 2009, the University of Wisconsin-Milwaukee (UWM) launched a project to create the School of Freshwater Sciences (SFS), which represented a key initiative in the university's aspirations to become an entrepreneurial organization and a driver of economic development in Milwaukee. This initiative builds upon and leverages an almost 50-year history of UWM scientists and students conducting internationally recognized research into freshwater science and ecology on Lake Michigan (Levine, 2009). This initiative received impetus in 2007 because of the work of a coalition of Milwaukee's civic and business leadership who were seeking to create a regional economic development strategy. One outgrowth of this strategy led to the desire to brand the city of Milwaukee as the "global capital of freshwater research and water technology" and to the establishment of the Milwaukee 7 Water Council (Schmid, 2007c; Schmid, 2008). The leadership of UWM envisioned the SFS as an institution that would serve as a "magnet or anchor tying together the water cluster" which the Milwaukee 7 Water Council was working to promote (Schmid, 2007c). As part of the rhetoric of local economic development the leadership of both the Milwaukee 7 Water Council and UWM marketed the SFS as a vital ingredient is creating a “Silicon Valley of water.” What would be established would be a world-class research center staffed with professors, graduate students, technologists, and policy experts that would be the only institution of its kind in the U.S. This team would work closely with local businesses to develop and commercialize water technologies (Milwaukee Journal Sentinel, 2008; Milwaukee 7 Water Council, 2009). The UWM was seeking to emulate other universities, such as Berkeley and the Massachusetts Institute of Technology, which are widely believed to facilitate innovation and entrepreneurship in their respective technology hubs (Levine, 2009; Schmid, 2014)

The promotional and networking efforts of the Milwaukee 7 Water Council and UWM eventually led to the state of Wisconsin agreeing in 2009 to fund the establishment of the SFS. The project, which cost $53 million, was approved in 2011 by the UWM Board of Regent and would involve the expansion and upgrade of the harbor campus which the UWM has occupied since 1971. The project involved the addition of 100,000-square-feet to produce a three-story facility with 200,000-square-feet of space divided among labs, classrooms, workshops, and administrative offices, as well as space for a water policy division (Schmid, 2014). The SFS, which opened in 2014, physically consists of two parts: the original Port Building which supports marine operations, on-site collaborators, research activities, and the Great Lakes Aquaculture Center; and the new Starboard research building which houses state-of-the-art facilities such as biosecure and quarantine laboratories for studying aquatic species, a pathogen testing facility, and the Great Lakes Genomics Center. The Great Lakes Genomics Center is the first DNA sequencing lab in the U.S. dedicated to water and environmental issues. The new SFS would build on a tradition of research excellence in freshwater science and ecology which includes work on industrial pollutants, pharmaceutical pollutants, invasive species, exotic pathogens, and sewer overflows; and also be a locus of much-needed interdisciplinary public policy research and teaching on issues of water economics and resource management, sustainable development, public health, and environmental infrastructure (Levine, 2009; Schmid, 2014; Bauter, 2014). The work of the SFS will be depend on an annual research budget of $10 million, but the intention is to secure additional resources to expand research. This vision for the SFS has not gone unchallenged.

The aim is to move from a facility dedicated to research to a multi-disciplinary institution conducting water-related research and education and offering newly introduced courses on water policy, management and economics (Bauter, 2014). Plans are to expand the faculty and create around each faculty member a project team of graduate students and technicians who would be capable of moving projects beyond research to include testing and commercialization of technologies. An example of the future direction of the research-commercialization nexus at SFS is the discovery of how to manipulate heat and light to speed up the growth of yellow perch and increase food yield by a factor of 12. Bell Aquaculture, an Indiana fish-farming company, has so far invested $50 million on applying the technology (Muller, 2013).

Levine (2009) has, however, challenged the notion of the entrepreneurial university in general and the business model of the SFS in particular. He has challenged the ability of the water cluster to generate the jobs promised; and he has even challenged the claim of Milwaukee becoming a national or globally significant water hub. Others have noted that the school has historically focused on ecological research and not on the commercial applications of water technology (Schmid, 2010). There are concerns that much of the research done at the school will not be able to secure a patent and should not be patented because the discoveries are of public value (Levine, 2009; Miner, 2010). The consensus seems to be that the academic, educational, and public policy aspects of the school are laudable; however, the notion that a research university can become involved in the commercialization of technology leads some to have concerns as to whether corporate and proprietary values, and the profit motive, will replace traditional university values built around the creation and dissemination of knowledge (Levine, 2009). The primary basis for the establishment of the SFS was local economic development, and this strategy was highly successfully in galvanizing ideological and material support from the civic and business leadership of Milwaukee. Conceptualization of the SFS as one cornerstone of a local economic development strategy, however, runs the risk of the academic and scientific mission of the school being subordinated to a business-dominated, and potentially conceptually flawed, economic development strategy (Levine, 2009).

B. Milwaukee Metropolitan Sewerage District (MMSD)

The Milwaukee Metropolitan Sewerage District (MMSD) is a regional government agency that provides water reclamation and flood management services to the Greater Milwaukee Area. The MMSD serves approximately 1.1 million people in 28 communities covering 411 square miles that includes six watersheds. The district is established by state law and had been granted taxing authority to fund its activities. The district is governed by 11 commissioners and is staffed by several hundred employees with a wide range of skills in engineering, management, and public policy.

The MMSD plays a significant role in safeguarding natural resources, protecting public and environmental health. The district treats billions of gallons of wastewater every year from a range of residential and industrial sources, as well as surface and storm water runoff. In addition to these core responsibilities in wastewater treatment and flood management, the MMSD is also responsible for public education, through facility tours and presentations on water quality issues, for developing green infrastructure, for promoting sustainability, and preparing the community for the hydrologic impact of climate change. The MMSD has worked to improve wastewater treatment, to meet statutory water quality requirements, and improve flood management to reduce the frequency of combined sewerage overflows. Much of the pollution which reaches Lake Michigan, and which impedes the ability of the city of Milwaukee to meet water quality standards set by the Clean Water Act, is the result of surface runoff and combined sewerage overflows. Wisconsin regulations allow combined sewers to overflow up to six times a year and since 1994, when a deep tunnel system was brought into operation, the district has reduced overflows from about 60 a year to an average of 2.4 overflows a year (Behm, 2013, 2017; Murphy, 2014). In recent decades the city of Milwaukee has spent $5 billion to address pollution from all sources and there are plans over the next 20 years to spend another $1-1.3 billion to control overflows, largely through green infrastructure capable of capturing all surface runoff, ending all combined sewerage overflows, and ending all backups of wastewater into basements (Bergquist & Behm, 2014; Behm, 2017). The district's current tunnel storage capacity for capturing surface runoff is 521 million gallons and the plans to upgrade the system, known as Fresh Coast 740, would raise this to 740 million gallons; the number of homes and businesses that remain in the 100-year flood zone have been reduced from 3,800 in 1999 to 1,300 in 2016; and while the national standard for capturing and cleaning all the rain and wastewater that enters their sewer systems is 85%, the MMSD has been able to achieve a rate of capture of 98.4% in 2016, with an average of 98.4% since 1994 (Bergquist & Behm, 2014; Behm 2017). For its record of achievement, the MMSD was a recipient of the 2012 U.S. Water Prize and many other awards.

The MMSD is at the forefront of waste and storm water management and in employing the latest water technologies. The MMSD embraces both innovation and entrepreneurship to meet its vision and mission. An innovation in relation to sustainable water use it the adoption the principle of 'one water,' which is both a philosophy and management approach that views all water – drinking water, wastewater, storm water, and grey water – as potentially renewable resources that moves through a closed system that must be managed holistically (US Water Alliance, 2016; K. Schafer, personal conversation, May 17, 2017). Another innovation is the 'management of water where it falls.' Early approaches to surface and storm water runoff involved conveying untreated runoff as quickly as possible to a receiving body of water. Current approaches involve conveying it to a treatment plant, although these plants are often overwhelmed when there are large volumes of water. Managing water where it falls involves learning from nature and employing green infrastructure to capture, store or absorb this runoff thus reducing the cost of infrastructure and the energy involved in treating water (K. Schafer, personal conversation, May 17, 2017). The treatment and conveyance of water is energy intensive and the MMSD is committed to reducing the energy it uses, and to becoming energy self-sufficient by the year 2035, by employing technologies such as landfill gas, solar power, and sewer heat (K. Schafer, personal conversation, May 17, 2017). An example of both innovation and entrepreneurship is the production and sale of Milorganite by the MMSD. Milorganite stands for Milwaukee Organic Nitrogen. The production of the organic-nitrogen fertilizer Milorganite, which began in 1926 as the result of research efforts at the University of Wisconsin-Milwaukee, is one of the oldest recycling efforts in the U.S. and demonstrates that sustainable and environmentally responsible practices can also help improve the financial bottom line (Steffan, 2016; K. Schafer, personal conversation, May 17, 2017).

C. Veolia Water Milwaukee

In 2006, the MMSD awarded a 10-year contract worth $400 million to Veolia Water to be its operations and maintenance partner while the MMSD retained ownership of the facilities. That contract took effect in March 2008 and Veolia replaced United Water Services which was awarded the first operating contract in 1998. The Veolia contract with the MMSD is the largest publicly owned wastewater treatment system under private operating contract in the U.S. serving 1.1 million in 28 municipalities. Veolia operates and maintains two water reclamation facilities, at Jones Island and South Shore with a combined daily capacity of 660 million gallons, the 320-mile system of interceptor and main sewers, the 500 million gallon 'Deep Tunnel' storage system, and the annual production of 48,000 dt of Milorganite. In 2016, the MMSD awarded a 10-year contract extension worth $500 million to Veolia Water to continue operating its two sewage treatment plants and other facilities. This contract would take effect in March

2018. The continuation of this public-private partnership is based on the belief that the city of Milwaukee saves money and gains access to the resources and expertise of a major multinational water business (Behm, 2016). Veolia Water Milwaukee is a part of Veolia Water North America, which is itself part of Veolia Water, a division of Paris-based Veolia Environment, the world's largest environmental company. Veolia conducts business in the infrastructure and utility sectors traditionally managed by public authorities - water management, waste management, public transport, and energy services. Veolia employs approximately 300,000 employees in 48 countries serving more than 108 million customers. Veolia Water North America is the leading provider of comprehensive water and wastewater services in the U.S., serving approximately 550 communities and about 100 industrial facilities (Veolia, 2017).

Veolia Milwaukee actively engages with the local community to support economic, environmental and social development and sustainability. This includes direct support from Veolia for the Milwaukee water cluster. As part of the contract with the MMSD, Veolia has committed to invest $1.5 million in R&D and active partnerships with regional universities. Veolia also has important relationships with The Water Council – it has offices at The Global Water Center. It has joined with the Council and the Wisconsin Economic Development Corporation (WEDC) to launch a national competition to support innovators and entrepreneurs seeking to improve sustainability and resiliency efforts in the water and clean-tech industries. The new program is called 'Pow!' - which stands for 'emPowering Opportunities in Water.' The Pow! program is an extension of The BREW program, and it functions as an accelerator to support promising water technologies and build channels to market their products. The specific support of the Pow! program includes cash prizes totaling $40,000 – with $25,000 from Veolia and $15,000 from the Council and WEDC - $10,000 worth of tuition to The BREW for business and entrepreneurship training, 12 months of free office space in Veolia's suite at the Global Water Center, access to the Global Water Center's Flow Lab, coaching and mentoring opportunities from water experts, and access to the Veolia network. The MMSD will provide on-the-ground testing support for new technologies that might be installed in their wastewater treatment facilities. This new program is connected to the Veolia Innovation Accelerator's clean technology sourcing program, which seeks to identify technologies that can help Veolia solve its problems; but it also confirms Veolia's commitment to the efforts of The Water Council to position Milwaukee as a major world hub in water resource management and water technology solutions (Behm, 2016; Thomas, 2016).

Pow! applicants must be entrepreneurs, innovators and companies with a water-related innovation with a high viability for commercialization in the areas of smart-data technologies, watershed management, resilience and sustainable water management, and disruptive water innovation. Each year three winners are chosen to enter the program. The first three winners were Nano Gas Technologies, Nutrient Recovery and Upcycling, and WAVVE Stream. Deerfield-based Nano Gas is working on a product that will recycle oil industry waste water, recovering the oil that otherwise would be lost and reducing demand for fresh water; Madison-based Nutrient Recovery and Upcycling is working on a product that removes phosphorus or nitrogen from wastewater and turns it into a high-purity, highly concentrated fertilizer; Houston-based WAVVE Stream is working on a gel made of food-grade materials that removes nutrients and heavy metals from water (The Water Council, 2016). This type of partnership with Veolia Water aligns with the second strategy of the Milwaukee 7 Framework which is to "become a global hub for innovation and startup activity in the water technology industry."

VI. Application of Porter's Diamond

A. Factor Conditions

The competitive basis of the economy of the Milwaukee region rests historically on its unique location to fresh water – both Lake Michigan, and by extension the Great Lakes, and to the Mississippi River (Foss-Mullan, 2001). Industries which were intensive users of water sprang up in Milwaukee and the port facilities on Lake Michigan enabled the city to become a major export center for both its own locally produced goods and the goods produced in the other areas of the state of Wisconsin. Even today, suggestions have been raised in some local economic development quarters that Milwaukee should exploit its natural advantage in fresh water to offer concessionary rates to water-intensive and water-enabled industries to encourage them to remain in the city or relocated there. Milwaukee already has some of the lowest water rates in the U.S. (Schmid, 2009). The suggestion to leverage cheap water, while supported in some quarters, has been challenged by those who suggest that both water conservation and water technology innovation are stimulated by charging customers the true economic value of water, or as close to this rate as can reasonably been ascertained (Miner, 2010). In this context the competitiveness of Milwaukee's industries was traditionally, and at least partially, built because of water being a 'basic' and 'general' factor. This factor is abundant available in Wisconsin but is not unique to this city (Longworth, 2015).

The Milwaukee economy was also, however, built on a set of more advanced and specialized factors. The city has a history of skilled workers, going back to German immigrants in the mid-19th Century. The city has several world-class research institutions, such as University of Wisconsin-Milwaukee. It also has a high concentration of water-intensive and water-enabled businesses, suppliers of technologies to those water users, and rail and water-based logistic capabilities. These advanced and specialized factors have also been upgraded in recent years, much of it because of the efforts of The Water Council; however, these advanced and specialized factors are not unique to Milwaukee and other cities in the region are also developing their water clusters (White, 2010; Longworth, 2015; McDearman, 2018). The cities in the region with emerging water clusters include the Michigan Water Technology Initiative, Current Water in Chicago, the Cleveland Water Alliance, the Akron Global Water Alliance, and the Confluence Water Technology Innovation Cluster in Cincinnati (EPA, 2017). These clusters may not be as advanced as Milwaukee's; these clusters are upgrading their institutional capacity and observing and learning from the work of The Water Council (White, 2010; D. Amhaus, personal conversation, May 17, 2017). The traditional technological capacity of Milwaukee's water technology firms rests primarily in mature technologies like meters, pumps, and valves rather than emerging technologies such as membranes and desalination (Miner, 2010).

Wisconsin has access to venture capital at the per capita rate of about $3. This is below the national median of $5 and well below Massachusetts at $109 and California at $94 (Clustermapping.us, 2017). The per capita rate must be considered against the state’s population of about 5.8 million which is 20th overall nationally which means that the pool is relatively small. Wisconsin's R&D expenditure is at the per capita rate of about $1005 – which is about the middle range among states with the highest being $4,137 in Massachusetts. - Federal R&D is at the per capita rate of about $117 – which is also in the middle range among states with the highest being US$469 in Maryland (Clustermapping.us, 2017). Venture capital and R&D expenditure are considered in Porter's Diamond to be advanced and specialized factors. Although it has had some success in attracting grants from the private sector and the federal and state governments, The Water Council needs to improve these for its industry. In 2013-14, Wisconsin placed 14th among the 50 states in academic R&D spending, with UW-Madison holding fourth place nationally in the NSF rankings, but the state ranked 21st in the nation in industry R&D spending which also represents the state's relative industrial position (Still, 2016; Conroy & Deller, 2017). In this environment Wisconsin struggles with low levels of economic growth and low levels of innovation – the state placed last among the 50 states in startup activity (Romell, 2017). From the Harvard Cluster Mapping Program, Wisconsin receives an innovation score of 8.44 which is an average score compared to California which scores 27.01; and Wisconsin's annual patent count of 1,815 is slightly above the average patent count but far behind the leader, California, with a count of 33,343 patents (Clustermapping.us, 2017).

B. Related & Supporting Industries

The Water Council has worked aggressively and persistently to build a working coalition of public, private and non-profit organizations to support the work of the Council and build the Milwaukee Water Cluster into a Global Water Hub. Clusters exist within a value chain and the water technology industry is connected to universities that supply it with talent and R&D support, and to water-intensive and water-enabled industries and public utilities to which it supplies technologies. Every major educational institution in the state of Wisconsin offers some form of specific water-related training. There are 36 water-focused academic programs and research centers available across 17 educational institutions to include several graduate programs at the School of Freshwater Science of University of Wisconsin-Milwaukee, at the Water Quality Center of Marquette University, at the Institute for Water Business of University of Wisconsin–Whitewater, at the Water Environmental Analysis Lab of University of Wisconsin–Stevens Point, and at numerous other colleges (Daigneau, 2013). Though not unique to Milwaukee, this educational and research base provides the Milwaukee water cluster the talent and research pipeline to successfully compete against other emerging water clusters (White, 2008; Longworth, 2015).

To further strengthen collaboration and build the networks necessary for innovation and the diffusion of technologies, The Water Council has championed the creation of a Global Water Technology Park on 18-acres adjacent to their offices at Freshwater Way. The Reed Street Yard has been set aside as the focal point of Milwaukee's Global Water Hub and is envisioned as a "evolving eco-industrial zone, balancing natural resources and economic development" (Daigneau, 2013). The reclaimed brownfield site which will include a system of sustainable infrastructure such as urban bio-swales and rain gardens to eventually make it water-and-energy-neutral will be home to research facilities, demonstration and educational projects and water technology firms (Daigneau, 2013). The first tenant to join The Water Council in the Global Water Technology Park is the 52,000 square-foot headquarters of Zurn Industries, which was relocated to Milwaukee from Pennsylvania in 2016 (Daykin, 2017). Zurn, which has been owned by the Milwaukee-based Rexnord Corp. since 2007, is a plumbing products manufacturer and makes toilets, faucets, waste water treatment systems and other water tech products. Rexnord Corp. - which designs, manufactures, markets and services specialized and highly engineered mechanical components that are used within complex mechanical systems - recently relocated its headquarters to the nearby Global Water Center.

C. Demand Conditions

The Water Council has identified considerable national and global demand for cutting-edge water technologies that should last well into the 21st Century. Nationally there have been declines in deep aquifer reserves and surface water supply sources, impaired water quality from both point and non-point pollution sources, contaminated municipal water from faulty water infrastructure, and high operating costs and maintenance challenges from aging water infrastructure. Globally many countries face challenges with water quality and quantity, and the need to address sanitation and hygiene deficiencies through expanded water and sanitation infrastructure. Water and sanitation has become a global development imperative and trillions of dollars of investments are needed over the next half-century to solve these challenges. There is also a growing consensus in Milwaukee about the need to protect and conserve the city's water resources which has led business and civic leaders and academics to collaborate to find solutions to local water quality and environmental problems; and Milwaukee is currently working to leverage both its water resource assets and its expertise in water technology, green infrastructure and sustainable water practices to align its water industries to meet national and global needs (Howard, 2015).

Strong local demand and sophisticated local consumers are the best drivers to pressure an industry to innovate and upgrade to become more globally competitive (Porter, 1993). The largest single source of demand for water technologies comes from the public utilities and public infrastructure. The city of Milwaukee has suffered in the recent past from seriously degraded water quality due to decades of pollution from industry and urbanization, including a 1993 breakdown in the city's clean water system that contaminated drinking water and caused more than 100 death; and Milwaukee has suffered from flooding that has caused considerable damage to infrastructure and private property, and has led to loss of life - the most recent severe flood being in 2010 (Bergquis & Crowe, 2014). Milwaukee has laid out its plan and stated its commitment in a comprehensive 10-year sustainability road-map and strategic framework called 'Refresh Milwaukee' (Howard, 2015); and a specific example of this political commitment, and the technical capacity to carry it out, is the $3 billion Deep Tunnel which was opened in 1993 and which has been the single most important contributor to improved water quality (Behm, 2013). The demands to address water and environmental quality and sustainability have created a healthier and aesthetically pleasing environment and improved water quality is linked to rising property values along Milwaukee's water ways (Daykin, 2017). The response to the water quality and environmental problems of Milwaukee have contributed to the development of the region's water technology and management expertise, offering the city's water technologists a home base from which to competitively launch into global markets (Miner, 2010).

Milwaukee industry has traditionally been heavily linked to the region's water resources (Foss-Mullan, 2001). Even with a reduction in traditional industries due to de-industrialization and economic restructuring, water remains an important component of Milwaukee's industrial base and continues to be sold by local economic development leaders as a reason to do business in Milwaukee (Schmid, 2009). To put things in perspective, Wisconsin's economy uses approximately 2 trillion gallons of water out of lakes, rivers and underground aquifers each year to run power plants, municipalities, large farms, paper mills, food and beverage processors, and other industries (Behm, 2013). The state's 30 power plants are the largest consumers of surface water; the 49 pulp and paper producers are the second largest consumers; and the 40 municipal water utilities are the third largest users of surface water (Behm, 2013). Ground water extraction is primarily to meet municipal and agricultural demand; but use of water by the multi-billion-dollar agricultural sector is becoming more efficient, even while yields increase, as farmers switch to more modern forms of irrigation (Behm, 2013). The Milwaukee economy, and Wisconsin economy in general, continues to be heavily influenced by manufacturing which is the largest single employer at 17% and second highest traded sector with a location quotient of 1.58 (Matoon & Wang, 2014). The competitiveness challenge for the water technology industry is that much of local demand, especially from industry, is for mature technologies; and much of the pressure for innovation is driven by government environmental and water quality regulations.

D. Firm Strategy, Structure and Rivalry

Milwaukee calls itself the World Water Hub and sees industries connected to water as key to the economic future of the city and one of the region’s most promising sectors to create jobs. The Water Council makes the claim that about 150 – 200 water-related companies employing up to 20,000 people, including five of the 11 largest water companies in the world and 38 water technology company headquarters, are based in and operate from the Milwaukee region. The prime objective of both The Water Council and the city of Milwaukee is job creation and economic growth to increase corporate profits for the Council's membership and increase government revenues for the city (D. Amhaus, personal conversation, May 17, 2017). Environmental and public health concerns are ancillary to local economic development in that these tend to affect the attractiveness of the city to investors and residents and boost property values (Daykin, 2014).

The goals, objectives and strategy of both the water technology industry and the city government – local economic development – is relatively easy to identify; however, determining the industry structure and nature of industry rivalry is much more problematic. The first step in determining the structure of the water industry - which consists of organizations directly involved in various stages of the water cycle - is to be precise about the term 'water technology firms.' The industry can be divided into (1) water and wastewater utilities that collect, treat, store and monitor water; (2) water infrastructure businesses that includes engineering and manufacturing firms that make water control equipment, such as pumps and pipes, and construction and consulting firms that design, build, and maintain infrastructure; and (3) water technology businesses that design and produce equipment and chemicals for improving water quality, for measuring and metering water, and improving the efficiency of water use (Calvert, 2008). The water technology industry therefore includes a broad spectrum of products and services, many of which are difficult to pinpoint within standard industrial classification systems. Water technology businesses are the primary constituency that The Water Council represents (D. Amhaus, personal conversation, May 17, 2017). There is no single NCIS classification for water technology firms, which presents practical challenges when analyzing this narrow segment of the water industry; however, The Water Council has identified several NCIS codes related to water and manufacturing which can be used for the Council's classification purposes (D. Amhaus, personal conversation, May 17, 2017). The exact number of firms in Milwaukee which would meet a more precise and objective definition of a water technology firm is not publicly known and at this point may be unknowable (Levine 2008), and a more accurate figure may be considerably below 100 firms and employment may be closer to between 3,600 and 7,500 people (Levine, 2009; Murphy, 2015). The number of firms and employees is not by itself a good indicator to the relative strength of a cluster. By way of comparison Israel multi-billion-dollar water technology cluster – one of the world's best established and most internationally successful – has about 300 firms employing 8,000 people. Milwaukee firms license technology from Israel (Levine, 2009; Siegel, 2015).

At the regional scale, employment in the water technology sector represents only about one percent of regional employment, while Milwaukee ranks 21st in the employment of water hydrologists nationally; patents for water technology constitutes less than two percent of patents generated regionally, while Milwaukee ranks 19th nationally; and of the global top-40 water companies by revenue, none have their headquarters in Milwaukee, while the city ranks seventh nationally for branch plants and offices (Levine, 2009; Miner, 2010). The limited evidence available therefore suggests that water technology firms, narrowly defined, consists of mix of small, medium and large firms at various stages of the industry cycle producing a range of highly specialized, heterogeneous technologies. This suggests that the cluster may not be as economically significant as its political and industry proponents have so enthusiastically claimed, and that domestic rivalry among these firms is limited and will not be the main driver of innovation.

At national and global scales, the water technology industry faces a different structure and degree of rivalry. Milwaukee is not the only city U.S. city promoting itself as a water innovation technology cluster (White, 2010; Longworth, 2015; Newberger & Toussaint-Comeau, 2015). At least 14 other regions in the U.S. are promoting these clusters and several well-established water clusters are scattered across the globe, each offering expertise largely based on unique characteristics and histories. Across the U.S., universities are bolstering their water-related curricula and research capabilities; and state and local governments and industry associations are putting in place institutional arrangements to develop nascent capabilities and market their water assets (Miner, 2010; Longworth, 2015). Milwaukee is one of six water clusters in the Midwest. The Nebraska Water Center, which is part of the University of Nebraska, was established in 1964 by Congressional mandate as one of 54 Water Resources Research Institutes in the United States. The Cleveland Water Alliance, which is a non-profit organization launched in 2014, joins together corporations, universities and government agencies in Northeast Ohio to drive economic development through water innovation. The Akron Global Water Alliance, which was launched in 2014, has partnerships with the City of Akron’s Economic Development and Water Departments, the University of Akron, the Akron Global Business Accelerator, Akron City Council and Summit County Council. Current

Innovation, which was launched in 2016 to promote local economic development by leveraging Chicago's expertise in water infrastructure, purification, and treatment, is a not-for-profit organization in partnership with the City of Chicago, the Metropolitan Water Reclamation District of Greater Chicago (MWRD), World Business Chicago (WBC), and the 'WaterCAMPUS' at the University of Illinois. Confluence Water Technology Innovation Cluster in Cincinnati, which was launched in 2011, has a particularly close working relationship with the EPA's water research facility in that city.

One potential rival to Milwaukee is to be found nearby in Michigan, which recently initiated the Michigan Water Technology Initiative through its state marketing arm, the Michigan Economic Development Corporation. The state also commissioned two reports, which were published in 2014 as the 'Michigan Blue Economy' and the 'State of the Great Lakes,' which highlight the strategy to promote innovation in water technology as part of the overall restructuring and 'greening' of the Michigan economy (Austin & Steinman, 2014; Department of Environmental Quality, 2014). The Initiative brings together nearly every major university in Michigan and seeks to leverage this talent pipeline which claims to have 68 undergraduate and graduate degree programs in water-related areas which produce 3,400 graduates in water-related fields (Department of Environmental Quality, 2014). The Initiative also makes the claim that more than 80 industry sub-sectors requires high quality and plentiful water as a key input, and one in five Michigan jobs, totaling 138,000 workers, is linked to core water products and services, such as water treatment facilities and solving water quality and quantity issues (Department of Environmental Quality, 2014). Across Michigan there are numerous companies and research facilities dealing directly with 'hard' water-related technologies from pumps, valves, meters, filters, controls, heaters, and bio-digesters; and other companies and research facilities working on 'soft' water-related technologies from software to monitor water quality and use, water resource conservation, and ecosystem management (Longworth, 2015). Examples of major industries located in Michigan that are connected to water include Whirlpool - developing more water efficient appliances - Dow Chemicals – which has a water and process solutions division with expertise in filtration – and auto parts maker Cascade Engineering – which is also now producing inexpensive water filters.

By improving water quality and protecting water ways and the environment in the most efficient and effective ways, Michigan is hoping to attract and retain the many industries such as agriculture, food and beverages, chemicals, paper, pharmaceuticals, computer chips and tourism that require clean water and a pristine environment (Longworth, 2015). The fact that Milwaukee is not the only potential water cluster and Global Water Hub in the U.S. should serve as a warning to The Water Council, but also as an incentive to innovate more aggressively; and home-grown success in improving Milwaukee's water quality and public and environmental health will be the single most important signal to the market that Milwaukee's water cluster is ready to compete in the global water market (Miner, 2010).

E. Role of Government & Chance

The Water Council has actively sought the support of the state in promoting and resourcing the Milwaukee water technology cluster, and the state at all scales has enthusiastically given its public endorsement and provided funds from public coffers. The mayor of Milwaukee has been described as an enthusiastic early support and the city’s political leadership has come to see water technology as a replacement for those traditional manufacturing sectors which are in decline and a way to nurture the new manufacturing economy in the city (Lowe, 2013). Milwaukee politicians have been at the forefront of re-branding the city as the 'Fresh Coast' or the 'Silicon Valley of Water' (Lowe, 2013). The city has even floated the idea of using low-cost - meaning publicly subsidized - but high-quality water to attract investors to the region. Public and private universities in the state have been willing to align their training and research to support the council and the state has helped with the resources to make this a reality, most notably the $53 million investment in University of Wisconsin-Milwaukee's School of Freshwater Sciences. The state has also been generous with financial resources and the federal government has given the Council and its partners over $4 million in grants for business incubation, job creation and water research. These grants include funds from the SBA to support startups, and from the DOC to start a seed fund; while the state of Wisconsin, through the WEDC, has provided grants for both the 'POW!' and ICE programs. In this case, the state is attempting to enhance competitive advantage by acting as a catalyst for change by influencing political, economic and social environment in which industry must operate and providing direct financial support.

The state can also act as a challenger of change, such as when the state government sued the city government in 1977 and 1978 over combined sewer overflows, forcing the creation of the MMSD we know today with greater regional responsibility (Nusser, 2015). Combined sewer overflows were polluting the Milwaukee, Menomonee and Kinnickinnic rivers - which flowed into Lake Michigan – and what was required was an inter-jurisdictional solution which crossed geographic boundaries. The higher water quality standards required by the Clean Water Act of 1972, and the last opportunity to use federal grant (as opposed to loan) money provided by the Act, facilitated the city solving its flooding problems through the construction of the 'Deep Tunnel' (Nusser, 2015). These days there seems to be much less focus on the state's role as a challenger for change, such as through raising water quality or environmental standards or ensuring that consumers pay the full-cost price of water that reflects its social, economic and environmental value.

Chance has also played a role in stimulating the emergence of a water cluster in Milwaukee. The location on Lake Michigan, and abundance of fresh water, stimulated many water-intensive and water-enabled industries and logistics companies to invest in the city; and to support these core industries many supporting industries that became the basis of a water technology industry emerged. The heavy concentration of industry, and urban development, however, came at a cost to public and environmental health which eventually over many decades forced public action (Foss-Mullen 2001). Milwaukee became a leader in wastewater management from the late 19th century and was one of the first cities in the U.S. to build combined sewers, to install a treatment plant, to use biological processes to treat waste, and to recover usable resources from the waste (Nusser, 2015). Initially the city conveyed its sewerage and storm water to Lake Michigan through its sewer mains, but disease outbreaks prompted construction of the sewerage plant at Jones Island, which opened in 1925 (Foss-Mullen, 2001). By 1940 about 85% of the city's residents were connected to the city's sewerage system - compared to zero in many other major U.S. cities, making Milwaukee an early national leader in waste and storm water management (Holmes, 2015). The head start means that

Milwaukee's environmental remediation efforts are ahead of other cities, which positively impacts property prices, restores many natural ecosystems, makes more recreational areas available for public use, and lowers the financial burden which taxpayers have to bear over time to pay for infrastructure (Holmes, 2015).These chance events have converged to give both the city government and the private sector considerable policy, engineering, scientific, and technological know-how which can be leveraged to help the rest of the U.S., and the wider global community, solve urgent water quality and quantity issues while supporting local economic development (Nusser, 2015).

VI. Conclusion

The water technology innovation cluster centered in Milwaukee, Wisconsin has the ingredients to be considered a growing cluster (Tichy, 1998). It initially emerged as a cluster largely through a process of spontaneous generation, but it has also received some external intervention to facilitate and accelerate the process of cluster formation (Brusco, 1990). Largely because of the work of The Water Council, Milwaukee can be classified as a growing cluster: it has a large number of supporting enterprises, agencies and service organizations; it has an evolving innovation network supported by information platforms and intermediary agencies that provide the needed industry knowledge and business services; it is developing robust communication channels for exchanging information and knowledge among its members; and The Water Council has developed a sustainable business model. To become a mature cluster, The Water Council will require time and continued concerted effort, both internal and external, on the part of key cluster stakeholders if the cluster is to become self-sustaining, and the region is to realize the long-term economic benefit that can be derived from a successful cluster made up of globally competitive firms.

The Water Council cluster boasts 'scientific preeminence' in water technology due to the presence of 36 water-focused academic programs and research centers available across 17 educational institutions, chief among them being the School of Freshwater Science at the University of Wisconsin-Milwaukee, a number of companies which are intimately connected to water technology innovation, and the historic relationship of the economy to water-intensive and water-enabled industries (Milwaukee 7, 2007; White, 2008). Home grown technology firms and universities have also produced many innovative technologies and scientific advances that have brought the cluster global attention. The claim of 'scientific preeminence' is a strength of the Milwaukee cluster (Smilor et al., 1989); however, this claim of 'preeminence' is not without challenge, and it has not been backed up by objective criteria (Levine 2009). Neither The Water Council nor the Milwaukee 7 offers list the number of patents and publications connected to water that have been produced by the cluster's universities and firms; there is no accurate number of water technology firms, and how this concentration compares with others clusters; and there is no accurate figures on the number of jobs that exist in this industry and the amount of money the industry generates.

The Water Council has been working hard to attract major water technology companies (Smilor et al., 1989) and has had some limited success: Zurn relocated its headquarters from Pennsylvania to Milwaukee, and French multi-national Veoila now operates both sewerage plants on behalf of the Milwaukee Metropolitan Sewerage District. There has been some interest from startups from around the world to utilize the incubator, accelerator and laboratory resources of The Global Water Center, which is operated by The Water Council; however, recent plans for expanding the Center by opening a second office in the Walker's Point neighborhood, with the support of a $750,000 grant from the Wisconsin Economic Development Corporation, were dropped after the proposed development failed to draw enough prospective tenants (Daykin, 2017). The difficulty in attracting existing technology firms could be an indication of a weaknesses relating to the structure of the Milwaukee cluster, and an indication that it should focus on core strengths that are locally based rather than building a broad-based water technology innovation cluster. The difficulty in attracting more startups could be an indication that The Water Council is overly ambitious about the rate of growth – the water technology industry is notorious for the slow adoption of technologies and is not a high priority for resources such as venture capital and R&D funds when compared to other sectors. To determine the relative strength and potential sustainability of Milwaukee's water cluster requires a more robust methodology.

The Water Council has been highly successful in its marketing and public relations initiatives, has raised the national and global profile of the Milwaukee cluster, and increased the amount of networking and collaboration that takes place through the auspices of the Council. According to Phillips (2006) there needs to be a high degree the interaction and collaboration between major sectors in the cluster to solve complex problems and achieve joint goals and there is considerable evidence that this is taking place. The Water Council has a high national profile in the general media, within the industrial and environmental communities connected to water and sanitation and is a key member of the member of the EPA's Water Technology Cluster Leaders Committee.

According to Smilor et al. (1989) a successful cluster also needs many key supportive elements: the Milwaukee cluster has a strong network of champions and support organizations, it has support in critical areas from all scales of government, it has several large corporations willing to use their resources in a catalytic role to support and sustain the cluster, and it has access to the research and laboratories of several well-resourced and high-quality research universities. This public profile, supporting infrastructure and institutional framework can be considers strengths of the Milwaukee cluster; however, caution must be exercised in separating rhetoric from reality (Miner, 2010).

Utilizing Porter's Diamond Model (1990), Milwaukee's cluster is well endowed with basic factors, such as fresh water, advanced factors, such as large pool of highly skilled labor, and specialized factors such as the School of Freshwater Science and The Water Council which acts as the industry association. These advanced and specialized factors are a potential source of competitive advantage for both startups and existing firms and a strength of the Milwaukee Cluster. Milwaukee is well endowed with related and supporting industries - to include public utilities, water-intensive and water-enabled industries – to provide inputs and services to support the process of research, development and commercialization of water technologies, and mutual innovation and upgrading. The Milwaukee Metropolitan Sewerage District and regional utilities have been supportive of water technology firms in the testing, validating, and commercialization emerging technologies, and this collaboration is supportive of the process of mutual innovation and upgrading which is vital to protecting water quality and reducing water use. These relationships can be considered a strength of the Milwaukee cluster.

Effective demand and sophisticated and demanding buyers push firms to upgrade quality and become more competitive and no industry can survive without these pressures (Porter, 1990). The main demand for water technologies comes from utilities, and the main driver for innovation in the water technology industry comes from government's regulatory requirements for water quality and environmental protection. The environmental challenges of Milwaukee have helped to produce a network of knowledgeable and experienced water technology firms, public utilities, and public regulators which have a long history of collaboration and coordination. This home gown base of experience is a source strength for the cluster, and continuing demand for meeting environmental and public health requirements is an opportunity for the cluster to generate income and test emerging technologies in the local market. Like many other markets for water technologies, the absence of a sustainable model to finance capital projects and maintenance is a threat to the industry; while the length of time it takes to test, validate and approve technologies to meet regulatory requirements is a weakness which is especially hard on startups which often lack the knowledge and resources to survive this long and complex process. The presence of The Water Council, which seems to have fund a sustainable business model, is a strength as this well-established and experienced industry association is ideally positioned to support the industry in this regard.

Local industry rivalry among water technology firms in Milwaukee is limited as firms within the region tend to produce heterogeneous products; however, when taken at the national or global scale there is considerable competitive pressure and customers have the option to source technologies from all over the globe. Multi-national firms like Veoila have the technical expertise and networks to bring technology to

Milwaukee and, conversely, to take Milwaukee's technology to the world. The absence of intense local rivalry is a potential weakness of the Cluster; however, the presence of national and global rivals should reduce this problem. Finally, the state is a key player in Milwaukee's water technology industry: it provides grants and seed capital to support startups and research, it sets regulatory standards, and it is the major customer for water technology through its water utilities. The Milwaukee water technology innovation cluster emerged because of spontaneous generation; however, it was supported through a process of external intervention by governments at all scales and the local research universities. The continued support of The Water Council by a cross-section of public and private collaborators must continue if the Milwaukee cluster is to shift from being a growing to a mature cluster (Brusco, 1990; Porter, 1990). The Water Council must remain vigilant and continue its aggressive marketing and public relations efforts as it still has a long way to go before the Milwaukee cluster reaches maturity (Gallagher, 2014).

CHAPTER 7

WATER TECHNOLOGY CLUSTER IN TACOMA, USA

I. Introduction

This case study examines Urban Clean Water Technology Zone, which is the water technology innovation cluster based in Tacoma, Washington. The City of Tacoma, and its neighboring communities, lies at the southernmost end of the Puget Sound and borders a body of water known as Commencement Bay; the region is the home to more than 800,000 people and 38 miles of waterfront; it is a highly desirable area to live and work and play; the juxtaposition of industrial, agricultural, commercial, residential and recreational land in an environmentally complex and fragile region has produced a major challenge for sustainable urban and environmental management; but Tacoma has been working to turn this challenge into a track record of environmental and commercial success. Tacoma is seeking to emerge as an important city in new global water economy by capitalizing on its decades long struggle to find a balance between the sustainable management of water resources, the protection of the natural environment, and the promotion of economic development; and a collection of both public and private partners are packaging their innovative environmental and technological achievements to compete in the global market for clean and green technologies. This case study will show that Tacoma's water technology innovation cluster is not as advanced, from a private sector-industrial perspective, as either Milwaukee or Cincinnati; however, it the case will outline that Tacoma is part of a larger struggle to restore the natural ecology of the Puget Sound, after a Century of unregulated exploitation, and that this struggle has allowed key water-sector stakeholders to accumulated considerable experience in the science of estuary ecology, in the practice of estuary protection, and in the planning and implementation of low-impact urban development.

This case study will begin by providing an overview of the economic history and ecology of the Puget Sound because this sets the context for the water economy of the region and eventual emergence of the Urban Clean Water Technology Zone in Tacoma. The case goes on to examine the State's Innovation Partnership Zones (IPZ) program in general and the IPZ in Tacoma in particular. The IPZ in Tacoma is the framework under which public and private partners are attempting to build a water technology innovation cluster in Tacoma. A small sample of emerging water technology firms will be briefly examined to see how local innovators and entrepreneurs are attempting to exploit or create opportunities. Supporting the work of the IPZ is the Center for Urban Waters which houses a number of key organizations - the Puget Sound Partnership, the City of Tacoma Environmental Services Unit, and the University of Washington Tacoma – which are all engaged is the science and practice of restoring and maintaining the ecological health of the Sound, in developing innovative and commercially viable technologies to assist this process, and in building an environmentally sustainable and competitive economical in the region. Several key stakeholders from the Tacoma cluster were interviewed: Jim Parvey and Geoff Coffman of the City of Tacoma Environmental Services Division, and Cathy Cochrane of the Puget Sound Partnership. The case will conclude with an examination of the level of development and competitiveness of this cluster using Porters Diamond Model which looks at the determinants of factor conditions, any related and supporting industries, demand conditions, firm strategy and structure and rivalry, and the role of government and chance events. The interaction of the four determinants in the unique context of Tacoma's water economy, and particularly the role of the government at all political scales, offers insights into the challenges this technology cluster faces to position itself as an innovative and competitive industry both nationally and globally.

II. Economic History and Ecology of the Puget Sound

A. Economic History

Water has historically been central to the economic, social and political life of Puget Sound going back thousands of years to the arrival of the first humans in the region and all the way up to the present day. Successive waves of humans have extracted food and other resources from the waters of the Sound, or put its waters to use by collecting, storing, or moving it. The archaeological evidence suggests that economic and social organization of Native Americans in the Puget Sound region of the state evolved from hunter-fisher-gatherer societies, to a network of permanent villages which relied on the high productivity of the natural resources specific to the region, to improvements in technologies for fishing, hunting, and food storage, and on increasing social complexity and organization, which together supported tens of thousands of people in flourishing material and artistic cultures and an economy of abundance (Kruckeberg, 1991; Batker et al., 2008). The European historical record begins in 1792 with the arrival of the British explorer Captain George Vancouver, who found a region peopled by about 50 named tribes, all sharing a common language and a similar culture, living on or near to rivers, lakes or to the Puget Sound itself, for whom water was their primary means of transportation, and water-based ecosystems a key economic resource. European explorers, trappers, hunters and traders arrived in Washington state via ship or the Oregon Trail during the early 19th century, attracted by sea otter and beaver; later in the mid-to-late 19th century logging, fueled by the California Gold Rush, became a focal point of economic activity; while in the late 19th century railroads increased the rate of European settlement and, when combined with mechanization, the rate of extraction of the Sound's natural resources (Batker et al., 2008; Quinn, 2010). The resource-based economy of the sound reached its peak of extraction and exploitation during the first half of the 20th century; during and immediately after World War II, the economy shifted towards industry; while by the end of the century the economy would gradually become increasingly diversified, shifting towards services, with the waters of the Puget Sound and its adjacent forests increasingly valued as an amenity with aesthetic and recreational value.

Washington State has a diverse and advanced economy focusing on the aerospace, information and communication technology, agriculture and food processing, clean technology, forest products, life science and health, maritime and logistics, and military and defense sectors; and the state government is committed to strengthening these sectors by supporting innovation and entrepreneurship to create a climate for an innovation-driven economy (Washington State Department of Commerce, n.d.). Although the economy of Washington State in general, and of the Puget Sound region in particular, is best known for high-tech industrial firms, such as Microsoft and Boeing, and high-end service firms, such as Starbucks, much of the economy is still intimately linked to water

(Batker et al., 2008). The state is the country's largest producer of hydro-power, which accounts for three-fourths of the electricity produced in this state; it is one of the country's largest agricultural producers, which would not be possible without irrigation water which makes much of eastern Washington's agriculture possible; it is the fourth largest exporting state in the country, with the ports in the Puget Sound handling 8% of all American exports and 6% of its imports; and tourism and recreation, mainly centered around water, are major contributors to the economy and to the high level of employment in the leisure and hospitality sector (Washington State Department of Commerce, n.d.; Cargill, 2016; Briceno & Schundler, 2015; BLS, 2017). Within the high-technology sector is the high-priority and growing clean technology sector, where more than 100 firms provide technologies and related production processes, services, and products related to water (Washington State Department of Commerce, n.d.; Batker et al., 2008).

The economy of the Puget Sound is ultimately built upon the land, waters, and other natural resources of the region; the economic value of the natural environment extends far beyond what is traditionally extracted and traded in formal markets; and all economies are built on a foundation of natural, built, human and financial capital which in combination produce the goods and services that satisfy human needs and wants (Batker et al., 2008). The natural capital of the Puget Sound includes the forests, wetlands, lakes, rivers, and shorelines of the region and they produce economically valuable goods and services such as natural goods – which include fish, timber, water, and agricultural products – and ecosystem services – which include flood protection, drinking water, waste absorption, climate stability, recreation, and aesthetic value (Batker et al., 2008). The natural capital of the Puget Sound are tremendously valuable economic assets which sustain livelihoods, while the ecosystem services which nature provides for free and in perpetuity sustains a high quality of life and public health more efficiently and effectively than would the built capital that would be used as a substitute (Batker et al., 2008). Unlike natural capital, which is self-maintaining and requires minimum investment, built capital, such as levees to replace natural flood protection, is often expensive to build, requires maintenance, depreciates, and often alters the functioning of natural ecosystems in devastating and unpredictable ways (Batker et al., 2008). Historically economic development has favored built capital; however, all forms of capital are required for development and sustaining a high quality of life. Given that human development is a necessity, and the fact that some natural assets like biodiversity cannot be replaced by infrastructure, natural capital and built capital are most often productively used as complements rather than substitutes.

All built capital is derived from natural capital, and natural systems provide a foundation of natural assets and ecosystem services upon which every economy depends. Every resident of the Puget Sound basin directly receives a flow of benefits from the natural assets of the Puget Sound; and while the natural goods of the Sound that are exploited receive a positive economic value, the economically valuable ecosystem services of the Sound have historically been given an economic value of zero and do not show up in national economic accounts (Batker et al., 2008). Historically, the natural resources of the Puget Sound were considered virtually limitless, requiring little human input for its exploitation, and thus void of economic value. The result was overuse and abuse of the Sound's natural assets; and this approach to resource exploitation must also be considered in conjunction with the significant increase in human development in the

Puget Sound region in the last two centuries which has exceeded the absorptive and regenerative capacity of the region's natural ecosystems. The failure to place any value on ecosystem services, and particularly to properly value water, leads to poor decision-making about where and how to develop land and infrastructure, where and how to procure water for drinking and irrigation, how to manage wastes and abate pollution, how much pollution is tolerable, how to manage flood waters and droughts, and how much to invest in restoring and protecting the environment (Batker et al., 2008; ECY, n.d.). The loss or degradation of natural capital has resulted in damage to human health due to air, water and soil pollution; it has resulted in losses to the economy from the increasing need to treat degraded fresh water and develop storm water and flood control systems, due to the loss of natural flood protection and water purification from watersheds; and it has resulted in rising costs to protect endangered species and habitats, restore natural habitats, and re-mediate the impacts from climate change, due to pollution runoff and the altering of about one-third of the Sound's shorelines (Batker et al., 2008; ECY, n.d).

Natural ecosystems in the Puget Sound have been lost and degraded over the past century, and they continue to be pressured by a combination of population growth, urbanization, and land use practices that increase the area of hard surfaces covering the land, cause losses of habitat, put pressures on fresh water supplies, and pollutes the water and air of the region (Batker et al., 2008; ECY, n.d). When the ecosystem services provided by natural assets are replaced by the services offered by built capital, these human infrastructural solutions often provide fewer and far less reliable benefits, at a greater economic and environmental cost, than the natural systems they replace (Batker et al., 2008; ECY, n.d). Although the methods used to determine the economic value of natural assets and ecosystem services is inexact and subjective, this does not negate the value of putting a value on these assets. It is now widely accepted in the world of business that the economic value placed on intangibles assets - such as propriety knowledge and intellectual property - is now a greater proportion of the total value of most businesses than traditional assets - such as machinery and equipment - and the creation and management of intangible assets is a strategic endeavor that is a necessary ingredient to building competitive advantage and ensuring long-term business success (Low & Kalafut, 2002; Hubbard, 2014). The same principle can be applied to natural capital. Estimates of the annual economic benefit that the ecosystems of the Puget Sound provides to residents of the region range from a low of $7.4 billion to a high of $61.7 billion, depending on the methodology used; the asset value of all the natural capital of the Puget Sound region range from a low of $243 billion to a high of $2.1 trillion; and the annual savings to Tacoma ratepayers from the natural filtering of the city's water supply by forests, compared to the capital and operating costs of additional water filtration infrastructure, is estimated at approximately $150 million (Batker et al., 2008). The reality that must be accepted by all stakeholders in the Puget Sound is that economies and natural systems are both essential parts of a larger, complex, integrated system that must be managed with these relationships in mind; and that natural capital and natural systems are an essential complement to built-capital, and together determines people's quality of life in the Sound.

B. Ecology of the Puget Sound

Natural capital is a necessary condition for both economic development and a high quality of life. The Puget Sound region has a thriving and advanced regional economy, its citizens have a high quality of life, and they live in one of the most environmentally desirable locations in the world. The Puget Sound is the second largest estuary in the United States, after the Chesapeake Bay; it is approximately 16,000 square miles, of which 80% is land and 20% is water; it is an extension of the Pacific Ocean that extends inland where is meets 19 different river basins which are drained by more than 10,000 streams and rivers; it experiences significant tidal flows, which reach a maximum of 14.4 feet at Olympia; its waters consist of a changing mixture of fresh and salt waters, whose unique combination of temperature, salinity and circulation is important to local aquatic life; and it has about 1,800 miles of shoreline which surround an estuary of about 1,020 square miles, which is a mosaic of beaches, bluffs, deltas, mudflats and wetlands (Batker et al., 2008; Quinn, 2010; ECY, n.d). The varying topography and geology of the Puget Sound region creates highly variable local-scale climate which, in combination with diverse soil types, results in a wide variety of environmental and ecological conditions which supports high levels of biodiversity and other important biological phenomena (Batker et al., 2008; Quinn, 2010; ECY, n.d).

The calm, nutrient rich waters of estuaries allow many plant and animal species thrive, and to support many food webs; estuaries are traditionally and historically excellent sites for human communities because their waters, wetlands and flood plains provide a rich source of wild game and allow for the development of irrigation and agriculture; and their geography provides protection against flooding and erosion (National Geographic, n.d.). The unique ecology and environment of the Puget Sound makes its waters one of the most productive salmon, oyster, and clam fisheries in North America (Puget Sound Action Team, 2007); its terrestrial landscape, particularly at higher elevations, is one of the most productive coniferous forests in the world; while between the forests, particularly at lower elevations, are a diverse range of ecosystems from prairie, to woodlands, to wetlands and bogs (Batker et al., 2008; Quinn, 2010; ECY, n.d). The hydrologic and geographic features that make the region desirable from an economic and residential perspective also mean that estuaries are particularly susceptible to pollution which accumulates in the water, sediment, flora and fauna of the estuary (National Geographic, n.d.). Unlike Chesapeake Bay which has a relatively flat bottom, the Puget Sound's shallow bays and inlets transition to a series of underwater deep valleys and high ridges, called basins and sills, where it takes approximately 5 months to completely exchange Puget Sound water with Pacific Ocean water. (Batker et al., 2008; Quinn, 2010; ECY, n.d).

The complex ecology of the region means that the relationship between water, human development, and the health of the Puget Sound is especially strong. The Sound has suffered serious environmental degradation due to the substantial modification of its shoreline, and the pattern and nature of coastal land use, resulting originally from the development of major ports and industries, and more recently from residential development (Batker et al., 2008; Quinn, 2010; ECY, n.d). In the past half century, it has become increasingly recognized that the Puget Sound's ecological integrity is threatened by a combination of habitat loss or damage, which some estimates put as high as 70%, species decline, and degraded water quality and quantity (Batker et al., 2008). The degradation results from a combination of the following: over-appropriation of many of the region's watersheds, with approximately one-quarter having insufficient water to supply granted water rights, support aquatic fauna, and maintain water quality; the modification of about one-third of the shoreline by artificial structures; the legacy of point sources of water pollution, which remains a threat to the environment even after being effectively controlled by new technologies and regulations; non-point sources of pollution, especially storm-water and new classes of chemicals which collect on paved surfaces to be channeled into storm-drains, and failing residential septic tanks which are emerging as the major threat to water quality and the health of natural ecosystems; and the fact that all the major cities, many of the towns, and most of the heavy industry of this region, are located at river deltas or along the shores of Puget Sound (Batker et al., 2008; Quinn, 2010; ECY, n.d).

The environmental decline of the Sound worsened during the 20th century, despite efforts at every scale of government to address the problem from at least the middle of the last century, and despite increasing recognition during the 1960s and 1970s of the extent of the problem, its causes, and consequences (Puget Sound Water Quality Action Team, 2000). By 1985, when the Puget Sound Water Quality Authority was established to replace the Pollution Control Commission, there was general agreement among key stakeholders that better coordination among programs would improve the effectiveness and efficiency of programs to improve the health of the Sound; and in 1987 the first Puget Sound Water Quality Management Plan was prepared by the Authority, which was also responsible for its implementation (Puget Sound Water Quality Action Team, 2000). Updates to this plan were issued in 1989, 1991, 1994 and 1996 in response to evolving public policy from the national level, emerging environmental issues, changing public priorities, and the addition of new programs and projects and the completion of others (Puget Sound Water Quality Action Team, 2000). Some of the national drivers include the

1987 establishment by Congress of the National Estuary Program as Section 320 of the Clean Water Act; and the 1991 approval by the EPA of the Puget Sound Water Quality Management Plan as the federal Comprehensive Conservation and Management Plan for the basin; in 1991. Because of species decline, there have been changes to the fishery practices, and an increase in petitioning to add species to the Endangered Species Act (ESA) (Puget Sound Water Quality Action Team, 2000).

III. Land-use Patterns and Demographics of the Puget Sound

A. Land-use Patterns

The Puget Sound in Washington State is a deep fjord estuary considered to be the largest by volume in the United States, outside possibly unexplored estuaries in Alaska. It is one of a network of 29 estuaries across the country that forms the National Estuarine Research Reserve System (NOAA, 2017). The Puget Sound is located within the broader Salish Sea, which in 2009 was the name given to identify the waters of the Strait of Georgia, the Strait of Juan de Fuca, and the Puget Sound which are shared between the United States and Canada. This deep, vast, complex, and delicate saltwater ecosystem was carved by receding glaciers more than 10,000 years ago and varies in its physical, chemical, and biological properties. The typical estuary forms a transition zone between river and maritime environments; their water is a changing mixture of fresh and salt water; they serve as natural filters for runoff; they provide food, breeding grounds, and migration stopovers for many species of birds, fish, and other animals; they provide food, recreation, jobs, and coastal protection for humans; and of the 32 largest cities in the world, 22 are located on estuaries (NOAA, 2017).

The Puget Sound also encompasses the mountains, farmlands, cities, rivers, streams, forests, and wetlands contained in a watershed that drain into this estuary and that impact the quality of its waters and the health of the ecosystem. Humans have long relied on the Puget Sound watershed for a range of economic, recreational, and ecological services. The Puget Sound supports a large part of the economy of Washington state and provides vital recreational, spiritual, and other essential quality of life benefits; however, over the past century, as the number of urban centers have reached 110 and the regional population living on its banks has soared to 4.5 million people, the Puget Sound has suffered severe ecological damage which threatens public and environmental health and the economy of the region. By some estimates the Puget Sound has lost approximately 70 percent of its original estuaries and wetlands, thousands of acres of the Sound's floor are covered with contaminated sediment, the Orca population has decline by 50%, some salmon populations have declined by as much as 90%, and populations of some seabirds have declined by as much as 95% (Seattle Audubon, 2017). The challenge facing the Puget Sound region is to protect and restore the estuary in spite of a growing human population which is bringing with it more land development, more infrastructure, and more pollution; and also, in the face of the potential threat of climate change which is bringing with it warmer streams and ocean waters, a reduced snow-pack, more extreme weather events, and increased propensity for fires and floods.

The Puget Sound's history of European colonization, the incorporation of the Oregon-Washington Territory into the United States, and the inclusion of the Washington State economy into the national and global capitalist system has had a profound effect on land use patterns, industrialization and urban development, and by extension of the ecological state of the Sound. The structure and role of government institutions and institutions of governance, both public and private, are of critical importance to solving social, economic, and environmental problems. These institutions need to be at the scale of the issue or problem they are intended to address and be provided with sufficient powers and resources to achieve their mission (Ostrom, 1990).

The first European settlement in the region was established in 1846 at New Market, near present-day Olympia, when Washington was still part of the Oregon territory; in 1853, the Washington Territory was formed as a separate entity from the northern part of the Oregon Territory; and in 1889 Washington achieved statehood within the Union. Between these years, the pattern of development that emerged in the Washington territory followed a very different path from elsewhere in the Pacific Northwest, with different philosophies emerging for property rights, land-use, and industrial development (Quinn, 2010). Oregon was founded largely by farmers while Washington was founded largely by those who would exploit the natural environment through trapping, hunting, fishing, and logging; and these activities in time gave rise to sawmills, ports and railways which changed the physical landscape and ecology of the region (Quinn, 2010). The constitutions which the state adopted thus favored local power over central government, favored private property over public or communal rights, and supported the exploitation of natural resources as the economic engine of the region, a legacy which remains to this day and which some argue makes protecting and restoring the Sound more difficult (Quinn, 2010). Although the era of unrestrained exploitation of the resources of the Sound has long since come to an end, the legacy of that exploitation remains and new environmental pressures from new economic and urban development are arising (Quinn, 2010; PSRC, 2016).

B. Demographics

The Puget Sound Basin contains 4.5 million people, which currently represents approximately two-thirds of Washington State's entire population, which is more than double its 1960 population of 1.8 million and quadruple its population of 1950. According to the Puget Sound Regional Council (PSRC), a board that plans for growth in the four central counties of the area, another one million people will live in the state by 2025 with most of that increase in the Puget Sound (PSRC, 2016). The Puget sounds is also one of the most vibrant regional economies in the world, and this is also expected to continue to grow rapidly in the coming decades (PSRC, 2016). In the face of these demographic and economic pressures, the government of Washington State and other entities are responding to the challenges of protecting and restoring the Sound, with the two most important programs being the Puget Sound Nearshore Restoration Project - a joint effort sponsored by the Washington Department of Fish and Wildlife and U.S. Army Corps of Engineers - and the Puget Sound Partnership - a relatively new state agency which works closely with the Environmental Protection Agency. The Partnership is designed to operate at the correct governance scale for protecting and restoring Puget Sound (Puget Sound Partnership, 2012).

IV. Governance of Puget Sound Water Resources

A. Growth Management

The Growth Management Act (GMA) of 1990 is a series of statutes that requires local governments to plan, coordinate and manage growth in Washington state, while protecting natural resources and public interests (PSRC, 2016). The GMA was passed by the Washington State Legislature because policy makers came to recognize that uncoordinated and unplanned growth posed a threat to the environment, sustainable economic development, and the quality of life in the state. The GMA requires local governments to develop long-term comprehensive plans for land use in their jurisdictions, to identify and protect critical natural areas and natural resource lands, to designate urban growth areas, to prepare comprehensive plans, to implement these plans through capital investments and development regulations, and to coordinate these plans with surrounding counties (PSRC, 2016). The GMA establishes state goals, sets deadlines for compliance, offers direction on how to prepare local comprehensive plans and regulations, and sets out requirements for early and continuous public participation in the planning process; however, the GMA continues the state's tradition of local control, it emphasizes local decision-making and implementation over centralized planning, and it gives discretion regarding the specific content of comprehensive plans and implementing development regulations (Laschever, 1998). Since its passage, the GMA has slowly, but significantly, changed the process used in Washington State to plan for and manage growth and protect critical natural areas (Laschever, 1998).

B. Washington State's Innovation Partnership Zones Program

One public policy initiative that has the potential to directly impact the water technology industry, and to indirectly impact the ecology of the Puget Sound, is the Innovation Partnership Zones (IPZ) program. The IPZ program was created in 2007 by Governor Gregoire, the Washington State Legislature, and the Washington State Department of Commerce (DOC). The DOC, the state agency charged with enhancing and promoting sustainable communities and economic vitality, was assigned as the lead state agency on this program. The goal of this program was to stimulate the growth of industry clusters, catalyzed regional innovation, and build regional economies, in both traditional industries – such as aerospace and agriculture – and in emerging industries – such as clean water and energy, and biotechnology; the mission was to encourage - through decentralized and organic initiatives - bottom-up collaboration among regional partners to advance innovation; while the strategy was to create an economic development model that would, in a 5 to 10 year period, support the building of regional organizational capacity that could better coordinate fragmented federal, state, and local economic development initiatives (Green, Woodson & Zerr, 2016). IPZs empower regions to form partnerships between public and private sector partners, academic and research institutions, and workforce education and training entities, to develop patentable ideas and commercially viable technologies, address the regional economic challenges, and grow firms and jobs (Green, Woodson & Zerr, 2016). Each IPZ focuses on a different area - which is usually linked to the geography, local assets, and local economy of the region - and all have one or more institutions of higher education, which serve either as anchors or key cluster institutions, and a local government partner (Green, Woodson & Zerr, 2016).

Initially, in 2007, the Department of Commerce designated 11 IPZs around the state and allocated to the program $5 million in capital grants that were distributed to five of the IPZs on a competitive basis. In 2009 a 12th IPZ was designated by the DOC and an additional $1.5 million in capital grants distributed to the program. In 2012, six of the IPZs received $13.52 in grants; however, in the 2013-2015 period, the Washington State legislature reduced and eventually eliminated funding for IPZs, but kept statutory obligations related to them, including tracking and reporting of metrics for private investment, patents filed, and jobs created (Green, Woodson & Zerr, 2016). Given that grants were competitive, not all IPZs received state capital grant funding; grants were not meant to be sufficient to fully fund any IPZs budget, and IPZs must find other sources of funding to meet or supplement their operating budgets. Many IPZs have used grant money to leverage private sources, obtaining money from local jurisdictions and the federal government. Some have formed 501(c)3 non-profit organizations and identified partners for fund-raising purposes. The largest award made to an IPZ by Washington State was $5 million which went to a project to build a new wine research and education facility at the Tri-Cities Research Zone of Washington State University-Tri-Cities; $3.67 million was awarded to the Walla Walla Valley IPZ to address a shortage of technicians to maintain the area's 5,000 wind turbines; $3.6 million was awarded for three new labs for Tacoma's Urban Clean Water Technology Zone; $750,000 was awarded to the Grays Harbor IPZ for the Coastal Innovation Zone R&D Business Incubator Facility; and finally $500,000 was awarded to the Bothell Biomedical Manufacturing IPZ to help design a new incubator space for companies that develop biomedical devices (Sokolowsky, 2012).

The designation and re-designation of IPZs occur in each odd calendar year, but once granted a designation lasts for four years before a designee must reapply. To qualify for designation, applicants must put together a collaborative team consisting at a minimum of a university research partner, a workforce training provider, and a globally competitive cluster or company who are all in close geographic proximity and are capable of planning and executing a cooperative, regionally located, research-based effort that will lead to new and commercially viable products and create jobs. The IPZ must also identify an individual or organization to be a Zone Administrator which must be an economic development council, port, workforce development council, city or county. The Zone Administrator has often been the driving force behind the IPZ but in some instances this key driver has come from industry or academia. In 2009 there were 12 IPZs; in 2011 four new IPZs were designated while one IPZ did not receive re-designation, giving a total of 15 IPZs; in 2013 three more were added, bringing the total number to 18 statewide; in 2015 two new IPZs were designated while six IPZs did not receive re-designation, giving a total of 14 IPZs which remains the case as of 2017 (Green, Woodson & Zerr, 2016; Department of Commerce, 2017). The success of this program has been mixed: many were, and still are, hampered by a lack of funding and the absence of a sustainable business model; a lack of grant writers and other in-house expertise, with many staff working part-time; and the lack of a standardized set of metrics for reporting activities meant that there was little consistency in the presentation of data in submitted reports, making it is difficult to demonstrate whether or not IPZs affect the growth of a targeted cluster or the region in which it operates (Green, Woodson & Zerr, 2016; Department of Commerce, 2017). The IPZ's stated goals include recruiting, retaining and expanding organizations, businesses and jobs. While the zone has obtained grants for research projects, equipment and facilities, actual economic development has been slower to materialize.

Despite the lack of funding and human resources to build and sustain IPZs, the administrators and partners in some regions reported that the IPZ designation had benefits: the IPZ designation increases the economic profile of the region and assists with branding and promoting their clusters; the IPZs provides a useful conceptual framework for building industry cluster strengths; the IPZs could be structured and resourced to function as small business incubators, providing shared access to office and laboratory space, research and development laboratories and facilities, expert advice, training opportunities, and administrative and business services (Elliott, Mitchell & Salmi, 2010; Wallen, Cohen, Nickell & Salmi, 2012; Trimarco, Woodson, & Zerr, 2014; Green, Woodson, & Zerr, 2016). One of the architects of the IPZ program, Egils Milbergs, stated that successful innovation clusters require a combination of “hard” infrastructure – such as physical transportation, telecommunications, water and energy systems, universities and research facilities, and factories - and “soft” infrastructure – such as human capital, culture, and institutions that cultivate and sustain “hard infrastructure. In developing Washington's IPZs Milbergs identifies four important factors that make up the “soft infrastructure” necessary to launch and sustain an innovation cluster: (1) business leadership, which is critical for mobilizing and sustaining support; (2) strategy, which is a shared road-map with genuine buy-in from multiple stakeholders and the key performance indicators which drive it; (3) governance, which provides a structure to integrate leadership and strategy to grow and evolve the cluster; and (4) culture, which creates and sustains the spirit of collaboration (Stroo, 2014). The “soft” infrastructure working together is often the necessary conditions to support nascent or emerging businesses through their most difficult startup years; and the IPZs are a public policy attempt to nurture “soft” infrastructure.

C. Tacoma Urban Clean Water Technology IPZ

In 2012 the city of Tacoma launched the Urban Clean Water Technology Innovation Partnership Zone (IPZ). This IPZ is the latest chapter in Tacoma's long history where water, economic development, and pollution intersect. Tacoma underwent a long economic boom from the late 19th Century when it became the western terminus of the Northern Pacific Railroad; and today it is the largest port in Washington state and a major logistic gateway to the Pacific (Barringer, 2014). In 1981 the *New York Times* reported that the Federal Environmental Protection Agency (EPA) had named Tacoma's Commencement Bay as one of the 10 worst toxic waste sites in the country out of a list of 144; and it noted that the city was engaged in a clean-up effort of the Sound for pollutants that had been discharged into its waters mainly between the 1940s and 70s (Turner, 1981). Since then there have been calls for a comprehensive and coordinated approach to reducing pollution flowing into the Sound and cleaning up the environmental damage (Turner, 1981); and despite expensive efforts to reduce pollution and carry out remediation of the environment, the people of Tacoma still live with the environmental and health consequences of past industrial pollution, combined with new pollution for storm-water, new chemicals, pesticides from lawns and farms, and pharmaceuticals from leaking septic tanks (Barringer, 2014; Wong, 2015; Dunagan, 2016). Increasingly, poor air and water quality have come to be seen by many in Tacoma as a threat to sustainable economic development, not just public and environmental health, as both businesses and people are increasingly attracted to healthy and clean local environments (Forster, 2014). In Tacoma, the IPZ has helped brand the city and county as a world leader in clean water in urban settings; and the IPZ is seen by many stakeholders as the best strategy for commercializing water technologies, forming new technology firms, and creating new jobs. In 2014, the *New York Times* noted that Tacoma's expertise in storm-water was being studied by officials from countries such as Brazil, Thailand, Italy and Russia (Barringer,

2014).

1. Vision, Mission, Goal & Objectives of Tacoma's IPZ. The vision of the Tacoma Urban Clean Water Technology IPZ is to enhance the economic and environmental future of Tacoma by leveraging decades of local experience and technical capability in storm-water management, pollution control, and environmental remediation that has accumulated in the local government, universities, and technology companies of the Puget Sound (J. Parvey, personal correspondence, July 20, 2017). The leveraging of experience would in turn support the development of globally competitive, research-based, urban clean water technologies (City of Tacoma, 2011, 2015; Trimarco et al., 2014; Green et al., 2016). The mission of the Tacoma IPZ, as laid out in its 2011-14 and 2015-19 business plans, is to accelerate the development of a globally competitive, research-based urban clean water cluster to strengthen the local economy of Tacoma and Pierce Counties through the creation of new firms, the expansion of existing firms, and creation of high-paying jobs (City of Tacoma, 2011, 2015). The IPZ laid out three goals which were expanded upon in the objectives of the 2011 and 2015 business plans: (1) retain and expand existing businesses and organizations; (2) recruit and attract businesses and organizations that enhance the value of the cluster; and (3) expand networking opportunities that increase the cluster's global profile.

In its 2011 business plan, the Tacoma IPZ lays out three key objectives: (1) business and job retention and expansion; (2) build a membership that enhances the cluster long-term value; and (3) raise the cluster's national and global profile through networking and knowledge sharing opportunities (City of Tacoma 2015). In its 2015 business plan it added several more objectives: (1) increase investments in key public assets; (2) update and expand the database of regional clean water businesses; (3) increase the talent base of water expertise through both recruitment and training; (4) establish at least one cooperative agreement between UW Tacoma and a local firm; (5) undertake a commercialization study by 2017 to identify additional business applications for local clean water research; and (5) develop a sustainable source of financing for the IPZ (City of Tacoma, 2015). Despite the challenges facing the Tacoma IPZ, there is the belief that this cluster can spur innovation and facilitate and accelerate the development and commercialization of new water technologies that can help to position Tacoma in the new high-technology, clean and green economy.

2. Structure, Leadership & Strategy of Tacoma's IPZ. The Tacoma IPZ is an economic development partnership that involves educational institutions, research laboratories, public economic development organizations, local governments, and workforce training organizations within Tacoma–Pierce County. Each partner has made a commitment to providing the human and material resources necessary for the Urban Clean Water Technology IPZ to be successful (City of Tacoma, 2011, 2015). The City of Tacoma acts as the Zone Administrator and is responsible for coordination, management and administration of the IPZ (J. Parvey, personal correspondence, July 20, 2017). The University of Washington Tacoma, the primary research partner, is responsible for providing staff, programs, and facilities to support research and training. The Port of Tacoma, as owner of substantial to real estate, provides commercial space to partners and investors, and works with partners in identifying and solving the Sound's environmental problems. The Economic Development Board for Tacoma-Pierce County is responsible for managing the collection of data regarding performance of the IPZ and recruiting new businesses for the cluster. The Tacoma Community College serves as the lead for workforce development and corporate training for the IPZ. The Institute for Environmental Research and Education serves as a resource providing consulting and evaluation services; the University of Washington Puyallup, which provides expertise in storm-water research. GeoEngineer, a technology firm specializing in earth science and engineering consulting services related to the natural or built environment. Finally, Parametrix, a private company providing engineering, planning, and environmental solutions to restore natural habitats and address infrastructure needs (City of Tacoma, 2011, 2015). Public sector agencies and academic institutions provide most of the staffing and operational support for the Tacoma IPZ (City of Tacoma, 2011, 2015; Trimarco et al., 2014; Green et al., 2016).

Leaders at the highest levels of these organizations have been engaged in crafting a strategy for growing the cluster, building on the community’s assets and achieving the vision and mission. The City Manager of the City of Tacoma, or his designee, acts as the zone administrator and fiscal agent . The Administrator oversees the promotion of best waste and storm-water management practices (J. Parvey, personal correspondence, July 20, 2017). The Chancellor of the University of Washington Tacoma (UWT) takes the lead in hosting workshops and establishing new graduate programs. The Science Director at the Center for Urban Waters, a professor from UWT, is lead researcher and collaborator, and assists in securing funding and database expansion. The Commissioner of the Port of Tacoma oversees the commitment to protecting waterways, assists with planning conferences, and brings private sector members to partner with the IPZ. The President and CEO of the Tacoma-Pierce County Economic Development Board leads business recruitment and database expansion and assists with planning conference and the commercialization study. The President of the Tacoma Community College leads workforce development and corporate training. The Chair of the Board and Executive Director for the Institute for Environmental Research and Education provides environmental evaluations for city, port and private businesses. Jeff Peacock, President & CEO of Parametrix is liaison to the private sector and a private sector adviser to the IPZ. Finally, the Director of the WSU Puyallup Research and Extension Center assists with planning conferences, works with partners to establish new graduate programs, and helps to secure funding for the IPZ. There has been considerable continuity among the leadership team of the IPZ between 2012-2017, with the only changes being the Zone Administrator, the Chancellor of UWT, and the President of the Tacoma Community College (City of Tacoma, 2011, 2015).

V. Water Innovation Technology Firms

Washington State is home to several water technology firms that are leading a wave of innovation in the water industry through the research, development and commercialization of water technologies. Some water technology firms are well established – such as older companies like the award winning Romac Industries of Bothell which makes water valves and couplings, Nelson Irrigation of Walla Walla which designs, develops, manufactures, and sells water devices for agricultural, environmental, and industrial applications, Itron of Liberty Lake which is a technology and service company that provides solutions that measure, manage and analyze energy and water use, and Northwest Pipe of Vancouver which manufactures and markets welded steel pipe for water transmission. Other firms are emerging. The Seattle-based CleanTech Alliance Washington counts several water-tech businesses as members and organizes several fora to promote the potential of the water sector in the state. This suggests that the State is in the early stage of developing a viable water innovation technology cluster but that more time, energy and resources are required to turn a nascent or emerging cluster into an established and sustainable cluster (Virgin, 2015). CleanTech Alliance is an industry association for businesses that represent all facets of clean technology; it consists of about 300 member organizations from six U.S. states and two Canadian provinces; and it is committed to growing the clean technology sector by supporting innovation and entrepreneurship through networking, business facilitation and incubation, policy advocacy, commercialization programs, and signature events that educate and enlighten and enhance commercial possibilities by connecting key stakeholders (CleanTech Alliance, 2017).

A sample of Washington's water technology firms provides a general picture of the industry landscape. First is WaterTectonics of Everett, Washington, just north of Seattle, which was founded in 1999 and in 2017 employed about 60 persons. WaterTectonics designs, manufactures, deploys and services integrated water treatment solutions for a global client base in oil and gas, mining, industrial and construction. Its technologies are designed to allow businesses to meet the demands of new and future environmental regulations. The company also claims to have a strong local market presence through its utilization by two-thirds of the construction projects in the Puget Sound region (WaterTectonics, 2017).

The startup HydroBee of Seattle, Washington was founded in 2013 and is a recent recipient of the Washington Manufacturing Awards. HydroBee designs micro-generators and charging systems whose power source can derive from water flows, wind, sun, fire, bicycles, and muscles. The technology can serve as a low-cost power source with multiple application, especially in remote places or in the Developing World where billions of people do not have access to public utilities (Bloomberg, 2017). HydroBee demonstrates the interconnected nature of high-technology industries and the difficulty in classifying them, because it can more correctly be classified as a renewable energy company. HydroBee, which designed its prototypes using 3-D printing, is currently attempting to scale up its manufacturing and marketing. In 2013 it unsuccessfully used Kickstarter, a global crowdfunding platform focused on creativity, to raise $48,000 in financing to support commercialization. It secured only $21,399 in pledges from 422 people (Kickstarter, 2017). HydroBee has been persisting and in 2014 Warren Evans of World Bank joined the company’s Board of Advisors. One of its designs won the Alaska Airlines Environmental Innovation Challenge and $20,000 in funding

(CleanTechAlliance, 2015a).

The startup Pure Stormwater of Silverdale, Washington, was founded in 2014 to solve what is now the one of the greatest sources of pollution of US waterways: stormwater. With financial support from the EPA, Pure Stormwater is developing a line of storm drain filtration basins to filter hydrocarbons, metals and other contaminants from storm-water before it enters the storm drain system and flows out into local bodies of water. The design uses a mix of textiles and natural fibers in filters inside stainless steel catch basins that will be installed in storm drains and the startup is in the process of applying for patents on the technology (Jerome, 2015). The principals of Pure Stormwater had tried, and failed, to partner in 2013 with a California-based company called Safe Drain International to develop and market a similar technology; however, they felt that they knew the needs of the market better and wanted to pursue a filtration system, with numerous points of interception of small quantities of contaminants, over a spill-containment system (Kelly, 2015).

Apana, a Bellingham-based water-use and waste-analytics firm is helping its clients save money and reduce their water footprint by reducing waste and improving the efficiency of water use (Virgin, 2015). Apana, which got its start as Hydro-Care International before becoming Kirkland Analytics, is a leader in automated water management systems that help clients make informed decisions by analyzing, operationalizing and accounting for water use. This saves water, reduces compliance risk, strengthens supply chains, and improves operational sustainability. Apana counts Issaquah-based retailer Costco Wholesale as a major client (CleanTechAlliance, 2015b).

A good example of the type of technology firm that exemplifies the emerging water technology industry is HaloSource, an award-winning clean water technology company based in Bothell, Washington, that provides innovative solutions to the 85 percent of the world who do not have access to a reliable supply of clean, safe drinking water. HaloSource has more than 10 million people in China, India and Latin America who use its proprietary technological solutions for water purification and contaminant adsorption that are adaptable to a wide range of point-of-use devices ranging from entry-level gravity systems to high-end pressurized systems (WaterWorld, 2010, 2012; Apfel, 2013; Miller, 2014). HaloSource vision has been to position itself as a world-leader in the growing multi-billion-dollar market for clean drinking water. Its mission is to solve complex clean water challenges; its evolving 15-year strategy has come to focus on its core strengths - which are as innovators in the chemistry of water purification, and integrators of multiple technologies to solve complex water challenges. The firm also leverages the strengths of leading multinational companies through partnerships to distribute HaloSource technologies to meet the needs of clients and be market-focused rather than technology-focused (WaterWorld, 2010, 2012; Apfel, 2013; Miller, 2014). HaloSource in many ways was ahead of the global fresh water crisis and had to wait for the market to evolve; but through its expertise, resources, and partnerships is in a position to rapidly respond to emerging water markets for purification and treatment (WaterWorld, 2010, 2012; Apfel, 2013; Miller, 2014). This reinforces the reality for many water technology firms that successful commercialization requires playing the long game.

HaloSource's technology focus is in three key sectors: (1) drinking water purification, (2) environmental water treatment and remediation, and (3) recreational water solutions. The global market for these three technologies is estimated at $16 billion, $3 billion and $23 billion respectively (WaterWorld, 2010, 2012; Apfel, 2013; Miller, 2014). Two of HaloSource's most innovative technologies are HaloPure Disinfectant, a novel contact biocide in the form of beads that bind to bacteria and viruses in water and kills them, and HaloPure Absorption, which is a novel composite engineered to selectively bind to contaminants such as lead, arsenic and fluoride. HaloSource is considered a key innovator in the residential drinking water market, supplying cutting-edge proprietary technology to household appliance makers and suppliers. HaloSource produces cartridges for several global partners who then take this class leading technology to market through their devices, channels and brands. HaloSource also recently entered the consumer market with two products, a water pitcher and water bottle marketed under the Astrea trade-marked brand, which uses the company's patented technology to remove 99.9 percent of bacteria, viruses, and heavy metals to ensure that the water is safe to drink (WaterWorld, 2010, 2012; Apfel, 2013; Miller, 2014). In 2012 HaloSource entered into a development and production agreement with Tupperware Brands Corporation, the U.S.-based direct selling company with a global sales force of 2.7 million, to provide HaloPure absorption technology in cartridges for Tupperware’s new line of gravity-based water purifiers that will be initially launched in India. This potentially is a huge market for low-cost home purification of drinking water (WaterWorld, 2012; Apfel, 2013; Miller, 2014).

HaloSource has had a successful track record of raising funds to expand operations, with $25 million raised in 2012 from the investment community through the London Stock Exchange; while in 2017 it secured $2.2 Million in funding to further accelerate its drinking water market presence (WaterWorld, 2012; Apfel, 2013). In 2009, HaloSource became the first drinking water technology in 30 years to have its technology registered by the United States Environmental Protection Agency (USEPA), widely recognized as having among the world's most stringent performance requirements for water purification. In 2010, its technologies were approved by China's Ministry of Health (MOH); in Brazil, where it has major market share through Pentair, HaloSource's technologies have met or exceeded all appropriate standards of the National Institute of Metrology, Standardization and Industrial Quality (INMETRO); and the company's portfolio of products also meets the rigorous standards of many state and local regulatory bodies, to include the Washington Department of Ecology (WaterWorld, 2010, 2012; Apfel, 2013; Miller, 2014).

VI. Center for Urban Waters

A. Vision, Goals, Mission, and Structure of Center for Urban Waters

The Center for Urban Waters in Tacoma is envisioned as a revolutionary focal point for research, policy and the real-life application of science and technologies to water and environment challenges (J. Parvey, personal correspondence, July 20, 2017; J. Coffman, personal correspondence, July 20, 2017). The Center achieves this by bringing together environmental scientists, engineers, and policymakers who are developing creative and sustainable solutions to restore and protect Tacoma and the Puget Sound; and it also does this by providing them with a collaborative environment where the best-available science and technologies can come together to form the basis for policy development and implementation (J. Coffman, personal correspondence, July 20, 2017). The Center for Urban Waters is the result of nearly a decade of work by a cross-section of community leaders who dreamed of a world-class research facility dedicated to finding solutions to the problems of urban living and its impact on the environment. The City of Tacoma is a community of about 800,000 residents to the south of Commencement Bay with large industrial, commercial, residential, and recreational areas, and 38 miles of waterfront. Tacoma and its surrounding region face both historic and ongoing environmental challenges that to date has represented an investment of more than $105 million in environmental cleanup, restoration, and mitigation (City of Tacoma, 2013a). The goal of the Center for Urban Waters is to serve all these sectors of the city by maintaining the quality of their water resources and the health of their natural environment (J. Parvey, personal correspondence, July 20, 2017; J. Coffman, personal correspondence, July 20, 2017). The efforts to establish a world-class, inter-disciplinary research and policy center, and to leverage the expertise of Tacoma in storm-water management and environmental remediation, led Water Online in 2014 to list Tacoma as one of twelve 'Water Technology Hot-Spots' in the United States (Martin, 2014).

In 2002, the City of Tacoma, the Port of Tacoma, the University of Washington Tacoma and business leaders met to outline a vision for the proposed center, to raise funds for a feasibility study, to establish an endowment to support a top-flight research facility for the University of Washington Tacoma, and labs and offices for the City of Tacoma’s Environmental Services Unit. In 2007, the City of Tacoma purchased former industrial land on the Thea Foss Waterway near Tacoma’s central business district; in early 2009 ground was broken for the facility; and in March 2010 staff began moving into the new building. The Center is housed in a 51,000-square-foot, $22 million, LEED Platinum building containing office and laboratory facilities that are designed to signal the commitment of the City of Tacoma to the water industry, and the application of science and technology to improving urban environmental outcomes (City of Tacoma 2013b). The Center, both in terms of governance and physical space, is designed to be flexible, adaptable and scaleable, so the research mission and the programs and projects that result can continue to evolve as new issues and opportunities arise (J. Coffman, personal correspondence, July 20, 2017).

The current tenants are the City of Tacoma, the University of Washington Tacoma, and the Puget Sound Partnership and together they work to address urban environmental issues through a process of applied research, policy analysis and development, and programs and projects for environmental remediation and protection (J. Parvey, personal correspondence, July 20, 2017; J. Coffman, personal correspondence, July 20, 2017). The Center for Urban Waters houses labs and offices for both the City of Tacoma's Environmental Services Unit (ESU) and the University of Washington–Tacoma (UWT). The UWT research laboratories at the Center are equipped with analytical instrumentation focused on the detection, identification, and quantification of organic chemicals in the environment using both targeted approaches, to deal with known compounds, and non-targeted approaches, to deal with unknown compounds, that may put at risk public and environmental health. Both the ESU and the UWT work together to carry out for the city forensic work on pollution to facilitate enforcement of antipollution laws. The center's emphasis on applied science is also designed to support the water technology industry and be a source of job creation and a greater, diversified tax base. It is hoped that innovative and commercially viable solutions may evolve from the center's research, that existing technology firms will expand or be retained in the region, that entrepreneurs will be encouraged to start new businesses new business, and that firms will relocate to Tacoma. The center is designed to grow both itself and the Tacoma community; and the Center represents an example of both the 'hard' and 'soft' infrastructure which Milbergs suggests that every cluster requires for success.

B. Puget Sound Partnership at the Center for Urban Waters

1. Vision and Mission of the Puget Sound Partnership

Many groups have an interest in protecting and restoring the health of the Puget Sound for the well-being of both the residents and the natural ecosystems of the region. The state agency charged with leading the collective effort to clean up, restore and protect the Puget Sound is the Puget Sound Partnership (PSP), which was created in 2007 as a successor to the Puget Sound Action Team which was itself created in 2001. The bill creating the PSP, which then Governor Chris Gregoire signed into law, tasked the new state agency with restoring the Puget Sound to a ‘healthy’ state by 2020, and to do so by developing a shared regional plan and common way to measure success which its predecessor agency lacked (Puget Sound Partnership, 2017). This time-frame was a decidedly ambitious task given the scale of the problem. The term 'healthy' is vague and clarification and operationalization of this term is of critical importance to any declaration of success (JLARC, 2016). According to then Governor Gregoire, the PSP was created to be a “community effort of citizens, governments, tribes, scientists and businesses working together to restore and protect Puget Sound” (Puget Sound Partnership, 2008). The vision of the PSP to is build “vibrant, enduring natural systems and communities,” and its mission is to “accelerate the collective effort to recover and sustain the Puget Sound” (Puget Sound Partnership, 2017). The

PSP, like its predecessor agency, also provides technical assistance on low impact development (LID) to numerous stakeholders in the region to help businesses and communities transition to more environmentally neutral methods for developing land and managing storm water, to reduce the Anthropocene impacts on the estuary (Wulkan, 2015).

2. Goals & Objectives of the Puget Sound Partnership

The goal of the PSP, as set by Governor Gregoire and the Washington State Legislature, was to restore and maintain the ecological health of the Puget Sound; and in 2008, the PSP created an Action Agenda that remains the road-map for cleanup and restoration efforts in and around Puget Sound. To achieve a more resilient Puget Sound, the broad goal was further refined by the Washington State Legislature which broke it down into six more specific ecosystem recovery goals that together were to achieve the following: (1) a healthy human population that is not threatened by changes in the ecosystem; (2) a vibrant quality of life that is sustained by a functioning Puget ecosystem; (3) thriving native species supported by a robust food web; (4) protected, restored, and sustained freshwater, estuary, nearshore, marine, and upland habitats; (5) abundant quality groundwater and stream flows that are sufficient to sustain people, fish, wildlife, and the natural functions of the environment; and (6) healthy water quality that is safe for drinking, swimming, and other human uses and enjoyment, and which are not harmful to the native marine mammals, fish, birds, and shellfish in the region (Puget Sound Partnership, 2017). These goals have been further clarified and linked to measurable objectives and objective indicators in the Action Agenda.

3. Governance of the Puget Sound Partnership

The Partnership is responsible for coordinating, prioritizing, and monitoring the progress of recovery efforts implemented by partner organizations. While it works with a broad range of partner organizations - state and federal agencies, tribes, counties, cities, and private entities - the Partnership does not implement recovery actions on the ground, deliver funding, or have regulatory authority (C. Cockrane, personal correspondence, July 20, 2017). The institutional arrangements through which the Partnership achieves its goals and objectives are its various governing and advising boards and the Action Agenda. The Partnership is led by the Leadership Council – a seven-member body representing various interests including government, business, agriculture, academia, and tribes, among others - which is advised by three other boards – the Ecosystem Coordination Board, the Science Panel, and the Puget Sound Salmon Recovery Council – which give technical and expert advice in specific areas of interest within the remit of the Partnership (Puget Sound Partnership, 2017). The Puget Sound Partnership is guided by an Action Agenda, which is a comprehensive, prioritized, science-informed, shared road-map for Puget Sound recovery. This agenda outlines the regional strategies and specific actions that are needed to restore the essential resources and functions the Puget Sound, and protect them for the future, while supporting ecologically sustainable economic and social development (Puget Sound Partnership, 2017). The Partnership is also responsible for assessing the effectiveness of recovery and restoration efforts by evaluating data to determine how well management actions and programs are working to achieve desired outcomes; and communicating the results to decision-makers, so they can improve future projects, through such medium as the Puget Sound Vital Signs, Action Agenda Report Card, and State of the Sound report (Puget Sound Partnership, 2017).

The creation of this Action Agenda, and the steps taken to implement it, required the contributions of hundreds of partners – including academia, businesses, tribes and citizen action groups - and has involved input from all parts of government. Although Action Agenda is as a shared road-map representing the collective effort of regional stakeholders and interest groups, it is supposed to be informed by science, and a rational-scientific approach is expected to guide prioritized and effective investments (Puget Sound Partnership, 2017). The philosophy of the Action Agenda is to prioritize cleanup and improvement projects on actions that have the biggest impact, coordinate federal, state, local, tribal and private resources, make sure all partners are working cooperatively, base decisions on science, and hold all partners accountable for results (Puget Sound Partnership, 2017). With regards to implementation, the strategic initiatives are led by state agencies which convene advisory groups of policy and technical experts to determine which projects are the best fit for sub-awards that most closely align with the Action Agenda and prioritize near-term recovery (Puget Sound Partnership, 2017). These advisory groups develop implementation strategies and use adaptive management approaches to address the challenges of the Puget Sound.

To achieve the large and complex task assigned to the Partnership, the

Action Agenda relies heavily on a combination of national, regional and local resources and efforts to achieve its goal (C. Cockrane, personal correspondence, July 20, 2017). Much of the resources and efforts of the PSP is devoted to creating and maintaining the institutional infrastructure needed by stakeholders to facilitate the collaboration and coordination needed to identify, develop, and implement the priority actions needed to accelerate ecosystem recovery. The nine counties and numerous cities and towns of the Puget Sound region play a particularly important role as focal points for local implementation of the Action Agenda. The Washington Association of Counties (WSAC) facilitates collaboration and communication between the PSP and city and county governments to identify issues and prioritize restoration projects. This institutional infrastructure ensures the alignment of the work of all the partners around a shared vision and strategy. Decision-makers are supposed to be well-informed and have the information they need to identify issues, determine solutions, and prioritize projects, and decisions are supposed to be science-driven and not dominated by politics and special-interests. The decision-making arrangement is intended to ensure the following: (1) investments in the recovery of Puget Sound are supposed to represent the most efficient and effective ways to allocate limited resources; (2) that the policy and regulatory environment is streamlined to ensure the flow of resources toward priority actions; and (3) that there is a shared, science-based system of measurement, monitoring, and evaluation that promotes accountability and effectiveness, and ensures progress (Puget Sound Partnership 2017). It is widely accepted that the ecology of the Puget Sound will never return to its state of 150 years ago, given the current level of human development in the region and expected additional development in the coming years; however, it is also accepted that the future health of the region's ecosystem, and the quality of life of its human population, will be determined by the current actions taken to restore and protect the Puget Sound.

4. Resources of the Puget Sound Partnership

The PSP finances its budget from a combination of federal, state, and local funds. An important priority for the Partnership is to develop a budget strategy to secure a stable and diverse stream of funds to implement Action Agenda priorities over the long-term (C. Cockrane, personal correspondence, July 20, 2017). The Partnership employs three approaches: the first involves getting the most from available funds by prioritizing projects and funding those that have the highest potential benefit to recovery efforts; the second is defining the size and nature of the funding gap; and the third involves identifying ways to bridge the funding gap (Puget Sound Partnership, 2017). The Partnership’s funding contributes to coordinating, prioritizing, and monitoring efforts. Partner organizations receive implementation funding directly, which is not included in the Partnership’s budget. The Partnership's budget for the 2015-17 biennium was $18.8 million, which included $9.9 million from the U.S. Environmental Protection (EPA) Agenda, $7.5 million from the State of Washington, and $1.4 million from the National Oceanic and Atmospheric Administration (NOOA). The Partnership receives the bulk of its funding from federal, state, tribal and local government sources; however, nonprofits, businesses, and foundations also make significant investments (Puget Sound Partnership, 2017). The federal government's contribution comes from the National Estuary Program, which is administered by the EPA, and the Partnership is one of six Washington state agencies to receive funds from this program. These resources are, however, considered inadequate for the task, and the 2013 State of the Sound report estimates a $390 million shortfall over a three-year period to implement near-term actions identified in the 2012 Action Agenda (Puget Sound Partnership, 2013). Although the goals of the PSP have largely been bipartisan, and there has been support for putting Puget Sound at the same priority cleanup level as Chesapeake Bay in Maryland and the Great Lakes, the resources have historically been inadequate. In 2016, however, the Obama and Washington state administrations promised an additional $500 million in funding for the Sound over five years (Ahearn, 2016). This promise requires Congressional approval and is currently threatened by budget cuts under the Trump administration. Funding requests fall far short of the estimated $8 billion required to restore the Sound (Chasan, 2010, 2012; Connelly, 2017). The Puget Sound cleanup is not alone in being targeted by the Trump administration - both Chesapeake Bay and the Great Lakes cleanup efforts would suffer a 90 percent reduction in their funding, and cleanup money for Long Island Sound and San Francisco Bay would be eliminated entirely (Connelly, 2017).

5. EPA Partnership.

The EPA receives money from Congress to help restore and protect the Puget Sound and support the Agenda using Cooperative Agreements (CA) with designated state agencies, local and tribal governments, universities and non-governmental organizations (NGOs) (Puget Sound Partnership, 2017). A CA is a relationship between the U.S. Government and a designated intermediary to carry out a public purpose which provides goods or services to an authorized recipient. Unlike a grant, a Cooperative Agreement involves a 'substantial involvement' by the federal awarding agency in directly performing or implementing parts of the program. In a grant, the federal government maintains more strict oversight and monitoring (grants.gov, 2016). The CA between the EPA and PSP focuses on regional engagement, stewardship, and managing the implementation of the Action Agenda. The CA targets three high priority issues in Puget Sound contained in the Action Agenda: natural habitats, shellfish, and storm water. Between 2010 and 2015, the EPA also provided 52 grants directly to local partners for projects that addressed specific areas of the Action Agenda that supported Puget Sound recovery and restoration. The federal government also gives sub-awards to local, tribal, state, and county governments, NGOs and academic institutions to carry out a wide variety of projects, assessments, and monitoring.

The 20 Northwest Treaty Tribes and three tribal consortia that are located in the Puget Sound region play an important role in restoring and protecting the Sound. The consortia represent regional leaders and partners who try to protect and restore the Puget Sound and co-manage the region's interconnected natural resources (C. Cockrane, personal correspondence, July 20, 2017). The EPA provides funds to support the Northwest Indian Fisheries Commission, to carry out projects of high tribal priority, and participate in regional coordination boards and management conferences that are consistent with the Action Agenda (NWIFC, 2015; EPA, 2017). It must be noted that Native Americans have a special economic and cultural relationship to the Puget Sound that includes their long and antecedent presence in the region. The tribes possess rights and privileges, to which they are entitled through treaties, which allow them to harvest fish, shellfish, wildlife and other natural resources in exchange for most of the land that makes up the region today (NWIFC, 2015).

6. Criticism of the Partnership's Restoration Efforts

Efforts to restore and protect the sound, and the agencies tasked with the restoration and protection, have been the subject of continual controversy, criticism, and competing perspectives. Some stakeholders suggest that efforts to clean up Puget Sound had been floundering for two decades, with growth-related damage still outpacing government funded efforts (Stiffler, 2005; Lipsky & Ryan, 2011). Other stakeholders suggest that efforts to address the ecological health of the Puget Sound threaten urban and economic development and burden businesses and the community with too many regulations that produce too few impacts (Stiffler, 2005); and yet other stakeholders suggest that some progress has been made, but with the provisos that much restoration work from earlier damage remains and storm-water from urban development remains the last major challenge to be addressed (Patrick, 2016). The PSP was not the first state agency to be tasked with restoring and protecting the Puget Sound: between 2001 and 2007 that task fell to the now defunct Puget Sound Action Team, before that to the Puget Sound Water Quality Authority which was established in 1985, the

Pollution Control Commission which was established in 1945, and the Washington State Pollution Commission was created in 1937 (The Olympian, 2006). Efforts to restore and protect the sound seem to face many ongoing challenges, chief among them being low public awareness of the extent of the problem and the ongoing challenge of poor leadership and governance which together provide strategic direction, delivers plans and policies, and ensures effective oversight (Dunagan, 2013; Myers, 2014; Myers, 2017). The Puget Sound Action Team, which the PSP replaced, was increasingly seen as lacking in independence and thus powerless to address the Sound's environmental and ecological problems. There has been an ongoing lack of political will to align the scale of resources required with the scale of the problem and there has been an inability among key stakeholders to keep the environmental and ecological needs of the Puget Sound ahead of narrow political interests (Puget Sound Action Team, 2004; Stiffler, 2005; Lipsky & Ryan, 2011; Morgan, 2014).

Many of the more recent criticisms of the PSP were driven by a scathing 2011 audit report issued by Washington State's bipartisan Joint Legislative Audit Review Committee (JLARC) which suggested that, despite some progress, the agency has largely failed to fulfill many of its responsibilities and that leadership and management committed numerous acts of waste, corruption, nepotism, and fraud linked to contracts for services and hiring of staff (Ryan & Gates, 2010; JLARC, 2011). This was followed in 2013 by a report from the Freedom Foundation which stated: “Unfortunately, like the two agencies that preceded it, the Puget Sound Partnership has been unable to create positive changes for Puget

Sound. Instead of effectively using its resources and influence to help clean up Puget Sound, the Partnership has engaged in corrupt practices, wasted taxpayer dollars, and failed to fulfill any of its responsibilities as a state agency" (Freedom Foundation, 2013). The Freedom Foundation was concerned that the PSP did not actually carry out any recovery and restoration work itself, did not properly monitor and evaluate the work carried out on its behalf, and felt that too much of its time, energy and resources were spent on public relations and branding the agency rather than solving the problem.

Concerns over poor leadership and governance have been driven by perceptions over the technical and administrative quality of its leadership cadre, the frequency of turnover of its executive team, and the agendas of various key people. To the matter of leadership agendas, the first Chairman of the Puget Sound Partnership Leadership Council was William Ruckelshaus, a Republican, who was the first to head the EPA where he served two non-consecutive terms. Ruckelshaus' daughter served as the chief scientist of the PSP for two and one–half years on a half-time basis, while on loan from the National Marine Fisheries Service, with the federal government picking up the cost of her placement. She had previously been turned down for a more junior position with the PSP before securing the position of chief scientist. The first Executive Director of the PSP was a Seattle lawyer, David Dick, who was the son of a longtime Democratic Congressman from Washington State, Norman Dick. Norman Dick was able to use his position as Chairman of the Interior Subcommittee in 2007 to increase federal money going to the PSP from about $500,000 a year to about $50,000,000;

however, some have argued that several of the projects to which these funds were allocated were of dubious environmental value, and based on a questionable scientific rational, which suggested as its underlying justification a benefit that was political rather than public. Under the leadership of both Ruckelhaus and Dick, the PSP became mired in accusations and investigations over appointments, hiring, and contracts that allegedly have involved nepotism, cronyism, and politics (Ryan & Gates, 2010; JLARC, 2011; Freedom Foundation, 2013). While none of the breaches may have reached the level of criminal intent and resulted in criminal charges they have left the public image of the agency tarnished and reduced its ability to achieve the public and political consensus necessary to secure a sustainable stream of public funding (Stiffler, 2010; Bradford, 2010).

With regards to technical and administrative capacity, the leadership of the PSP seems to lack a sense of how to execute its vision and mission, and to find the correct balance between politics, science and public relations. At its formation, the legal mandate of PSP was to provide science-and-evidence-based leadership for the many political jurisdictions in the region responsible for reducing the environmental impact of human development on the functioning of the ecosystem of the Puget Sound. The Washington Policy Center is one stakeholder that seems to be leading the case for the PSP to have a primarily science-based and science-driven agenda (Chasan, 2010; Myers, 2012, 2014). There are other stakeholders, among them former executive director David Dicks and former PSP chair Martha Kongsgaard, who seem to represent a more political agenda (Morgan, 2014; Myers, 2014). A third approach, which probably represents middle ground between science and politics, suggests an emphasis around partnerships and collaboration among the hundreds of stakeholders in the Sound, and an Agenda built primarily from the bottom-up (Sea Grant, 2008; Nunnally, 2016; Patrick, 2016).

With regards to leadership turnover, the first executive director, David Dick, was perceived of being too political and left the agency following questions about weak administrative capacity, breaches of ethical guidelines, and a negative report from the State Auditor. The second executive director, Gerry O'Keefe, who was perceived as being more of a scientist than politician, was regarded as having the correct focus for the agency and for putting it on the right track. He was abruptly fired by the Governor. The third director, Anthony Wright, was perceived as being outspoken, and having a higher public profile that would energize the agency, but he offered his resignation after six months to return to work at a private consulting firm. The fourth director, Marc Daily, had previously served as deputy director at the PSP from 2011 and served a year as interim executive director. In 2014 the PSP appointed its fifth and current executive director, Sheida Sahandy, who came to an agency where only five of its 21 'vital signs' improved and was unlikely to reach its 2020 goals (Dunagan, 2013; Myers, 2014; Myers, 2017).

This history has put a cloud over the agency and caused many to question its value. At its worst, the PSP was a political agency, designed to deliver symbolic and politically useful environmental stories, even as scientific priorities were being ignored. At its best, the PSP provides scientifically-based environmental performance audits, helping ensure funding is spent where it can do the most good for the flora and fauna of the Sound. When science-based priorities are combined with economics, and all underlying assumptions are made clear, it is much easier to determine which projects are worthwhile and effective, and which are political (Myers, 2017). Short planning time-frames, an incomplete inventory of actions and funding, and an unclear monitoring approach hinder recovery efforts (JLARC, 2016). In recent years there is evidence that the PSP has returned to a scientific approach, but continued success in restoring the Sound, and preventing further damage from new urban development and emerging pollutants, requires a balanced approach that takes into account several considerations: first, environmental degradation is a problem with environmental, economic, and political aspects and must be solved with all these in mind; second, environmental remediation on this scale is a long-term effort, that requires a realistic time-frame, that will transcend the lifespan of the organizational leadership of the PSP and the political leadership in Olympia; third, the scale and scope of the problems of the Sound will require sufficient resources to be committed over many years, and the dependence on federal funds must be reexamined; fourth, the Partnership must share information with the Legislature and public about the health of Puget Sound, and the efforts that are required to restore its health, to gain both public and political support; fifth, good program and project management requires a comprehensive monitoring system to judge progress, prioritize projects, and allocate scarce resources; sixth, the efforts of stakeholders, partners, agencies, and programs at multiple scales must be properly coordinated, and organizational and disciplinary silos must be transcended; and sixth, the efforts of the Partnership must be continuous and consistent, which requires a sound game plan (Chasan, 2010, 2012; Dunagan, 2013; Myers, 2012, 2014; Myers, 2017).

C. City of Tacoma Environmental Services Unit.

Tacoma's Environmental Services Unit is responsible for ensuring the city's public and environmental health by protecting and restoring natural resources, and keeping the city clean, safe and livable (City of Tacoma, 2013a). The Environmental Services Unit does this by providing the following services for approximately 210,000 citizens: garbage collection and recycling, wastewater treatment, household hazardous waste disposal, and protection from storm-water pollution which is driven by Tacoma's average rainfall of more than 37 inches a year (City of Tacoma, 2013b). Solid waste management provides garbage, collection, recycling and yard and food waste services for about 85,000 housing units and 13,000 businesses; surface water management prevents pollution from storm-water from 500 miles of public storm-water pipes, 22,000 storm drains, four pump stations, and several water detention ponds. The city also provides wastewater management of more than 10 billion gallons of wastewater each year through more than 700 miles of sewer pipes, 45 pumping stations, and two wastewater treatment plants (City of Tacoma, 2013a).

The City of Tacoma is nationally and globally recognized for its expertise in environmental remediation and storm-water management (J. Parvey, personal correspondence, July 20, 2017). Much of this expertise comes from parts of Commencement Bay being declared a Superfund site, and the subsequent historically significant cleanup effort on the Thea Foss & Wheeler-Osgood Waterways which the City and its partners completed in 2006 (Center for Urban Waters, 2016). The City and its public and private partners worked for more than two decades to clean up and restore marine sediments and shoreline habitats in the City's waterways and throughout Commencement Bay. These efforts have restored the City's waterways to the state where citizens and visitors can now live, work, and play on clean waters (J. Parvey, personal correspondence, July 20, 2017). Being good environmental stewards going forward is a priority for Tacoma (Center for Urban Waters, 2016). The cleanup cost the city and its partners about $105 million, and the Environmental Services Unit controls an annual budget of at least $3.5 million to monitor storm water pipes to ensure that environmental disasters do not happen again (Barringer, 2014).

Clean water engineering projects recently completed by Tacoma's Environmental Services Unit include an innovative set of storm-water treatment installations, including those along Pacific Avenue, the Prairie Line Trail, and at Point Defiance Park. These projects are important because Tacoma has separate systems for sewerage and storm-water and does not treat storm-water before it enters the Sound. The Pacific Avenue Rain Gardens are designed to combine function and beauty. During 2013, the City of Tacoma installed 14 aesthetically attractive rain gardens for intercepting and filtering storm water along Pacific Avenue, which is a low-technology and low-cost way of using natural systems to filter out pollutants. The Prairie Line Trail is a regional storm-water treatment facility at the University of Washington Tacoma which is the result of a partnership between the City of Tacoma, UW Tacoma and the Washington State Department of Ecology to establish a demonstration site for dealing with the emerging challenge of non-point pollution. The Prairie Line Trail is what is known as a bio-retention facility, and it treats runoff from 42 acres of existing urban areas, which lie upstream of the facility, before the runoff is discharged into the Thea Foss Waterway (UWT, 2015). The Point Defiance Regional Stormwater Treatment Facility is a joint project by the City of Tacoma and Metro Parks Tacoma that is designed to improve the quality of storm-water flowing into Commencement Bay near an historically impaired area of Puget Sound overloaded with heavy metals from the Tacoma Asarco Smelter that operated for nearly 100 years. This innovative approach provides treatment for up to 8 million gallons per day from 754 acres, in a footprint of only 5,500 square feet. The $2.5 million project was jointly funded by the Washington State Department of Ecology and the City of Tacoma Surface Water Management Fund (City of Tacoma, 2013c).

The technical and management capacity developed and refined by the Environmental Services Unit enables it to trace pollutants right back to individuals, housing units and businesses who are responsible for a discharge. This capacity creates a different public policy environment and conversation with citizens about responsibilities and remedies for pollution and pollution prevention. The sources of pollution have evolved considerably over the past 40 years from industrial pipes contributing 85 percent of water pollution, to storm-water and the runoff from farmers' fields now contributing 85 percent of all pollution flowing into Commencement Bay (Barringer, 2014). The critical tools for the city in tracking pollution to its source is a combination of data – which provides a detailed, continuing and chemically specific picture of what flows through its system into the Thea Foss Waterway - and forensic techniques which create chemical maps of the city's storm-water system (Barringer, 2014). The City of Tacoma committed $7 million to co-locate its analytical lab at the Center for Urban Waters, enabling the center's partners to share resources and coordinate work and share knowledge. The City also committed $500,000, which was matched with $250,000 from the University of Washington, to support storm-water research as one of the center's priority areas. An example of the investigative skills and capabilities took place in 2014 when city engineers investigated the source of a white cloud in the Thea Foss Waterway. They traced the cloud upstream to a catch basin near a yard where wrecked cars were stored by Bill's Towing Services. It turned out that a trailer full of coffee creamer had been towed to the yard after an accident by the local towing company, but the towing company had crushed a good portion of the creamer containers during the cleanup of the accident site. Bill's Towing was fined $10,000 for the improper cleanup which led to the pollution (Barringer, 2014).

D. University of Washington Tacoma

The Center for Urban Waters was conceived as providing an intellectual environment where a community of environmental scientists, analysts, engineers and policy makers would collaborate to develop innovative and sustainable approaches to restore and protect the Puget Sound, and to encourage low-impact urban development. A key resident of the Center is the University of Washington Tacoma (UWT) which has located laboratories and scientists to conduct research which seeks to understand and quantify the sources, pathways and impacts of pollutants in urban waterways in general and the Puget Sound in particular. The UWT coordinates many programs and partnerships at the Center for Urban Waters in support of its scientific mission: (1) the Puget Sound Institute, (2) the Encyclopedia of Puget Sound, (3) the Washington

Stormwater Center, and (4) the Clean Water Innovation Laboratory.

1. Puget Sound Institute.

The Puget Sound Institute is a cooperative agreement between the University of Washington, the U.S. Environmental Protection Agency, and the Puget Sound Partnership. The Institute seeks to synthesize various streams of scientific research, ensure robust and rigorous analysis, and create a forum for the transparent discussion and dissemination of science in support of the restoration and protection of the Puget Sound ecosystem (UWT, 2017). The institute achieves this by doing the following: it brings together scientists, engineers and policy makers to work difficult issues faced in the restoration and protection of Puget Sound. The Institute provides expert advice that is based on the best-available science; and it serves as the bridge between the scientific community and those charged with restoring and protecting Puget Sound (UWT, 2017). One example of how the Institute achieves its mission is convening leading authorities from a diversity of disciplines to conduct commissioned critical reviews and evaluations. These reviews are meant to provide credible, consensus-based information to key decision-makers and other stakeholders (UWT, 2017). Funding for the Puget Sound Institute comes primarily from the EPA, which provided $4 million for creating the Puget Sound Institute from $50 million which was appropriated for cleaning up Puget Sound (UWT, 2017).

2. Encyclopedia of Puget Sound.

The Encyclopedia of Puget Sound is an open-access web-based encyclopedia that is a publication of the University of Washington Puget Sound Institute, but which is guided by the Puget Sound Action Agenda which is produced by the Puget Sound Partnership (UWT, 2015). The encyclopedia is meant to be a comprehensive guide to the science and practice of Salish Sea ecosystem recovery, with articles that describe the region's major environmental threats and areas of concern, and that emphasizes the facts that the Salish Sea is an estuary of international importance. The encyclopedia receives major support from the Environmental Protection Agency's National Estuary Program and it works closely with numerous federal and state agencies. The creators of the encyclopedia are scientists, policymakers and educators who find and share information about many aspects of the Salish Sea ecosystem and its recovery. Much of the content of the encyclopedia is peer reviewed in a process facilitated by the Puget Sound Partnership; its primary audience represents many different backgrounds and interests but are expected to be science-literate. A secondary audience are college and university-level instructors and students who use it as a resource and teaching tool. Another audience are scientists and policymakers looking for a summary of the best available science describing the Puget Sound ecosystem (UWT, 2015).

3. Washington Stormwater Center.

The Washington Stormwater Center (WSC) was established in 2010 as a partnership between Washington State University Puyallup (WSU) and the University of Washington Tacoma (UWT) with two physical locations: the UWT's Center for Urban Waters, and WSU's Research and Extension Center located at WSC which serves as an information clearinghouse on low-impact development and emerging technologies. The goal of the WSC is to protect the state's waters by addressing storm-water pollution which has emerged as the critical current pollution issue in the Puget Sound area. The WSC does this by providing independent, non-regulatory assistance to storm-water permittees and storm-water managers as they navigate the complexities and challenges of storm-water management. The WSC serves as the central resource in Washington state for integrated National Pollutant Discharge Elimination System (NPDES) education. The WSC provides technical assistance, training on storm water management, information on storm-water management best-practices, and new technology research, development, and evaluation. The Center provides tools for storm-water management by supporting municipalities, storm-water permittees, and businesses in their efforts to control storm-water and protect water quality (UWT, 2017). Providing technological solutions that help municipalities and businesses meet NPDES requirements is an innovation stimulus for water technology companies like Pure Stormwater of Silverdale, Washington, whose principals anticipate a storm-drain filtration product like theirs will be in high demand as federal and state lawmakers and regulators implement laws and regulations for controlling water pollution (Kelly, 2015). The WSC also offers a training program for low-impact development that is now being used as a resource by state agencies and the state legislature to ensure that all pertinent audiences in the state receive the training needed to meet new stormwater regulations and codes. The Washington State Department of Ecology provided grant funding to begin the process of creating the WSC, and support Center development, overall management, and the administrative strategy for the organization (UWT, 2017). Private foundations and the private sector have been supportive of the WSC: two Pacific Northwest foundations, The Bullitt Foundation and The Russell Family Foundation, and the Boeing Company jointly fund the director's position at the WSC, as well as the center's long-range business-planning efforts (Kelly, 2015).

4. Clean Water Innovation Laboratory.

The mission of the Center for Urban Water includes both driving economic development in the Tacoma region, and restoring and sustaining the natural ecosystem of the Puget Sound. These tasks require the application of both science and technology. The Center for Urban Waters therefore has an integral role to play in supporting Tacoma's new Urban Clean Water Innovation Partnership Zone (IPZ). This supporting role will require collaborations between local research universities, private sector scientists and engineers, and government experts which is designed to increase the likelihood that new knowledge and inventions will make their way into new water technology products and services (UWT, 2012 & 2017b). This process of research & development, technology transfer, and commercialization is a well-established path to building and expanding technology companies and creates jobs. This innovation and entrepreneurial process helps to achieve the goal of Tacoma's economic development leaders, the leadership of both UWT and WSU, and the IPZ program to build a clean water technology cluster (UWT, 2012, 2017b).

Commencement Bay has for several decades provides a unique real-life laboratory for addressing many water quality issues affecting urban centers and the natural environment. To leverage this history, public and private interests across the Tacoma region have been building an impressive collection of science laboratories to support high-level environmental research. This research capacity enables the region to grow and strengthen current local assets in environmental science, while building innovative programs in environmental engineering; and the considerable local investments in research and development publicly signals a commitment to make Tacoma the regional and global center of excellence for clean water technologies (UWT, 2012, 2017b).

The laboratories at the Center for Urban Waters, UWT and WSU were funded in part out of a $13.5 million package which the Washington State legislature funded through the Department of Commerce to provide IPZs across the state with enhanced facilities and infrastructure. The Department of Commerce approved an application to establish an Urban Clean Water Technology IPZ in 2012 provided the UWT with $2 million for a new 'Clean Water Innovation Development and Technology Transfer Laboratory,' which was in remodeled space on the UWT campus. The Department of Commerce also provided the Center for Urban Waters with $800,000 for specialized lab equipment to support the commercial development of clean water technologies (UWT, 2012, 2017b). In addition, the WSU's Puyallup Research and Extension Center, which partners with UW Tacoma on the IPZ and other applied science initiatives, also receives $800,000 to modify its Salmon Toxicology Lab into a multi-use Aquatic Toxicology Lab.

VII. Water Technology Networking

A. Wellspring Conferences

Networks, communication, personal relationships and community ties and are vital for the success of business clusters and ecosystems (Porter, 1998). To help ensure that market, technical, and competitive information accumulates within the Tacoma cluster, the IPZ created the Wellspring conferences, and hosted three consecutive conferences between 2012 and 2014, to bring together local, national and international experts in water policy and management to present their ideas and share their experiences. Conferences facilitate local and national vendors of water technologies and services to showcase their offerings. The first conference in 2012 was organized by the Economic Development Board of Tacoma-Pierce County and hosted at the University of Washington Tacoma (UWT). The theme of this conference was the "sharing ideas to build a water economy" in the region. Although Tacoma has a lot to learn from the experiences of others, the city also has much knowledge and experience to share about how to manage complex water quality issues amid a complex natural ecosystem of immeasurable beauty and economic and aesthetic value. The clean-up to the Thea Foss and Wheeler-Osgood Waterways taught Tacoma much about environmental remediation. The area is successfully transitioning from a once polluted waterfront real estate into assets of new uses and purposes. One of the important issues identified by the 2012 conference was the challenges presented by the lack of national standards and absence of permitting reciprocity across states which increased the time and costs associated with testing and approval of technologies. One solution to this challenge was seen to be the creation of a national water technology network for organizing and coordinating water innovation clusters across North America.

The second Wellspring conference was held in October 2013 and again hosted by the UWT. The theme of this conference was advanced waste-and-storm-water management and clean water technologies, and the topics covered included remediation and filtration systems, the effects of pollutants on biological systems, government regulatory trends impacting public and private water sectors, policy fragmentation, and the disconnect between water networks worldwide. The attendees were able to listen to, and gain ideas and insights, from nearly 20 expert presenters. Attendees were afforded the opportunity to participate in a guided tour of three Tacoma locations using current storm-water management techniques. The Water Partners of Tacoma, Washington hosted its 2nd annual Wellspring Conference in October, at the University of Washington-Tacoma. The planners considered the conference a huge success as it was attended by hundreds of water professionals and innovators from around the world, a 60 percent increase in turnout from 2012.

The third Wellspring conference was held in 2014 and was hosted by the Water Partners of Tacoma. The themes of this conference were the idea that water, sustainability, economic development, clean water technology, water management, and sustainability in a field that is experiencing unprecedented change and unpredictability from water emergencies, climate change, extreme weather, storm-water events, and natural disasters. The attendees discussed the emergence of water technology innovation clusters all over the country, and how each cluster focused on developing innovative solutions to largely local problems and scaling those solutions to national and global customers. The attendees all agreed the time had arrived to formalize a national network of water innovation clusters around information exchange projects, evaluation of new technologies, compiling best practices, improving access to financing, strengthening entrepreneurship, overcoming obstacles in the rapidly evolving industry, and developing increased capacity for policy change advocacy. Also discussed was the critical economic role played by water in the performance of many key Washington State industries, from agriculture and tourism to manufacturing and mining. The 2014 Wellspring Conference featured more than 30 speakers and was attended by hundreds of delegates from across the country, including water professionals from both the private and public sectors, engineers, elected officials, foundations and NGOs, private business consultants, financial institutions, and sustainability experts (Stroo, 2014)

VIII. Prior Cleanup Efforts - Thea Foss and Wheeler-Osgood Waterways

In the 100 years up to the 1960s, when Tacoma grew to become a major industrial center, the city was home to lumber mills, a cement factory, petroleum processing plants, a chemical processing plant, and ship-building operations. These factories and the surrounding communities dumped industrial wastes, raw sewerage and untreated storm-water into the waterways of the Puget Sound, without restriction, under the false assumption that the waters of the Sound would eventually be carried away by the tides into the Pacific Ocean where the open water would safely dilute their toxic effect. What happened instead was that pollutants settled onto the floor of the waterways, either by bonding with the sediments or by being trapped within the Sound by a combination of the irregular shape of the estuary floor and the different densities of salt and fresh waters. This historical practice led to the accumulation of more than 1 million cubic yards, and more than 125 acres, of contaminated sediments on land and in waters of Tacoma; to the detection and identification of more than 1,000 man-made compounds and metals in the bottom sediments; and to the identification of more than 150 potential pollution sources in the city. Prior to 1981, when the Environmental Protection Agency (EPA)placed Tacoma among its top 10 national priorities for cleanup, there had been no significant coordinated efforts or investment of money to try to fix the environmental problems of Tacoma's waterways; however, after EPA designated the Thea Foss and Wheeler-Osgood waterways and Commencement Bay as Superfund cleanup sites a more concerted local effort began to take shape, backed by the necessary leadership and resources.

Between 1983 and 2006 the City of Tacoma - in partnership with agencies, organizations, property owners and other responsible parties - invested about $105 million to clean up its waterways and construct four new habitat restoration sites at the Middle Waterway Tide-flats, North Beach, Puyallup River Side Channel and Hylebos Creek which the City now monitors under the Environmental Stewardship Project. A fifth habitat restoration project has been constructed at Swan Creek, but this is monitored through an agreement with the Port of Tacoma. The cost of the cleanup was shared between as follows: $56.5 million from surface water rates from the City of Tacoma, $24.5 million in grants from the Washington State Department of Ecology, $13 million in private contributions, $7.3 million from PacifiCorp and Puget Sound Energy, and $3.7 million from the Washington State Department of Natural Resources. The restoration project primarily involved a combination of habitat restoration, and the removing or capping in place of sediments contaminated by more than a century of environmentally detrimental practices; however, the ongoing protection of the waterways required that pollution be traced through the city's subterranean maze of sewerage and storm-water drainage pipes to its many sources. While some areas of the Thea Foss Waterway were capped with clean sediments to contain some of the contamination in place, between 2002 to 2006 about 425,000 cubic yards of contaminated sediments were dredged from the waterways and the toxic sediment buried in a sealed disposal site, under a permanent cap, behind a containment berm in the nearby St. Paul Waterway. The site for this disposal facility was made available in a partnership agreement with Simpson Tacoma Kraft pulp mill, for whom the 12 acres land is now available for environmentally appropriate industrial development. The final cap from the Superfund cleanup action on the Thea Foss Waterway occurred back in February 2006.

The designation of Tacoma as a Superfund site was not universally embraced by all segments of Tacoma society: some say it as a stain on the reputation of the city that could impact its attractiveness to investors, visitors and residents. Others were concerned that the clean-up would impose an unfair economic burden on the city. Over time, however, Tacoma's leaders came to see the clean-up as an opportunity to improve the waterways and revitalize the struggling downtown and declining industrial core of the city for both residents and businesses. Tacoma also viewed the cleanup as an opportunity to raise property values which would positively impact the public coffers. The 1983 designation of the Thea Foss Waterway as a Superfund offered the City of Tacoma, the Tacoma Planning Commission, and the Community and Economic Development Department a unique opportunity to rally a coalition of stakeholders around a common redevelopment vision for the City; to lead this coalition through a challenging process of transforming a declining community and Superfund site into one of the premier mixed-use waterfront communities in the United States. In the process Tacoma struck a balance between preserving historic and traditional uses of the waterfront, while creating new opportunities for education, recreation, housing, and economic development. In 1990, Tacoma voluntarily took the lead in redeveloping the water front by purchasing and cleaning-up for future development 27 acres of Thea Foss Waterway land. In 1992 the city developed a plan and put forward a vision of a revitalized waterfront that included hotels, retail space, public access, parks, and restaurants that both residents and visitors could enjoy, and that would offer the city a long-term return on its investment. To coordinate and expedite redevelopment of the waterfront, the City of Tacoma established the Foss Waterway Public Development Authority in 1996 as the coordinating agency for the waterfront's development. This represents the city's commitment to local economic development. The 'design and development' phase of the Thea Foss Waterway redevelopment program was completed in 1998, and the program has subsequently benefited from being made a federally designated Renewal Community. This designation has allowed the city to allocated $12 million in annual tax deductions which, in turn, allows the City to create financial incentives for developers such as a 10-year property tax exemption for new residential construction of four units or more to encourage investment in the area.

Although the entire vision for the revitalized Tacoma waterfront has yet to be realized, the achievements of the Thea Foss Waterway project has brought the city national and international recognition for urban redevelopment. It has also allowed the city, its government agencies, and it partners in industry and higher education to develop unique expertise in environmental remediation and clean water technology; and it requires the city to ensure it has the capabilities and capacity to keep pollution is kept in check and ensure the environment stays clean. Tacoma has emerged as a real-world laboratory for researching and testing clean water technologies and products, and for finding sustainable solutions for restoring and protecting precious and vulnerable estuary ecosystems.

The development project faces many challenges going forward. First, the success of redevelopment in the urban core of a city depends on increases in population density to support business through consumer spending. Developers must be assured of an attractive return on their investment. A major issue slowing progress on the waterway project is that relatively low number of people who live and work in downtown Tacoma. For the full realization of the redevelopment vision, the city and its partners must ways to increase the number of residents and visitors. Second, success depends on keeping the waterway clean, and since the cleanup was completed in 2006 this has been the focus. The city, under a plan developed jointly with EPA, will employ several different types of ongoing monitoring from chemical tests of sediment samples, to underwater surveys, to monitoring the health of the sea life; and to prevent a recurrence of pollution the city has developed what has become a nationally recognized stormwater quality programs that are probably to date the most comprehensive in the United States, to dramatically reduce the level of contaminates entering the waterway. Third, success requires the maintenance of consensus among key stakeholders. While there has been considerable redevelopment on the west Foss waterfront, the future of the east Foss waterfront remains unclear because many port industries have opposed the development of condominiums on the waterway’s industrial side. The one major new development on the east waterfront that has been acceptable to all stakeholders has been the Urban Waters Institute. Despite many challenges and some disagreements, the historic cleanup of Tacoma's Thea Foss and Wheeler-Osgood Waterways has largely been a success: aquatic life is slowly returning to the waterways; people live a row of new condominium buildings with nearly 1,000 residential units that line a bustling promenade that passes along a leafy park, restaurants and museums. People play on a clean waterway which also has a marina filled with boats. (Nunnally, 2016)

IX. Application of Porter's Diamond Model

A. Factor Conditions

Tacoma, and the wider Puget Sound region, is endowed with a considerable base of factor conditions from which to build and support a strong water economy and a water technology industry. With regards to basic factors, Tacoma is endowed with considerable fresh water which comes from a combination of high rainfall and snow packs which feed numerous rivers and streams. The Puget Sound estuary supports fishing and recreation; and the Puget Sound also provides Tacoma with a gateway to global markets through its ports. With regards to advanced factors, Tacoma is endowed with a highly skilled workforce, many scientists and engineers, modern logistics and telecommunications, and access to sophisticated financial products. Washington State has been ranked as one of the top ten states in terms of quality of life (Hess & Frohlich, 2014). The state is part of one of the most vibrant regional economies in the United States, and is home to firms like Microsoft, Amazon, Infosys, HCL Technologies, Boeing, Cosco, and Starbucks (Kotkin, 2013); and the State is home to 15 Fortune 1,000 companies (clustermapping.us, 2017).

With regards to advanced and specialized factors, Tacoma is also well endowed.

In 2010, 32.3% of Washington's workforce had a bachelor's degree or higher, which is slightly higher than the national median of 27.74%; it compares favorably with Wisconsin at 25.79% and Ohio at 24.14%; but it lags Massachusetts at 38.29% (clustermapping.us, 2017). In 2014 the state awarded 14,716 scientific degrees in a population of about 7.2 million, which is slightly higher than the national median of 9,378; it compares favorably with Wisconsin at 14,196 with 5.7 million people; but lags Ohio at 28, 894 with 11.6 million people, and Massachusetts at 38,038 with 6.8 million people (US Census 2017; clustermapping.us 2017). In 2010, the percentage of the Washington workforce made up of advanced scientific workers is 0.28%, compared to both Wisconsin and Ohio who were at the national median of 0.19% of the workforce; but it lags Massachusetts at 0.56% (clustermapping.us 2017). Between 2006-10, the number of scientific workers in Washington grew by 2.81% per year, which is higher than the national average; it compares favorably with Wisconsin at 2.7% and exceeds Ohio at 1.38%; but it lags Massachusetts at 3.3% (clustermapping.us, 2017). In 2010, venture capital in the Seattle MSA was $11 per capita compared to the national median of $1, which also applies to Milwaukee and Cincinnati MSA; but it lags Massachusetts at $29 (clustermapping.us 2017). In 2014, R&D expenditure in the state was $2,692 per capita, compared to a national median of $1,019; it exceeds Wisconsin at $1,005 and Ohio at $1,035; but lags far behind Massachusetts at $4,140; while Washington's federal funding for R&D per capital was $138 compared to a national media of $107, which is similar to Wisconsin at $117 and Ohio at $108, but it lags far behind Massachusetts at $310 (clustermapping.us, 2017). The State has historically had many water-intensive and water- enabled industries – such a pulp and paper, smelting, and chemicals – but the generous availability of fresh water, a basic factor condition, and the ability to discharge waste into a salt water body, stifled innovation in the water economy and the water technology industry. The water economy is now beginning to upgrade, supported by a generous base of advanced and specialized factors.

B. Demand Conditions

The historical presence of water-intensive and water-enabled industries in Washington State such as fishing, agriculture, hydro-power, smelting, pulp and paper, oil refining, and chemicals created a base domestic demand for water technologies. This can be seen from the sample of long-established water technology firms such as Romac Industries of Bothell, Nelson Irrigation of Walla Walla, Itron of Liberty Lake, and Northwest Pipe of Vancouver. Many of the state's traditional industries have gone into decline or have been shut down altogether. The ample supply of fresh water, and few restrictions on the disposal of wastes into the Puget Sound all combined to weaken demand for innovative water technologies. Long-term declines in traditional industries spanning decades and the recent impacts of the Great Recession of 2008 have slowed investments in water technologies, causing some existing firms to contract and others to retrench, reducing the number of new entrants into the industry, and discouraging existing firms from elsewhere to locate in the Tacoma region - despite marketing efforts by the Tacoma IPZ to build relationships with a national network of water technology firms (City of Tacoma, 2011, 2015; Virgin, 2015; Green, Woodson & Zerr, 2016). The state is currently, however, the largest producer of hydro-power in the United States; it is one of the largest producers of agricultural products, with 1.7 million acres of irrigated crop land annually generating about $4.8 billion in crops, which is slightly more than half of all agricultural output; and fish-bearing waters generates about $1.3 billion a year (Washington Department of Ecology, 2010; EPA, 2016).

The current national and global technological trends are, however, towards water technologies which improve the efficiency of water use and guarantee water quality. One emerging stimulus for Washington's water technology firms to innovate has been less reliable supplies of fresh water to the west of the Cascades, because of over-abstraction of surface water; and increasing drought conditions to the east of the Cascades, which gets one-quarter the rainfall of the Puget Sound, due to climate change (EPA, 2016). The primary stimuli for Washington's water technology firms to innovate, however, has been the Clean Water Act of 1972, and the declaration of several areas of the Puget Sound as Superfund sites which meant federal mandates to local governments to carry out environmental remediation and to protect against further pollution. Despite the Great Recession and budget restrictions, the greatest source of demand for innovative water technologies seems to come from the public sector: public water, waste-water and storm-water treatment systems represent the largest customer group in the sector; demands for environmental remediation, such as the multi-decade cleanup of the Thea Foss & Wheeler-Osgood waterways, represent another source of demand; and the emerging requirements for technologies to support low impact development (City of Tacoma, 2011, 2015; Virgin, 2015; Green, Woodson & Zerr, 2016). These are areas for which there is growing national and global demand, worth potentially trillions of dollars over the next several decades, and several of the State's public water entities and private water technology firms have been making inroads into markets in Asia, South America, and Central America (Barringer, 2014; Virgin, 2015). The public utility industry, driven by demands to meet stringent regulations for water quality and pollution control, represents a sophisticated local consumer, a large and stable local market, and a platform from which to launch a globally competitive water technology industry.

C. Related & Supporting Industries

The success of water technology firms is closely linked to many related industries such as clean energy, oil and gas, and information and communication technologies, and supporting industries such as universities, research facilities, government agencies, and technology firms which provide direct inputs such as components or software. Tacoma and the Puget Sound region possesses both categories of industries. The Tacoma IPZ is directly supported by two universities – University of Washington Tacoma and Washington State University's Puyallup Research and Extension Center – and a new public-private research and public policy facility – the Center for Urban Waters. The offices of the United States Geological Service's Washington Water Science Center are in Tacoma a few blocks from UWT. It is a major resource for information on the State's rivers, streams and lakes, and its extensive satellite network of stream-gauging stations form the backbone of the state's flood-warning systems. This emphasis on supporting industries is related to the position that the water economy has political, social, economic and environmental aspects; and that solutions to problems in the water economy requires social and engineering solutions, and governance and regulation that goes beyond hard science (Stroo, 2014). There are, however, some concerns about the long-term research and technological capacity supporting the water technology industry. Concerns have been raised that too much of the research is closer to social science than the basic or applied science and technology which is required to build a viable technology sector (Miller,

2017).

The nature of water technology is evolving from devices that are primarily mechanical, towards devices that are primarily information and communication technology (ICT). Tacoma is well placed to leverage that trajectory because of the large concentration of ICT firms in Washington State, numbering about 14,000 firms, such as Microsoft and Infosys, employing about 200,000 people including game developers, programmers and software engineers (Washington State Department of Commerce, 2017). Technological trends in the water industry are going to be dominated by Big Data, the Internet of Things, online customer engagement, smart meters, machine learning and automation, leak detection, and real-time water quality monitoring sensors which require the incorporation of ICT into water devices (Siegel, 2015; Ben-Dak, 2017; Barclay's Impact Series, 2017). This trend towards more employment of ICT-related devices by water-intensive-and-water-enabled industries and water utilities, offers opportunities to reduce the waste of water, reduce the use of energy, increase the resilience of facilities, and streamline operational performance (Ben-Dak, 2017). The water utility industry is an energy intensive industry and Washington is emerging as a center for clean energy (Young, 2017). This also presents opportunities for mutually beneficial collaborations across two emerging clean industries – water and energy (Meola, 2016).

D. Firm Strategy, Structure, & Rivalry

The economic history and natural ecology of Tacoma and the Puget Sound have shaped firm strategy, industry structure and degree of rivalry of the water technology industry in Washington State. Older water technology firms arose to support logging and lumber, pulp and paper, chemicals, smelting, oil refining, and agriculture; current water technology firms, whether startup or well-established, are more likely to support clean manufacturing, water-and-energy conservation, waste-water treatment, storm-water treatment, environmental remediation, and low-impact development. Romac Industries of Bothell for example designs, manufactures, and sells water valves, couplings, sleeves, fittings and tools, and other pipe products for the water and waste-water industry. Romac's products are critical for keeping water and waste-water distribution, collection, and treatment systems operating efficiently and safely; however, the products are unseen to all but the engineers and technicians who work in the water industry (Virgin, 2015). The company was founded in 1969 with two employees and today its workforce stands at several hundred; its original offering was the first all stainless-steel repair clamp; its value proposition includes first-rate customer service, high quality products, continual innovation of new products, and fast product delivery. It invests consistently in R&D spending and in applying for new patents (Virgin, 2015; Bloomberg, 2017). Romac Industries has a simple supply chain because it keeps nearly all phases of manufacturing in-house - to include gaskets - to ensure that parts can be made to exact specifications, meet unique requirements, and ensure that design changes can be made quickly. Romac Industries is headquartered in Bothell, Washington with facilities in Seattle, Washington; Dallas, Texas; and Charlotte, North Carolina.

Itron of Liberty Lake is a world-leading technology and services company with a broad product portfolio that measures, manages and analyzes energy and water to ensure its efficient use. Some of the specific products include electricity, gas, water and thermal energy measurement devices and control technology. Other products include utility prepayment systems, including smart key, keypad, and smart card communication technologies; advanced and smart network collection technologies employing a range of handheld, mobile, and fixed devices; meter data management software; as well as knowledge management applications and consulting services (Bloomberg, 2017b). In 2013 the company claimed that a major contract in Mumbai, India for smart meters was able to cut water losses by 50% after installation of Intron's smart, remotely read meters (Bloomberg, 2013). The company, which was founded in 1977, now has 450 workers in Spokane and 2,200 worldwide; it has 27 manufacturing and 49 facilities; it has nearly 8,000 customers in more than 100 countries. It has annual revenues of more than $500 million (Dobosz, 2011; Bloomberg, 2017b). Intron has over the years acquired many companies to strengthen their portfolio; and it has also engaged in many partnerships with high technology companies. In 2013, Itron and Cisco formed an alliance to deliver Internet Protocol (IP) communications to the smart grid market revolutionizing networking capabilities for utilities. Itron is also a partner of Microsoft's CityNext, helping with global Smart City initiatives; and it is a founding member of the Smart Cities Council, having joined in 2013 (Bloomberg, 2017b). Itron has received numerous awards and recognition, to include national recognition from the White House in 2010 for its commitment to manufacturing in the United States and its contributions to a clean energy economy.

The oldest company in our discussion is Nelson Irrigation Corporation of Walla Walla, WA. Nelson has been associated with manufacturing and irrigation products for over 100 years when it opened as Central Brass and Stamping Company in Peoria, Illinois in 1911. This company later became L.R. Nelson Mfg. Co. Inc., which ultimately was sold in 1972. Nelson Irrigation was founded at the time of the sale and moved to

Walla Walla after the Port of Walla Walla provided a 15,000 square foot facility for manufacturing (Townsend, 2014). In the nearly four decades since its founding, Nelson irrigation has been an innovator in the agricultural irrigation industry where it designs, develops, manufactures, and sells irrigation products around the globe (Nelson, 2017). Its product range includes pivot products, sprinklers, irrigation control valves and systems, pressure regulators, spinners and sprays, sprinkler stakes and tube assemblies, and impact sprinklers for agricultural, environmental, and industrial applications (Bloomberg, 2017). The company also provides irrigation design software that helps dealers to create irrigation designs. It has sold millions of its products through a network of dealers and distributors worldwide; about one-third of its products are sold overseas; its annual revenues are almost $50 million; and it employs about 200 people (Townsend, 2014; Nelson, 2017; Bloomberg, 2017). Nelson Irrigation values innovation and the company has 74 active U.S. and foreign patents which it sees as key to its future competitive position. Its success in innovation and quality extends to processes, having designed a robot to assemble sprinklers and in seeking to achieve zero defects in its products (Townsend, 2014)

Finally, Northwest Pipe of Vancouver which is the largest manufacturer in North America of engineered steel pipes for water and waste-water utilities, the energy industry, and numerous other industrial applications from mining and quarrying, to agriculture, construction and structural work, and fire protection. Northwest Pipe Company was founded in 1966 in Clackamas, Oregon with 20 employees. The company initially focused on the agriculture and wood products market before growing to become a major West Coast producer of steel pipe for the water and energy markets; at its peak it grew to

50 employees in Vancouver and 1,200 others across the United states, although it has been recently forced to restructure and downsize its workforce to 650 globally. It has annual revenues of close to $500 million (Copenhaver, 2016). The company has faced mixed fortunes over the years. In its first decade the company struggled to build market share; it was hard hit by the Great Recession; in recent years it has once again sustained losses, been plagued by overcapacity, and has had to lay off staff and close plants; it is looking to lean manufacturing to improve productivity; and it is refocusing on its core business, water transmission pipes (Sherwood, 2013; Copenhaver, 2016). Luckily for Northwest Pipes, welded steel pipes for water transmission involves the manufacturing and supply of a completely engineered system that will stand up to soil pressure, the corrosive characteristics in any type of soil, and have the flow characteristics that meet the customer specifications, making it a process that is anything but routine and hard to replicate (Farr, 2015). Despite its internal challenges, Northwest Pipe continues to innovate. One recent example is a partnership with Portland-based Lucid Energy to jointly develop and commercialize a steel pipe that generates electricity when water runs through it. In 2012, Portland, Oregon signed a contract to be the first city to test out this emerging technology (Sherwood, 2013). Northwest Pipe is also betting that its future will lie significantly with infrastructure, which has the potential to make its business portfolio more stable to the effects of economic cycles. Northwest Pipes believes that the water transmission side of Northwest Pipe's business, which is driven by long-term city water projects and population demographics, is looking strong. It is concerned that much of the rest of its business portfolio will likely lag in the coming years (Sherwood, 2013; Bell, 2009). In 2012, Northwest Pipe signed a $69 million deal to supply pipeline to a water

project in Texas. It is hoping to win a contract for as much as $50 million in pipes, out of a planned $274 million Michigan water project (Bell, 2009). Northwest Pipes is also pursuing remedies against foreign competitors with the International Trade Commission, which is currently reviewing oil-pipe imports from nine countries. If Northwest Pipe gets its way, imports from these countries would face new tariffs, making its products more competitive in this country.

These four firms suggest that the firms in the water technology innovation cluster do not face the vigorous local rivalry that can stimulate productivity and competitiveness by creating a pressure to upgrade factors, innovate processes and products, and find new markets. For older firms there may even be a measure of path-dependency which comes from the local economic context in which these firms arose. However, all the firms discussed demonstrate that competitive firms must continually evolve or reinvent themselves to remain relevant in the marketplace. Washington State's water technology firms are more likely to face competition from overseas, which can be particularly challenging for firms whose products involve more basic and easily replicated technologies; however, technologies like trench-less piping are complete engineering solutions that go beyond simply supplying pipes. In markets for these specialized products and services, Washington firms like Northwest Pipes continue to have a competitive advantage for the near future. There appears to be a trend whereby firms are upgrading their competitive capacity by employing advanced factors, focusing on core strengths, and leverage capabilities unique to the firm to gain a competitive advantage. This trend is particularly strong when water technology firms can draw on the considerable ICT capacity and capabilities available in the Seattle region.

E. Role of Government and Chance Events

The role of government and chance events does not directly create innovative and competitive firms, but it can be significant in shaping the direction and magnitude of each of the four determinants, by influencing how the determinants interact, by shaping the context in which firms must compete, or by creating the incentives or disincentives which firms face. The first way in which government can support the development of clusters and encourage the growth of competitive firms and industries is through its procurement, especially for infrastructure, and acting as a demanding customer (Porter, 1990, 1998, 2000). Both Intron and Northwest Pipes depend to a considerable degree on municipal projects for fresh, waste and storm water systems.

A second way in which government can support the upgrading of existing clusters, the entry of new firms with innovative technologies, and encourage the growth of competitive firms and industries is through more stringent health, safety and environmental regulations which raise product, process or performance standards (Porter, 1990, 1998, 2000). The Clean Water Act (1972), the designation of Commencement Bay as a Superfund Site, and other regulations for waste and storm-water have encouraged technicians, city engineers, public utilities, universities, and private water technology firms to invest in the science and practice of water resource management, and to find innovative solutions to prevent pollution and to restore natural ecosystems damaged by years of uncontrolled pollution. The startup Pure Stormwater of Silverdale, Washington, is an example of a technology firm rising to the challenge of reducing pollutants in storm-water, which is now the greatest sources of pollution in U.S. waterways. Pure Stormwater is developing a line of storm drain filtration basins to filter hydrocarbons, metals and other contaminants from storm-water before it enters the storm drain system and flows out into local bodies of water (Jerome, 2015; Kelly, 2015).

A third way in which government can support the upgrading of existing clusters, or nurture nascent clusters, is through support for education and training which promotes the creation of advanced and specialized factors. In support of Tacoma's IPZ, the State government allocated $2 million to the University of Washington Tacoma for a new laboratory at the Tacoma Campus, and $800,000 for specialized equipment for the laboratory at the Center for Urban Waters. The state government also allocated $800,000 to Washington State University's Puyallup Research and Extension Center to modify its Salmon Toxicology Lab into a multi-use Aquatic Toxicology Lab (UWT, 2017). A Port of Tacoma Endowed Chair was created for the UWT, and this was funded by four contributors: The Port of Tacoma with $1 million, the City of Tacoma and SSA Marine with $500,000 each, and the UWT Foundation with $1 million.

A fourth way in which the government can support the upgrading of existing clusters, or nurture nascent clusters, is through public-private economic development partnerships, especially when there is the absence of an industry association. Washington's IPZ program encourages regions to form partnerships between public and private sector organizations, academic and research institutions, and workforce education and training entities, to address regional economic challenges, grow firms, create jobs, develop patentable ideas, and commercialize viable technologies. Washington State lacks a dedicated water technology industry association; and although many industry stakeholders see the value of a vibrant cluster and a strong industry association, “it remains a fragmented and semi-organized affair" (Virgin, 2015). Tacoma's IPZ is attempting to address this absence and has brought together the City of Tacoma, the Port of Tacoma, the University of Washington Tacoma, the Economic Development Board for Tacoma-Pierce County, the Tacoma Community College, the Institute for Environmental Research and Education, and several private water technology firms. Here, though, governments acting in the role of industry facilitator should proceed with caution, as industry associations tend to serve as better advocates for private capital (Porter, 1990, 1998, 2000).

Chance events, although they are beyond the control of firms, can play an important role in stimulating innovation and entrepreneurship and in shifting competitive advantage in many industries. One example involves Northwest Pipe in the early 1980s, when the company was pivotal in alleviating the water issues which stemmed from the eruption of Mount St. Helens in Washington in 1980. After the eruption the U.S. Army Corps of Engineers used 3,600 feet of pipe manufactured by Northwest to divert water from a failing dam away from several endangered communities. The pipe – which was buried in trenches carved through avalanche rubble, volcanic ash, sinkholes, erosion channels and enormous chunks of ice - maintained its integrity despite the continuous shifting of the ground. This project demonstrated the effectiveness of Northwest's products and services and contributed to the company's growth at the time (Farr, 2015). The success of individual firms, and of entire clusters, is not guaranteed, even if governments and private actors actively work to establish a viable, growing cluster. One example is Hydrovolts, the Seattle startup, which has been developing generators that produce clean power, but which work off existing flows of water like those found in irrigation canals, municipal waterways, industrial waterfalls, as well as in tidal currents (Bloomberg, 2017). Hydrovolts' turbines don't require expensive new infrastructure; and although they generate only 1 to 20 kilowatts each, depending on stream velocity, they can be grouped to produce more power. Hydrovolts was founded in 2007 as Puget Sound Tidal Power, after its future Chief Executive Officer was hired to help the City of Tacoma explore tidal energy opportunities in the Tacoma Narrows waterway. Although the conclusion was that the Puget Sound had promising hydro-kinetics potential, the environmental regulations and permitting burdens in the Sound's waterways were insurmountable at a large scale. The company, which won the 2011 Water-Energy Nexus Prize in San Francisco for its technology, and raised $1.5 million in 2012 alone, had been missing milestones, hemorrhaging money, and been unable to raise new cash to help close potential sales. Although it raised a total of $2.8 million from angel investors, Hydrovolts argued that raising additional funds was difficult in an investment climate that was more familiar with the business models of information and communication technology firms (Romano, 2013). Hydrovolts had estimated a market with huge potential both in the United States and in the developing world and had been buoyed by early interest from an Indian energy firm that had wanted to install 400 turbines on the Chilla Canal that feeds into the Ganges River (Chard, 2010). Hydrovolts had been looking to 2013 to start commercializing its turbines and had been targeting its systems for use in factories, water treatment plants and wastewater facilities (Cook, 2013).

X. Conclusions

The City of Tacoma is in one of the most vibrant regional economies in the United States and is home to many of the country's leading technology and service firms. Many of these globally competitive firms are in clusters for information technology, aerospace, logging and paper, and several others. Some of these clusters are well-established – like information technology and aerospace – some are emerging – like wine – and others are nascent – like water technology. Tacoma and the Puget Sound region in which it is situated have had a long economic relationship to water through natural resource exploitation, transportation and logistics, and urban development; and that economic relationship has been historically responsible for generating considerable pollution, which was dumped untreated into the waterways of the Sound causing considerable environmental damage to the region’s ecosystems. Decades of efforts to clean up the pollution and current efforts to prevent further pollution from both industrial sources and urban development have resulted in Tacoma accumulating considerable expertise in potentially valuable areas of environmental science and management. Washington State is also home to a small number of water technology firms which emerged to offer products and services for Washington's water intensive and water enabled industries. As the state's industries have evolved these firms – and the new ones that emerge – are evolving to serve emerging markets both in the United States and globally.

The Washington State water industry in general, and the water technology industry, is fragmented and semi-organized, like it is over much of the United States. No industry association yet represents the water technology industry; however, the State of Washington and the City of Tacoma have been working since 2011 to promote the Urban Clean Water Technology Zone under the state's Innovation Partnership Zone program. This program is meant to provide both the “hard” and “soft” infrastructure necessary for building and sustaining a water technology cluster. These two infrastructures are best exemplified by the Center for Urban Waters with the “hard” infrastructure – of research facilities – and the “soft” infrastructure– of partnerships and collaborations. Progress has been slow and faulty, but clusters take decades to build and Tacoma's water technology innovation is in its very early stages. Part of the challenge that Tacoma faces, when compared to advanced water technology innovation clusters in places like Israel and Singapore, is that water scarcity and water security pose more compelling and immediate reasons for upgrading industry clusters. When compared to emerging clusters in places like Milwaukee and Cincinnati, some places are simply further along in the process of building a cluster and have a larger and more geographically concentrated set of partners than Tacoma, for whom the technology firms are scattered across the state serving a diverse market of public and private customers with very different needs. Tacoma's challenge will be to move from a public-sector led and dominated initiative to one where a dedicated industry association represents the interests of Washington State's water technology firms.

CHAPTER 8

WATER TECHNOLOGY CLUSTERS IN THE NETHERLANDS

I. Introduction: Water in the Netherlands

The Netherlands, situated in the north-west corner of Europe, has been described as a hydraulic society because of its historic relationship with water. Dutch social, political and economic development has been significantly shaped by collective measures to manage both salt and fresh water. Dealing for more than eight centuries with a constant stream of water challenges forced Dutch society to produce continuous innovations in science, engineering, economics and governance to protect the people from the hazards associated with water, to secure an ample supply of freshwater, and to facilitate economic development (Lintsen, 2002; Metz & van den Heuvel, 2012; Lonnquest et al., 2014). For the Dutch, water has always been either too little, too much, too salty, or too dirty; and from addressing these challenges its scientists, engineers, policymakers, and administrators have accumulated considerable experience with water management, coastal protection, land reclamation, water supply, water quality, water reuse, the treatment of industrial waste-water, and the reintroduction of "used" water into the water cycle.

The management of water has transformed The Netherlands into one of the most physically engineered landscapes on the planet: about 17% of the country's current land mass has been reclaimed from the sea and lakes, and without polders, dunes and dykes 60% of the Netherlands would regularly be flooded (Lintsen, 2002; Metz & van den

Heuvel, 2012; Lonnquest et al., 2014). Despite the risks posed by water - with about one-quarter of its area and almost half of its population located below sea level - the Dutch have engineered one of the safest delta regions in the world. Water is both a threat and a resource essential to life, so the water sector is, more than any other, fundamental to Dutch culture and character. The Dutch water economy is the long-term result of a complex and constantly evolving interplay of climate, geography, population, economics and politics with water being both adversary and ally.

The Netherlands that emerged spatially, environmentally, and culturally is therefore a result of centuries of evolving and adapting to water management; yet despite these physical constraints and limited natural resources, the Dutch have created one of the most productive and competitive economies on the planet. (Lintsen, 2002; Metz & van den Heuvel, 2012; Lonnquest et al., 2014). The Dutch government sees the water sector as one of nine 'top-sectors' in the economy with three primary focus areas - water technology; maritime technology; and delta technology - and these are concerned with protecting the land, conserving or generating renewable energy, designing, building, and operating safe and efficient ships, and developing and commercializing smart technologies for water recycling (OECD, 2014). The ‘top sectors’ approach is a form of innovation and industrial policy which focuses public resources on specific sectors and seeks to foster the co-ordination between businesses, knowledge institutions, and government actors to make these sectors more competitive. Dutch policy recognizes that water is essential for the health and well-being of its citizens, its industries, and its agriculture; that technological advantage translates into competitive advantage; that Dutch expertise in water technology and management is traded worldwide; and that water is therefore a key element of economic development (Top Team Water, 2011).

There are several drivers and enablers behind the development of world-class Dutch expertise in water resource management and water technology (hollandtradeandinvest.com, 2017). Here drivers are structural features of a social, economic or ecological system to which society must respond; while enablers are areas for the exercise of human agency where society can respond to the wider social, economic, and environmental system in which it finds itself. The first driver is the country's geography and the exposure of Dutch society to both long-term and man-made climate changes (Lintsen, 2002; Metz & van den Heuvel, 2012; Lonnquest et al., 2014). The second driver is the long-term trend of a growing population, expanding economy and urbanization which puts pressure on scarce fresh water resources, but also threatened that fresh water with increasing pollution (Lintsen, 2002; Metz & van den Heuvel, 2012; Lonnquest et al., 2014). The first enabler is good governance and robust institutions, which the Dutch have gradually developed over considerable time to allocate roles and responsibilities, distribute benefits and burdens, ensure the availability of sufficient financial resources, and create networks for collaboration and coordination (Lintsen, 2002; Lonnquest et al., 2014). The second enabler is the development of knowledge and skills which translate into technologies, policies, and practices for the improved management of water resources (Lintsen, 2002; Metz & van den Heuvel, 2012; Lonnquest et al., 2014). Here the Dutch developed scientific and engineering training and world-class educational institutions; systematically recorded, stored and disseminated information on water resource management and flood control; and invested both public and private resources in R&D, and now possess world-class research institutions. The final enabler is the increasingly integrated manner in which water resources are managed, with the singular reliance on engineering, or 'hard', solutions giving way to multi-disciplinary approaches that balance social, economic, environmental and engineering needs, and an emerging philosophy of working with nature rather than 'taming' her (Lintsen, 2002; Metz & van den Heuvel, 2012; Lonnquest et al., 2014).

This chapter will show the following: (1) The Netherland's historical relationship with water and how development of a national water economy was critical for underpinning its key political institutions and economic development; (2) The Netherland's governance and institutional framework and how the country's political leaders and technocrats gradually developed policies and institutions that are developing a financially and ecologically sustainable water economy; (3) The Netherland's water resource management strategy and how it evolved exclusively from a technological and engineering orientation to a strategy that employs a combination of economics, science and technology to deliver a reliable supply of fresh water; (4) The Netherland's innovation and economic development strategy and how it is continually upgrading its historic expertise in water resource management and water-related technologies; and (5) The Netherland's competitive position in relations to its water technology sector and how the country is working to maintain its position as a major global exporter of flood control and water quality technologies.

II. History of the Dutch Water Economy

The development of Dutch society, and of its the political and civic institutions, can be understood through an examination of the processes of change and adaptation in response to dynamic societal, ecological and climatological conditions. The history of the

Dutch water economy can be divided into roughly five periods. Each period reflects important changes - in the roles of national and local governments in water infrastructure development and management, in the state of hydraulic technology and scientific knowledge about water, and of socio-economic and demographic factors.

Each of these periods can be understood in terms of tensions between competing philosophies of water policy and management, between various stakeholders and their economic and political interests, and between the technical and organizational approach to addressing the ever-present threat of flooding. Each of these tensions could be conceptualized as Dutch society being presented options that fall along a spectrum between the following: centralization versus decentralization of political authority; continuity versus path dependence of institutions; craft versus rational-scientific orientation of water professionals; economic development versus the limited fiscal capacity of the state to effect projects; flood control and public safety versus hydro-logical and hydraulic knowledge; and project engineering versus technological capability (Lintsen, 2002; Lonnquest et al., 2014).

The five periods in the history of the Dutch water economy also provides insights into the process of institutional change and the diffusion of innovations within a hierarchical socio-technological system which eventually emerges, coalesces, and diffuses to create paradigm shifts in the form and function of the Dutch water economy (Geels, 2002; Geels & Schot, 2007). One example of the paradigm shift in the Dutch institutional and socio-technological landscape was the process of the diffusion of innovations in sanitation and hygiene, which took place roughly between 1870 and 1930 (Geels, 2002). This shift was possible because of the convergence of a number of factors, reinforcing the idea that institutional change and the diffusion of innovation takes place within a context: the expansion of the economy, population and urban centers; the development of specific water technologies; the increase in knowledge about diseases and their causes; the changes in cultural practices surrounding hygiene; and changes in public attitudes about the proper role of the state, and what should be collective versus individual spheres of responsibility (Geels, 2002; Geels & Schot, 2007).

Socio-technical systems exist at several levels within a hierarchy. At the macro-level, or socio-technical landscape, economic and demographic expansion stimulated considerable urbanization, which ultimately reshaped the Dutch water economy (Berkhout, Smith, & Stirling, 2004). Urbanization and economic and population growth became important landscape drivers for the building of water and sewerage infrastructure; while geography, geology, and the state of public finances were important constraints which influenced which Dutch cities led the way in developing water and sanitation systems (Geels, 2002; Lintsen, 2002; Lonnquest et al., 2014). Local factors therefore created conditions in which a few (Geels, 2002). The initial driver for the provision of piped water was economic development; concerns for hygiene and public health came later.

At the meso-level, or socio-technical regime, changes in institutions, technologies, practices, values and attitudes, and industry structures ultimately affected the water economy (Berkhout, Smith, & Stirling, 2004). Coinciding with the change in the fiscal landscape were changes in attitudes about the appropriate level and type of state intervention in favor of a more interventionist state (Lintsen, 2002; Lonnquest et al., 2014). The absence of public water and sewerage systems meant that a limited market was opened for the private sector to supply water to those who could afford it, while more wealthy people made provisions for the independent supply of water through wells and catchment systems. Over time, solving the quantitative and qualitative problems of water supply stimulated a demand-pull for water and sewerage infrastructure at a scale beyond that which could be provided by the private sector. Also, at the meso-level, insights from new medical theories about disease and germs gradually began to take hold in the medical and public health fields; and new attitudes about personal hygiene and cleanliness slowly diffused from a more socially conscious urban elite to the working classes (Geels, 2002).

The micro-level, or socio-technical niche, is were fledgling technologies or radical innovations develop and take root (Berkhout, Smith, & Stirling, 2004). In the 1860s Louis Pasteur developed a new theory about the origin of disease based on micro-organisms; in 1854 John Snow, a skeptic of the then-dominant miasma theory of diseases, traced the source of a cholera outbreak in Soho, London and launched the field of epidemiology; and greater affluence drove increasing demand for water closets, showers, baths, and soap - all of which had been available for decades, but subject to very limited demand and therefore high cost. The dynamics of change within institutions and socio-technological systems can be seen at work in the following five periods.

A. Period 1 - Pre-1795

The period before 1795 is often referred to as the period of the Dutch *Ancien Regime.* It was characterized by a laissez-faire political and economic regime with a decentralized form of Republican government, which resulted in decentralized water governance and management with local governments and private bodies taking primary responsibility for all aspects of water resource management (Lintsen, 2002; Lonnquest et al., 2014). The numerous local water boards that gradually emerged after the 11th Century are the oldest civil water management and democratic institutions in the Netherlands, and their scale and scope were largely determine by local geographic and hydraulic characteristics. The primary focus of the water boards was flood protection and over time they designed and constructed increasingly sophisticated water works, which delivered increasing levels of flood protection, created a pool of hydraulic expertise, and contributed considerably to economic, social, and cultural development.

B. Period 2 - 1798-1848.

The period between 1798 and 1848 was shaped by the ideas of the Enlightenment, by the French Revolution, and by the 'enlightened despotism' associated with monarchy which led to the rise of national, and increasingly centralized, institutions in water management. Dutch society was influenced by the intellectual, scientific and political changes sweeping Europe which inspired it to seek new solutions to its increasing struggle to manage water. The political and institutional reforms of this period were to have a lasting impact of Dutch society and the water economy. What occurred in this period was a long political struggle to create national institutions to manage and finance complex, large-scale hydraulic projects; an equally long intellectual struggle to find technocratic and scientific solutions to hydraulic projects of increasing scale and scope; and the gradual rise of a national cadre of formally trained hydraulic engineers (Lintsen, 2002; Lonnquest et al., 2014).

This period of Dutch history in water management was fraught with tension and political struggles between factions who sought to institutionalize the French model of professionalized bureaucratic-centralization, and those who sought to maintain the Dutch model of craft democratic-decentralization (Lintsen, 2002; Lonnquest et al., 2014). Complete centralization failed primarily because of fractured politics, and also because central government at that time lacked the financial resources, technical knowledge, skilled personnel, and legal instruments available at the local and regional level; complete decentralization also failed because regional and local governments lacked the capacity to manage and finance large projects; and both regimes were weakened by a lack of clarity about the division of responsibilities between the various scales of government (Lintsen, 2002; Lonnquest et al., 2014). The result was a working political compromise between the two extremes, which emerged after 1815 and remained in place until 1848.

Behind this period of political tension and turmoil several important developments in water management took place. Administratively, a national water resources organization, the Rijkswaterstaat, was established in 1898, and national water management was divided into coastal water management, river management, and internal water management; water management gradually became subject to legal rules and standardized practices; a formal bureaucracy gradually emerged with hierarchical roles and responsibilities, and staff positions emerged with detailed and formal job descriptions (Lintsen, 2002; Lonnquest et al., 2014). Professionally, formal training grounded in science and scholarship was established at national institutions, and gradually a cadre of trained, professional engineers and administrators emerged (Lintsen, 2002; Lonnquest et al., 2014). Intellectually, empirical knowledge about water management was systematical collected, centrally archived, and available to all involved in water resource management; the collection of metrics on rivers and water quality, the creation of a river atlas, and the performing of technical-scientific research into hydrology and hydraulics were begun; and the formal evaluations of water hazards, and the coordination of national responses to flooding and other natural disasters were instituted (Lintsen, 2002; Lonnquest et al., 2014).

Dutch success as a colonial power and a capitalist state also brought enormous wealth, strengthened the fiscal base of the national government, and compensated for the fact that the Netherlands was slow to industrialize in the 19th Century compared to several other Western European nations. These developments in Dutch water governance and management indicate a combination of continuity and path dependence, as well as incremental change and adaptation; and it also indicates the long time-frame necessary for institutional change to take place.

C. 1848-1900

The period between 1848 and 1900 which saw the emergence of liberal democracy, a strong central state, and national water projects. The national government became increasingly entrepreneurial and willing and able to deploy public resources for the expansion and modernization of key infrastructure projects that were in the national interest, that supported economic development, and that maintained or improved the country's competitiveness (Lintsen, 2002; Lonnquest et al., 2014). This change in policy took place for several reasons: (1) a peaceful revolution in 1848 by liberal politicians laid the foundations of the modern liberal-democratic state, and a series of constitutional, legal, financial, and trade reforms provided the framework for improved management of the Dutch water economy (Lintsen, 2002; Lonnquest et al., 2014); (2) civil engineering and geographic knowledge increased, civil and mechanical technologies improved, and new construction materials were developed that facilitated larger and more complex water infrastructure projects (Lintsen, 2002; Lonnquest et al., 2014); (3) the growth of tertiary institutions for the training of civilian engineers, and trade schools for the training of laborers, expanded the number of people with scientific, theoretical, and technological skills, and increased their social and professional status and political influence (Lintsen, 2002; Lonnquest et al., 2014); (4) public finances improved as the Dutch economy expanded in the context of increasing world trade, the reduction in protectionism, and the intensive exploitation of Dutch colonies (Lintsen, 2002; Lonnquest et al., 2014); (5) the establishment in 1887 of the Ministry of Public Works, Trade and Industry consolidated the core related development portfolios of infrastructure, trade and industry and increased the profile and influence of engineers and other technocrats, facilitating the implementation of large scale projects of increasing complexity (Lintsen, 2002; Lonnquest et al., 2014); and (6) economic development increased demand for access to ports and navigable waterways in support of commerce, and to more fresh water to support an increasing population, urbanization, and the growing needs of agriculture (Lintsen, 2002; Lonnquest et al., 2014).

All these changes were built upon the experience of the previous half century; however, it is important to recognize that improvements to water infrastructure and water resource management also required the co-evolution of geographic, geodetic, and cartographic infrastructure alongside developments in the legal, institutional, educational, and fiscal infrastructure of the Netherlands (Lintsen, 2002; Lonnquest et al., 2014). The scale and scope of projects required innovations in organizational structures and contractual arrangements: the result was a rise in public-private partnerships and a new division of responsibilities with local entrepreneurs and business associations being actively involved in project financing and implementation, and the Dutch state underwriting project risk (Lintsen, 2002; Lonnquest et al., 2014). The Constitution of 1848 and the growth of enabling legislation clearly defined the relationship between the different levels of government, allowing Dutch water management to pragmatically and gradually evolve to became one of co-governance between the various scales of government; it began to resolve the issue of fragmentation; and it afforded a greater role for parliament and civil society in decision-making about water management and infrastructure (Lintsen, 2002; Lonnquest et al., 2014). One unintended consequence of these political changes and the increasing technological complexity of water projects was an increase in the time for decision-making: projects which historically took 6 years to approve now took on average 12 years to proceed through the decision-making process (Lintsen, 2002; Lonnquest et al., 2014).

D. 1900-1970

The period between 1900 and 1970, which saw the rise of an industrial economy, the welfare state, centralized planning, and a water technocracy. In this period Dutch water resource management became a 'hydraulic technocracy'; the scale, scope, and complexity of water projects increased; the approach to infrastructure development moved from planning and implementing individual projects to regional and national systems of projects; the balance of power over technical policy areas shifted from lawyers and bureaucrats to engineers; and hydraulic administration became more centralized and less fragmented (Lintsen, 2002; Lonnquest et al., 2014). In the governing regime of a hydraulic technocracy, engineers tackle problems in accordance with their scientific and technical training, and expert knowledge; empirical knowledge is replaced by theory, modeling, and experimentation; traditional 'shop culture' is replaced by 'school culture'; and technocrats define problems, identify solutions, and take decisions without the input or opinions of non-experts (Lintsen, 2002; Lonnquest et al., 2014). In this context the balance of power among actors in the field of water resource management shifted in favor of the central government and its agencies – a process started over 100 years earlier – and national standards and practices were increasingly imposed on the water boards, thus encroaching on their autonomy (Lintsen, 2002; Lonnquest et al., 2014).

The ascendancy of a hydraulic technocracy would not have been possible without a number of complementary developments: the Polytechnical School – which focused on the education of civil, marine, mechanical, and mining engineers – was elevated to university status in 1905; new engineering schools were opened over several decades; knowledge in fields such as coastal engineering, flood control, soil mechanics, and foundation engineering increased; and each project became a lesson for the subsequent projects of greater complexity as engineers built on the knowledge and experience of subsequent generations of civil engineers (Lintsen, 2002; Lonnquest et al., 2014). The gradual development of a hydraulic technocracy took place within the wider context of the rise of an interventionist state, a process which began in the 1890s, gained momentum after World War I and the Great Depression, and was fully in place by the of World War II (Lintsen, 2002; Lonnquest et al., 2014). Within the philosophy of modernization, the state was seen as modern, efficient, and effective and the marriage of politics and technology was seen as capable of addressing societal problems.

Widespread environmental criticism was suppressed as both public policy and public opinion favored modernization, rapid economic growth, full employment, and low inflation. Environmental values were largely subordinated to the dominant technocratic and economic orientation of the technocrats (Lintsen, 2002; Disco, 2002; Lonnquest et al., 2014). By the end of the 1960s, however, the primacy of the hydraulic technocracy, and their application of 'hard' engineering solutions to most water management problems, came under challenge with the emergence of the environmental movement (Lintsen, 2002; Metz & van den Heuvel, 2012; Lonnquest et al., 2014). High levels of economic development, improvements in the standard of living of the Dutch people, the emergence of an affluent post-war generation, the reduction in risks from natural hazards through the taming of the country's waters, a slowing of growth and productivity, and competing fiscal demands from the emerging welfare state converged to encouraged a shift in national priorities away from flood control to concerns over water quality and environmental health (Lintsen, 2002; Metz & van den Heuvel, 2012; Lonnquest et al., 2014). The high capital and maintenance costs of 'hard' engineering solutions also put pressure on the hydraulic technocracy to find less expensive solutions that worked with nature while preserving the natural environment (Lintsen, 2002; Lonnquest et al., 2014).

E. 1970 to present

The period after 1970 saw a reduction in public faith in grand technological solutions to water management and the rise of concerns for environmental protection and sustainable development (Lintsen, 2002; Lonnquest et al., 2014).

III. The Rijkswaterstaat

A. Overview

The Rijkswaterstaat is the Dutch national water resources organization, but it is also responsible for other types of public works. The Rijkswaterstaat is geographically and culturally specific to The Netherlands and it has had a profound impact on the physical and cultural landscape of the country (Lintsen, 2002; Van Den Brink, 2009; Lonnquest et al., 2014). It was founded in 1798 but has undergone numerous changes in role, organization, and practice over the last 200 years in response to social, political, economic, environmental, demographic, and technological changes in The Netherlands (Lintsen, 2002; Van Den Brink, 2009; Lonnquest et al., 2014). The Rijkswaterstaat therefore operates in a complex and evolving environment: it must work with many other agencies and actors, both public and private, to influence and implement public works and infrastructure.

The Rijkswaterstaat is considered to belong to the non-commercial service cluster and the innovation models which best describes this agency are that of 'knowledge creator and diffuser' and 'knowledge absorber' (Roelandt et al., 1999). The Rijkswaterstaat is a knowledge intensive agency that creates and supplies innovations through its research to its sub-contractors and water resource partners at lower political scales; and it also absorbs innovations from its suppliers, sub-contractors, and research partners. The Rijkswaterstaat contributes significantly to innovation in the Netherlands in its role as a demanding and sophisticated purchaser of engineering services.

B. 1798 to 1848

In this period the Rijkswaterstaat played a limited role in the provision of infrastructure because of fiscal and human resources constraints, because of a profound lack of theoretical insights and authoritative central expertise in water management, and because of the lingering tradition of laissez-faire policies of the liberal political and economic state which actively discouraged national expenditure on public works (Lintsen, 2002; Lonnquest et al., 2014). The driver for the establishment of the Rijkswaterstaat, then, was the political imperative of centralization by the new government rather than economic needs or the threat from water hazards. Probably the most important role of the Rijkswaterstaat in this period was the collection and organization of all types of knowledge about the practice of hydraulic engineering as it had been carried out by water practitioners (Lintsen, 2002; Lonnquest et al., 2014). During this period a cadre of professional engineers was slowly created, which received their education in civil engineering at the Military Academy at Breda; however, this trend in moving from a craft to a military tradition proved, in hindsight, to be ultimately far from satisfactory in overcoming deficiencies in human resources and engineering knowledge (Lintsen, 2002; Lonnquest et al., 2014). A turning point in education came in 1842 when the national program of studies in civil engineering was moved to the civilian Royal Academy in Delft.

C. 1848 to 1900

In this period, the Rijkswaterstaat played an increasing role in the provision of infrastructure as the national government became increasingly willing and able to deploy public resources for infrastructure projects that supported national development and were in the national interest (Lintsen, 2002; Lonnquest et al., 2014). The roles and responsibilities of the provinces and the national government became more clearly demarcated with the provinces establishing public works departments and the Rijkswaterstaat focusing on national projects that crossed provincial boundaries (Lintsen, 2002; Lonnquest et al., 2014). Projects of increasingly scale and scope became feasible with the application of steam, dredging and excavating technology; and the actual construction of many projects was delegated to private contractors, which developed indigenous civil and hydraulic engineering capacity (Lintsen, 2002; Lonnquest et al., 2014). The selection and education of the engineers and supervisors, and the acquisition of knowledge, was adapted to modern times: personnel were increasingly recruited through competitive examinations, for which the acquisition of theoretical knowledge became more important; and for those who wished advancement; and to legitimate their authority, the acquisition of formal education became necessary (Lintsen, 2002; Lonnquest et al., 2014). Although water resource management remained decidedly Dutch in its character, French and German water resource management and engineering sources were studied, much trial and error experimentation took place and the results duly reported, and Dutch contractors acquired much knowledge and equipment from British contractors employed to assist with major projects (Lintsen, 2002; Lonnquest et al., 2014). By the end of the 19th Century, Dutch knowledge, skills, and innovative ability developed to the point that the Rijkswaterstaat no longer needed to employ foreign contractors.

D. 1900 to 1970

In this period, the Rijkswaterstaat was now fully committed to scientific water management and had the expertise, political backing, technology, and increasingly the resources to put this into practice (Lintsen, 2002; Lonnquest et al., 2014). Dutch hydraulic imagination began to conceive of flood control, navigation, and fresh water supply projects and programs of increasingly complexity, scale and scope; new technologies, such as steel reinforced concrete and electrical power, were applied and their impact carefully studied so that these promising new technologies could be effectively and efficiently integrated into the management and organizational structure (Lintsen, 2002; Lonnquest et al., 2014).

Technical and vocational education was expanded further with the establishment of two new technical universities - at Eindhoven in 1956 and Twente in 1961 - and several technical colleges. There was a major expansion in flood and storm control infrastructure along the coast, polders to create freshwater lakes, and projects to better manage and protect the country's fresh water resources (Lintsen, 2002; Lonnquest et al., 2014). The Rijkswaterstaat also began to develop a more proactive engineering culture, but the major floods of 1916 and 1953 provided the powerful political catalysts for implementing costly engineering plans. The Zuiderzee Works – a man-made system of dams and dikes, land reclamation and water drainage works in the northwest that dammed the Zuiderzee from the North Sea - was implemented in phases between 1920 and 1978; and the Delta Plan - a major flood protection scheme in the southwestern delta region - was implemented between 1954 and 1986. In this climate of political stability, respect for authority, general confidence in technical solutions, and a growing government budget, the Rijkswaterstaat's power grew to unprecedented heights (Lintsen, 2002; Lonnquest et al., 2014).

E. 1970 to Present

In the period after 1970, environmental and budgetary concerns, and political pressures, forced a shift in the policies and practices of the Rijkswaterstaat (Lintsen, 2002; Van Den Brink, 2009; Lonnquest et al., 2014). The two traditional pillars of Dutch national water management - floods and waterways - were joined by a third, water quality; and new, large-scale, engineered projects gave way towards maintenance of existing infrastructure, 'soft' solutions, or the application of the lessons from nature to solve engineering challenges (Lintsen, 2002; Van Den Brink, 2009; Metz & van den Heuvel, 2012; Lonnquest et al., 2014). The prestige that the Rijkswaterstaat had acquired in the previous 70 years was undermined, its engineering approach was criticized as environmentally and economically unsustainable, the public's general faith in modernization, technology and progress was diminished, and the agency personnel shrank from 14,000 in 1982 to 9,600 in 1994, but this rose in recent years to about 12,000 people. The agency was accused of destroying the landscape and harming the environment, of operating with a lack of transparency and accountability, and manipulating water management and infrastructure in the Netherlands (Lintsen, 2002; Disco, 2002; Van Den Brink, 2009; Lonnquest et al., 2014). After 1994 the agency underwent a cultural and organizational transformation: its budget and the number of personnel began to grow; biologists, ecologists, planners and behavioral experts began to take their place alongside engineers; planning and design became more inter-disciplinary and integrated; and civil society was once again included in decision-making (Lintsen, 2002; Van Der Brugge, Rotmans & Loorbach, 2005; Van Den Brink, 2009; Lonnquest et al., 2014).

IV. The Zuiderzee Works

The Zuiderzee Works is the largest hydraulic engineering project undertaken by

The Netherlands during the twentieth century and is considered by some as an engineering wonder of the modern world (Lonnquest et al., 2014). The works were performed in several steps from 1920 to 1975 and involved the damming of the Zuiderzee, a large but shallow inlet of the North Sea, and the reclamation of large tracts of land from the newly enclosed body of water behind those dams (Borger, Kluiving &. De Kraker, 2010; Lonnquest et al., 2014). The main purposes of the project were to protect the central Netherlands from the North Sea, improve flood protection, and create additional land for agriculture works (Lintsen, 2002; Van der Vleuten & Disco, 2004; Borger, Kluiving &. De Kraker, 2010; Lonnquest et al., 2014; Lonnquest et al., 2014). The works consists of a system of man-made dams, dikes, and water drainage works; and it represented the culmination of a battle with water that lasted 700 years (Tol & Langen, 2000; Lintsen, 2002; E Van der Vleuten & Disco, 2004; Lonnquest et al., 2014). The Zuiderzee Works turned the Zuiderzee into a fresh water lake, the IJsselmeer, and allowed the creation of 1650 km² of land (Borger, Kluiving &. De Kraker, 2010; Lonnquest et al., 2014). The losing battle that the Dutch had fought with rivers and the sea to prevent floods and reclaim land had prompted proposals to tame and enclose the Zuiderzee as early as the seventeenth century; but; the ideas were impractical given the technology then available (Lonnquest et al., 2014).

The Dutch government started developing official plans to enclose the Zuiderzee in 1914; but the breaching in 1916 of several dykes along the Zuiderzee, and subsequent flooding of the land behind them, provided the decisive impetus to implement the plans (Lonnquest et al., 2014). In addition, the stresses of World War I put food supplies at risk, which added to widespread support for the project. In 1918, the Dutch parliament passed the Zuiderzee Act with three goals: flood protection, agricultural expansion and food security, and improved management of freshwater resources against saltwater intrusion (Lonnquest et al., 2014). Following the damming of the Zuiderzee, large areas of land were subsequently reclaimed in the new freshwater lake by means of polders. A polder is a low-lying tract of land enclosed by dikes that forms an artificial hydrological entity with no natural connection with outside water (Metz & van den Heuvel, 2012). Polders can either be reclaimed from formerly submerged land or formed by separating floodplains and marshes with dykes and draining the water. Polders are susceptible to subsistence, as the soil dries out or settles, or to water infiltration, and constant care must be taken to manage the water level as polders face the constant risk of flooding. The Zuiderzee Works has reduced the country's coastline from 3,400 to 650 kilometers, more than 350,000 hectares of land have been reclaimed, and an enormous new freshwater basin, the IJssel Lake, was created in the heart of the country (Lonnquest et al., 2014). The IJssel Lake is fed a continuous flow of fresh water by the IJssel river, itself a tributary of the Rhine, which allowed the engineers of the dams to release excess water at every low tide, and progressively reduce the lake's salinity (Lonnquest et al., 2014). By 1936 the Ijssel Lake was declared nominally fresh, just in time to address the challenge of the increasing scarcity of non-polluted water sources which was a consequence of urbanization, population growth, and industrialization. Despite growing problems associated with water quality the focus of the Zuiderzee Works until the 1970s remained flood control and land reclamation.

V. The Delta Works

The Delta Works is a series of civil and hydraulic engineering projects in the south-west of the Netherlands. It was constructed to protect a large area of land around the Rhine-Meuse-Scheldt delta from the risk of flooding from the North Sea (Borger, Kluiving &. De Kraker, 2010; Lonnquest et al., 2014). The works consist of a system of dams, sluices, locks, dykes, levees, and storm surge barriers with the main aim of shortening the Dutch coastline and reducing the number of dykes that had to be raised (Knoester, 1984; Lonnquest et al., 2014). The Delta Works system is both the Netherlands and the world's largest flood protection project, with more than 16,500 kilometers of levees and 300 structures, and it is responsible for keeping the port of Rotterdam, and around four million people in southern Holland, safe from the sea (Borger, Kluiving &. De Kraker, 2010; Lonnquest et al., 2014; water-technology.net, 2017; dutchwatersector.com, 2016). The project started in 1958 and was largely completed in 1997 with the inauguration of the Maeslantkering, a storm surge barrier on the Nieuwe Waterweg that is one of largest and heaviest moving structures on Earth (Lonnquest et al., 2014; water-technology.net, 2017). After 1997, new projects are periodically started to renovate, renew, and upgrade the Delta Works to meet evolving risks from water. Along with the Zuiderzee Works, the Delta Works is the other Dutch engineering wonder of the modern world.

The Dutch have long contemplated shortening the country's south-west coastline, to reduce the risk of flooding caused by North Sea storms and turn the Delta into a group of freshwater lakes (Knoester, 1984; Lonnquest et al., 2014). In 1937, the Rijkswaterstaat published a study which showed that the sea defenses at that time in the southwest river delta were inadequate to withstand a major storm surge (Knoester, 1984; Lonnquest et al., 2014). The proposed solution was to dam all the river mouths and sea inlets of the Delta thereby shortening the coast. The scale and complexity of the project, and the intervention of the Second World War, delayed construction and only two small projects were completed in 1950 (Lonnquest et al., 2014). The North Sea flood of 1953 became a major driver to speed up the project, and a Delta Works Commission was installed to research the causes and develop measures to prevent such disasters in future (water-technology.net, 2017). What resulted was a comprehensive system of civil engineering works throughout south-west Netherlands which included raising 3,000 kilometers of outer sea-dikes, raising 10,000 kilometers of inner, canal, and river dikes, and closing off the sea estuaries of the Zeeland province (Knoester, 1984; Lonnquest et al., 2014; water-technology.net, 2017). A main goal of the Delta project was to reduce the risk of flooding in the Delta to once per 10,000 years, compared to once per 4000 years for the rest of the country; however, unlike the Zuiderzee Works, the Delta Work's purpose is largely defensive and not for land reclamation. The Works also have an important economic development component to stimulate the economy of the province of Zeeland: the Works are combined with road and waterway infrastructure to improve the connection between the ports of Rotterdam and Antwerp (Knoester, 1984; Lonnquest et al., 2014). The Delta Works was projected to cost the public purse no more than €900 million, but the final cost was closer to €5 billion (Meyer, 2009; water-technology.net, 2017).

The Dutch have been battling the North Sea and climate change for more than a millennial and the Dutch coastline has changed considerably because of natural disasters and human intervention. The impact of natural disasters is exacerbated through human activity, which works against nature (Disco, 2002; Van Der Brugge, Rotmans & Loorbach, 2005). The storm of 1134 caused terrible loss of land and created the archipelago of Zeeland in the south-west; the storm of 1287 affected the Netherlands and Germany, killing more than 50,000 people in one of the most destructive floods in recorded history; the flood of 1421, and the mismanagement in its aftermath, destroyed a newly reclaimed polder, replacing it with a 72 km^2 tidal floodplains in the south-central region of the Netherlands; and the flood of 1953 which caused the collapse of several dikes in the south-west of the Netherlands, killing more than 1,800 people and flooding 150,000 hectares of land (Tol & Langen, 2000; Lonnquest et al., 2014). A politically neutral Delta Works Commission was initiated twenty days after the 1953 North Sea flood, and it developed a new risk-based conceptual framework, called the 'Delta norm', to guide investments in flood defenses (deltawerken.com, 2004). To ensure a high-quality project the Delta Works Law was passed in 1959, new norms have been incorporated into the Water Law of 2009, and the Delta Works Commission keeps abreast of evolving hydraulic technologies, the expanding engineering and scientific knowledge base, and climatic trends that will produce multiple sources of hazard risk from stronger and more frequent storm surges, altered rainfall patterns, and increased river run-off (water-technology.net, 2017). Climate change, expanding economies, and urbanization are converging to put the world's delta populations at increased risk for the foreseeable future. Dutch expertise in hydraulic engineering, flood control and protection, foundation technology, storm surge barriers and levees, high-tech dredging, coastal and river engineering and maintenance, harbor construction, integrated coastal development, river basin management and climate adaptive construction is expected to be in great demand worldwide.

VI. Governance in the Dutch Water Economy

A. Overview

The Netherlands is a small, densely populated county of almost 17 million people organized politically and administratively into 12 provinces and 443 municipalities (Marques, 2010). The Netherlands is a decentralized unitary state whose governance is characterized by consensual politics and a high degree of participation by citizens in decision-making processes: there is generally a reciprocal relationship where the Dutch populace cooperates with authorities who, in turn, ensure that people are kept informed of and involved in every initiative (Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010). This consensual and participatory political culture evolved over considerable time, with roots in the Dutch relationship to its water economy (Lintsen, 2002; Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010; Lonnquest et al., 2014). According to the Global Water Partnership, water governance refers to 'the range of political, social, economic and administrative systems that are in place to regulate the development and management of water resources and provision of water services at different levels of society' (Rogers and Hall, 2003).

The Netherlands has successfully established a globally respected reputation for good water governance, which ensures the universal provision of safe, reliable and affordable fresh water, environmental protection through the treatment of wastewater water supply, and a high level of public safety against flooding from both rivers and the North Sea (Marques, 2010). With the support of the government, Dutch water technology and expertise is also being exported around the globe. Given ongoing societal and climatic changes, and greater complexity of water problems, the stakeholders in the

Dutch water economy place good water governance as the cornerstone of a strong economy and a sustainable and resilient environment.

The institutional framework for the Dutch water economy is characterized by diverse players at all three political scales operating in a decentralized management structure, but with policy guidance from the national government (Marques, 2010). The national government draws up policy and takes some responsibility for national or regional water issues that cross provincial boundaries, while the provincial government is responsible for implementing these policies in specific measures and plans. Each player in the Dutch water economy has its own areas of responsibility but the complex nature of Dutch water resource management requires considerable cooperation, coordination and collaboration among the parties (Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010).

The national government is responsible for managing Dutch surface water, in particular the major rivers, which is important for the drinking water supply, and for monitoring water quality and supply security; each provincial governments, using national guidelines, are primarily responsible for managing ground water, for determining the managing functions and supervising the activities and accounts of the water boards, and for representing the municipalities and water boards before the national government; other waters come under the responsibility of the provinces, but they normally delegate these tasks to local water boards; the water companies are responsible for water abstraction, treatment and distribution; the municipalities are responsible for managing wastewater collection services; and the water boards are responsible for wastewater treatment (Lintsen, 2002; Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010;

Lonnquest et al., 2014). This complex institutional framework has been created over considerable time through a process of learning and adaptation and it creates the conditions for successful water resources management, environmental protection and hazard risk reduction (Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010).

The main stakeholders in the governance of the Dutch water economy at the national level include the following (Marques, 2010):

1. The Ministry for Transport, Public Works and Water Resource Management; the Ministry for Housing, Territorial Planning and the Environment; the Institute for Water Management and Wastewater Treatment; and Directorate-General for Public Works and Water Resource Management, the *Rijkswaterstaat;* the RIONED Foundation; the Dutch scientific community; a national consumer protection NGO, the *Consumentenbond*; and the Dutch Union of Water Boards, the *Unie van Waterschappen.*
2. The Ministry for Transport, Public Works and Water Resource Management is responsible for waste-water treatment services and the quality of surface water;
3. The Ministry for Housing, Territorial Planning and the Environment is responsible for drinking water supply and for safeguarding its quality;
4. The Institute for Water Management and Wastewater Treatment is responsible for preparing new legislation and regulations, for data collection, for research, and the provision of advice to the *Rijkswaterstaat;* the RIONED Foundation is a center focused on waste-water services

research which is disseminated to national ministries, municipalities, water boards, consultants, and builders;

5. The *Consumentenbond,* is responsible for publishing statistical information about the water economy to the public; and the Dutch Union of Water Boards is a government supported center that acts as a network organization with the aim to make better use of Dutch knowledge on water governance, both in the Netherlands and abroad.
6. In addition to the political and policy stakeholders at the national level, there are also the associations, which represent the water companies and water boards and two banks – the Water Boards Bank and the Municipality Bank – which provide the sector with financial support. The Water Boards Bank was created in 1954 by the water boards to finance all aspects of water-and-wastewater management; and this highly successful and very solvent bank has branched out into international markets.

Water policy and management is implemented by various public authorities (central government, water boards, provinces and municipalities) and the water supply companies (Marques, 2010):

- The dunes are managed by the water boards, though drinking water companies and conservation organizations also play a role in this occasionally.
- Sand replenishment at the coast and on the beach is commissioned by Rijkswaterstaat.
- The water boards ensure the safety of small dykes.

- The Rijkswaterstaat manages the large dams and dykes, such as the IJsselmeer Closure Dam. The standards that the dykes are required to meet are set down by the Ministry of Infrastructure and the Environment.
- Drinking water is produced and distributed by the drinking water companies.
- The Rijkswaterstaat is responsible for the storm surge barriers, such as the Maeslant storm surge barrier in the Nieuwe Waterweg and the Hollandsche IJssel storm surge barrier at Krimpen aan den Ijssel. The Delta Works is managed by the largely independent Delta Commission (Knoester, 1984).
- The standards for the quality of surface water are set down by the Ministry of Infrastructure and the Environment. The water boards are responsible for ensuring that there is enough surface water and that it is clean. The Rijkswaterstaat performs this role for the major bodies of water.
- The drainage of rainwater and waste-water falls within the remit of local government authorities.

B. Water Boards

The Dutch water boards are the oldest democratic forms of government in the Netherlands, going back to at least the 13th century, and are responsible for water management at the local level (Lintsen, 2002; Lazaroms & Poos, 2004; Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010; Lonnquest et al., 2014). The water boards are independent local government bodies based on a tradition of local, cooperative and participatory governance with the governing principle being that individuals and groups with the greatest role in the management of water are those stakeholders with the greatest stake in water (Lazaroms & Poos, 2004; Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010). The primary scope of the water boards has remained basically unchanged over many centuries although their scale has changed and their numbers have been significantly reduced to achieve greater administrative and technical efficiency (Lazaroms & Poos, 2004; Marques, 2010). In 1850 there were about 3,500 water boards in the country although by 2011 mergers eventually reduced the number to 25 water boards (Lintsen, 2002; Lazaroms & Poos, 2004; Van Der Brugge, Rotmans & Loorbach, 2005; Lonnquest et al., 2014). The administrative structure and financial arrangements for contemporary water boards are set out in several pieces of legislation: the Surface Water Pollution Act of 1969, the Groundwater Act of 1981, the Soil Protection Act of 1986, the Water Management Act of 1989, and the Water Services Act (1992) (Marques, 2010). The Surface Water Pollution Act (1969) sets out the framework for preventing and monitoring the pollution of water resources (Marques, 2010).

Dutch water boards manage local water resources and some aspects of wastewater treatment services but are not responsible for the water supply to the general public and are therefore not considered a utility (Lazaroms & Poos, 2004; Marques, 2010). Within its territory a water board is responsible for the following: management and maintenance of water barriers, which includes dunes, dikes, quays and levees; managing the correct water level in polders, ditches and canals by means of weirs, locks and sluices, culverts and pumping stations, thus enabling water to be drained, retained or let in as necessary; ensuring nature conservation and environmental protection; and, in conjunction with the municipalities, maintaining surface water quality through wastewater treatment, which today is its most important responsibility (Lazaroms & Poos, 2004; Marques, 2010). The water boards together with the Department of Public Works and Water Management are responsible for the quality and quantity of regional water in the Netherlands. The Dutch are served by about 101,000 kilometers of sewers which covers 99.9% of the population (Marques, 2010). The umbrella organization of the water boards is the Association of Dutch Water Boards, *Unie van Waterschappen*. The organizational structure of the water boards is characterized by horizontal integration with the collection of waste water being separate from treatment (Marques, 2010). This is considered as an example of direct public management.

Water boards hold elections, levy taxes and function independently from other government bodies (Lazaroms & Poos, 2004; Marques, 2010). Their structures vary, but they each have an elected general administrative body, an executive board and a chair. In addition to taxes raised by water boards, central government contributes to their finances by paying construction and maintenance costs of water barriers and main waterways (Lazaroms & Poos, 2004; Marques, 2010). The costs of waste water treatment are financed by a water pollution levy, which is based on the polluter pays principle, and an operating tax; the costs of impact of human activity on the environment are recovered by charges for all discharges, abstractions, impoundments and engineering works that affect water quality; and farmers pay the full-cost of drainage for their farms (Marques, 2010). The rear instances of deficits are subsidized by the central and local governments.

C. Water Supply Companies

Dutch water supply services are provided by 10 semi-public bodies (PLCs) which are governed by private law and operate as private operators (Schwartz & Blokland, 2002; Marques, 2010). The PLCs manage about 116,000 kilometers of mains and are responsible for all pipes up to the customer's home water meter, while homeowners are responsible for the state of the water supply lines in their homes (Marques, 2010). Dutch water companies manage and maintain one of the most reliable and efficient water collection, treatment, an distribution supply systems in the world: the PLCs ensure that clean, chlorine-free drinking water drinking water flows from the tap 24 hours a day for nearly 17 million inhabitants; they have a level of service coverage of 99.9% of Dutch households; and they keep water losses to about 6% of the total volume produced, which is better than the European average of 12% (Marques, 2010). The Dutch consume about 124 liters of water a day, which is one of the lowest among developed countries (Marques, 2010). The water companies extract water from the ground, rivers, canals and lakes, purify it, and pump it to the customer. The main source of water is groundwater, which represents about 60% of the overall production. Water companies and water boards work together in some regions as both benefit from clean groundwater, rivers and canals. In this framework, water supply services are vertically integrated with all stages from abstraction to delivery to households under the control of the PLCs.

The Association of Dutch Water Companies, *Vewin*, represents practically the entire Dutch drinking water sector, and works with its membership to help them achieve their strategic goals (Marques, 2010). The institutional framework for the PLCs is considered as an example of delegated public management; and the decision not to privatize this aspect of the water sector was seen by the Dutch government as a strategic step to prevent the rise of private monopolies in an essential service, although Dutch water companies have their roots in the private sector (Schwartz & Blokland, 2002). An important feature of the PLCs is the financial arrangement which calls for low levels of equity and full-cost recovery, allows limited profit sharing as an incentive for performance, and which avoids the use of public subsidies (Schwartz & Blokland, 2002). The financial and operational performance of the PLCs is widely considered to be good and this is largely a result of the its largely independent management, the requirements for transparency, and the check and balances that are designed into its governance regime (Schwartz & Blokland, 2002).

D. Legal Framework

The national government has over time developed a very robust legal framework for managing water supply with the important governing documents being the Water Supply Acts of 1957, 1975, and 2000, the Water Services Act of 1992, and the Water Ownership Act of 2004 (Marques, 2010). The Water Services Act (1992) strictly prohibits the private sector from supplying water to private consumers, although such provision is not prohibited to industrial and commercial customers. The success of the water supply sector is credited to the balance between the efficiency and effectiveness of private sector management practices; and the accountability, legitimacy and transparency of public authorities which are disciplined by periodically having to face the electorate which they serve (Schwartz & Blokland, 2002; Marques, 2010). Dutch water supply has a history of providing an exceptional quality of service which has deterred the entry of the private sector into water services and negated the need for independent regulatory oversight.

D. Local Government

Dutch municipalities play an important role in urban water management. They are responsible for providing waste-and-storm water collection services, for supervising or managing the 443 wastewater service operators in the Netherlands, and for town planning (Marques, 2010). The level of recycling of industrial waste-water is high, the water is of sufficient quality for use in the food and beverage industries, and the energy and raw materials being released during the treatment process are increasingly being recycled to reduce the environmental footprint and for conservation. Unlike water supply to private citizens which is provided by public water companies, private operators actively participate in wastewater treatment under contracts from municipalities (Marques, 2010). Veolia Water current provides wastewater treatment services for the 1.7 million citizens of Rotterdam under a 30-year, BOT scheme. The Environmental Management Act (1992), which sets out an integrated approach to environmental management in the Netherlands, requires municipalities to prepare annual environmental and wastewater plans and to publicly circulated drafts to facilitate public consultation. The institutional framework for waste-and-storm water collection services is considered an example of both delegated public and delegated private management.

E. Pricing & Cost Recovery

The Dutch water-and-wastewater sector has a successful record of financial solvency, which helps to ensure operations are efficient and infrastructure is maintained at a high standard. This is partially due to the overall quality of management within the water-and-wastewater sector, but also importantly to the fact that the Dutch public pay tariffs and taxes on water they consume to ensure both full-cost recovery and environmental conservation (Marques, 2010). The solvency of the system ensures that infrastructure is well maintained and regularly upgraded. Every Dutch household pays a water safety tax and a fee to compensate for water pollution, calculated on the number of occupants. In 1995, the national government introduced a tax on groundwater abstractions to discourage excessive consumption of this resource; however, the tax was considered too low, some farmers evaded the tax, and the regime facilitated the maintenance of inefficient irrigation practices by some farmers (Hellegers et al., 2001). It was abolished in 2012.

The Netherlands spends generously to ensure a high quality of service. In 2010, the Netherlands spent €3.8 billion, or about 0.6% of GDP, on treating drinking water, managing the sewer system and treating waste water; and this level of expenditure is expected to rise to €4.4 billion by 2020 (hollandtradeandinvest.com). Dutch prices for water-and-wastewater services, although high by international standards, are a tiny fraction of the total household budget for utilities and local taxes – in 2005 domestic water cost €1.69 per cubic meter and in 2015 is was €1.61 per cubic meter (Marques, 2010; Vewin, 2016). These costs are not considered a burden by European standards given the quality and reliability of the service, and there are provisions for remission of charges for poor households. The average household pays about 100 Euros a year for water-and-wastewater services, which is less than 1% of household income and compares favorably to the 1-2% of household income which is the EU average (Bartram et al., 2002; Vewin, 2016). There is, however, some criticism that the substantial revenues raised in the water sector, when they become a surplus, are sometimes committed elsewhere by local governments rather than invested back or reserved for the future needs of the sector. Netherlands, unlike other parts of Europe, is expecting population increases and its water-and-wastewater sector will benefit from a dense population (Statistics Netherlands, 2012), which, other things being equal, generally reduces the infrastructure needed and thus the costs associated with delivering a given amount of drinking water (European Environment Agency, 2013).

F. Reflections on the Governance of the Dutch Water Economy

Dutch policies and practices in the water-and-wastewater sectors are considered as models of excellence in the water economy and serve as a benchmark for other countries. The success of the Dutch water resource model is due to several factors: the application of private sector management practices in select areas of operations; the commitment to transparency, public accountability, and self-regulation; the practice of bench-marking to continuously improve the quality of service and lower costs; the application of science and technology; the commitment to full-cost recovery; and the culture of continuous learning and adaptation (Schwartz & Blokland, 2002; Lintsen, 2002; Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010; Metz & van den Heuvel, 2012; Lonnquest et al., 2014). The local and regional water management in the Netherlands is largely decentralized, immune from day-to-day political considerations, and almost exclusively focused on water governance and water resource management (Schwartz & Blokland, 2002; Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010). In this regime the Water Boards, as the lowest level on the water resource governance scale, play a key role as a decentralized functional government authority (Schwartz & Blokland, 2002; Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010). Dutch Water Boards keep pace with social, economic, and technological developments in society; their organizational and financial structures and their legislative framework are continuously adjusted and updated to remain relevant; while their essential purpose, elements and governing principles remain intact (Schwartz &

Blokland, 2002; Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010). This balance between institutional change and institutional continuity ensures stability while delivering results.

The Dutch water economy has both public and private actors and considerable attention is given to the appropriate roles and spheres of responsibilities of each. The policy of the Dutch Government is that domestic water supply should be a public responsibility; however, the private sector is involved in supply to industrial and commercial users and in waste-water management and competition is encouraged where possible (Marques, 2010). Bench-marking and performance management are considered important for maintaining service quality and accountability; while cooperation with the private sector through outsourcing and public-private partnerships are encouraged along parts of the water chain to keep prices affordable (Schwartz & Blokland, 2002; Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010). The Dutch Association of Water Boards creates benchmarks for its members on the effectiveness and efficiency of wastewater treatment. Despite the ability of the Dutch water economy to adapt, change was usually reactive rather than proactive, a result of natural disasters, environmental and ecological crises, and public health emergencies (Lintsen, 2002; Van Der Brugge, Rotmans & Loorbach, 2005; Lonnquest et al., 2014). Nevertheless, the Dutch at least had the human and technical capacity to effect change.

VII. Dutch Water Technology Innovation Sector

A. Water Technology as a 'Top Sector'

The water technology innovation sector has been selected by the Government of the Netherlands as one of nine ‘top-sectors’ of the Dutch Economy which together currently represent about 80% of the country's R&D and 30% of its value-added and employment (OECD, 2014). The water sector is believed to have considerable potential to help support and sustain Dutch economic development because of the local and international demand for technological and managerial solutions for water resource management (Netherlands Enterprise Agency, 2017; dutchwatersector.com, 2017). The Dutch water technology innovation sector was chosen specifically because the Netherlands is well known for water management skills and because the water technology innovation sector can draw on over eight hundred years of experience with water management, coastal protection, land reclamation, water supply and water quality (Netherlands Enterprise Agency, 2017; dutchwatersector.com, 2017). Water is essential for people, industry, agriculture, and the environment, and water technology is therefore seen by policymakers and planners as a key element in developing a strong sustainable economy, in safeguarding public health, in protecting the health of the natural environment, and as a tool of international economic and environmental diplomacy (Netherlands Enterprise Agency, 2017). As a matter of public policy, Dutch water expertise is designed to provide win-win-win solutions to national and global water issues while also balancing planet, people, and profit.

The Netherlands is part of a Europe-wide development strategy that has identified innovation as one of the pillars of smart, sustainable and inclusive growth, international competitiveness, and economic success; and in response cities and regions across the Netherlands are organizing their own innovation hubs (Ahonen & Hämäläinen, 2012). The economic development model employed by the Dutch government is the 'quadruple helix,' which is designed to support cooperation and collaboration between four key stakeholder groups: government, academia/research, business and customers/users (Water Alliance, 2016). The goal of the quadruple helix model is to create an 'innovation-friendly ecosystem' which increases the economic contribution of targeted sectors of the economy (Ahonen & Hämäläinen, 2012). The philosophy behind the quadruple helix is that innovation is multi-faceted and involves the interplay of technologies, infrastructure, organizations, support services, and collaborative networks which co-produce a wide range of economic, social, and environmental innovations (Ahonen & Hämäläinen, 2012; OECD, 2014). Additionally, an innovation ecosystem needs to be well resourced; all partners need to develop their own technical skills and abilities; and all actors need to be flexible and adaptable, have the capacity to cope with constraints in social, economic and political systems, and be able to reform regulations and restructure organizations as and when necessary (Ahonen & Hämäläinen, 2012; OECD, 2014). In the context of the water economy, the quadruple helix ensures that government, research institutes, and businesses combine and transform their knowledge and expertise into innovative products, services, and skills that deliver smart, cost-effective, and commercially viable solutions for the management of water resources (Ministry of Economic Affairs, 2017). To further support the overarching national framework for innovation, the Dutch government - in recognition of the value of foreign startup entrepreneurs to the Dutch economy - introduced a startup visa law starting January 1, 2015 so foreign nationals can more easily acquire a residence permit in the Netherlands.

The Dutch society is one of the most world's most sophisticated and innovative and its economy one of the most open, outwardly-focused, and competitive. It is recognized, however, that there could be improvements in productivity and competitiveness, more diversification into emerging economic sectors, more diversification into new exports markets outside Europe, an increase in entrepreneurship and risk taking among small and medium businesses, an increase in domestic R&D, an improvement in access to financing, and an improvement in the graduation rate for scientists and engineers (OECD, 2014). The 2015-2016 Global Competitive Report by the World Economic Forum placed the Netherlands 5th in economic competitiveness, 3rd in education, 3rd in infrastructure, and 10th in institutions (Schawb & Sala-i-Martin, 2016). The Dutch Ministry of Economic Affairs estimates that in the water sector there are almost 1,500 active water technology companies, with 51,000 full-time employees, and 500 delta technology companies (Ministry of Economic Affairs, 2017; dutchwatersector.com, 2017a). The Ministry estimates that turnover of the Dutch water sector was €16.4 billion in 2008 and €15.6 billion in 2011, of which 57% was earned by water technology companies; that exports amounted to €6.5 billion in 2008 and €7.4 billion in 2011; that 40% of the freely accessible world market for water management is in Dutch hands; and that this represented about 2% of GDP (Wijedasa, 2013; Hisham, 2015; dutchwatersector.com, 2017).

The globally competitive position of Dutch water technology and expertise would not be possible without heavy investments in water-related innovation, entrepreneurship, and R&D by three of the partners in the “helix' - government, academia and business; through a well-established system of public-private partnerships that align the interests and resources of government, business and research partners; and through the development of high-quality human capital with cutting-edge scientific, technological, and management knowledge and skills (Netherlands Enterprise Agency, 2017). While

Dutch hydraulic engineering expertise has deep historical roots, Dutch water technology expertise was largely, and purposely, developed from the 1970s on-wards and now includes global leadership in membrane, bioreactor, Anammox microbial, and anaerobic water purification technologies. Some of the world leading Dutch research institutes include Deltares, MARIN, KWR Watercycle Research Institute, and Wetsus (Netherlands Enterprise Agency, 2017).

B. Global Reach of Dutch Water Technology Businesses

The global reach of the Dutch water technology innovation sector is considerable: the global market is receptive to both Dutch goods and services, and for partnerships and collaborations with Dutch businesses and research institutions (Wijedasa, 2013). Some examples of Dutch innovation, and of the more than 252 current Dutch projects abroad, include river basin management in upper Niger, hurricane risk reduction in New Orleans, the use of brackish water for potato cultivation in Egypt; relocation of a port in Ho Chi Minh City in response to climate adaptation, the removal of iron from well water in Moscow, and the use of the natural resistance of oysters to water flow as a defense against coastal flooding and erosion, and as a source of food, in Bangladesh (Wijedasa, 2013). Future projects under investigation include navigable storm surge barriers for New York, and Dutch hydraulic experts and officials are increasingly being employed in the US to advise the authorities there on flood control (Wijedasa, 2013). Dutch water technologies available for export consist of both advanced, high-technology solutions, and simple, inexpensive and locally-appropriate technologies that are capable of alignment with the social and economic realities, financial and institutional constraints, and technological capacities of developing countries.

The Netherlands is home to the world's ten best engineering firms in the field of water and to two world leaders in land reclamation, dredging and coastal construction. In water technology, innovative Dutch companies lead the way in the purification and re-use of water. There is also a large network of smaller companies which offers cost-effective, bespoke solutions. Skilled Dutch NGOs operate worldwide in the field of water and international cooperation; and the long-established ecosystem of research institutes, universities and local governments sustains a high standard of water resource management and a wealth of knowledge and skills. If necessary, Dutch organizations will form alliances to deliver tailor-made solutions for clients around the world (dutchwatersector.com, 2017a)

C. Netherlands Water Partnership

The Netherlands Water Partnership (NWP) is an independent body, which represents the Dutch water sector on the global stage. This public-private partnership, which was started in 1999, is located in The Hague, and consists of approximately 200 members including private businesses, government, knowledge institutes, and NGOs. The partnership represents a comprehensive network that unites Dutch water expertise to collectively achieve more in solving global water related challenges; it acts as a one-stop center for the exchange of information on Dutch water expertise, policy developments and market opportunities; it initiates, coordinates and executes special projects for its members, such as trade missions, exhibitions and conferences; and it helps Dutch companies increase their world market share for water technology and water management expertise (nwp, 2015). The main goals of the NWP are to harmonize the activities and initiatives of the Dutch water sector overseas and promote the Dutch water expertise worldwide. The NWP reflects the Dutch philosophy to water, which involves the pursuit of integrated solutions that requires multiple disciplines; it offers its members networking, knowledge management and diffusion, and greater visibility and influence, than could be achieved by any individual member acting alone; and its members work together to offer their global client base sustainable, multi-functional water solutions that serve 'people, planet and profit' (nwp. 2015).

VIII. Leeuwarden Water Technology Innovation Cluster

A. Leeuwarden.

The city of Leeuwarden is the capital and main economic hub of the water-rich northern Dutch province of Friesland. Leeuwarden. It is also home to a public-private initiative to build a Dutch water technology innovation cluster out of the city's current involvement in the field of water technology. Leeuwarden's goal is to become Europe's capital of water innovation and technology, and the city is in a province already characterized by a relatively high density of independently owned, highly organized, and globally exporting water technology companies (Wetsus, 2016; Di Palma & Huizinga, 2012). At the core of the cluster is an international water technology institute, The WaterCampus, which will host Wetsus, the city's leading scientific institute for water technology, in addition to several other water technology companies and organizations. The city of Leeuwarden is hoping to attract scientists from all over the world to conduct research into solutions related to drinking water, waste-water purification, and water distribution; to act as a ‘hub’ for a worldwide network of water technology businesses and research organizations; and to serve as a central point where knowledge about water is collected, where innovation takes place, and where water technology is commercialized (watercampus.nl, 2014).

The emergent role of networks and hubs is a good example of Quadruple Helix development in the Dutch economy. Stakeholders now expect well-balanced roles between government, companies and research institutes to improve local and national productivity, and to drive innovation and stimulate business development. A success factor in cluster development is the engagement of these multiple stakeholders in reaching win-win managerial solutions for patent technology and innovation, by combining their complementary skills, for the benefit of entire communities. Friesland has a well-deserved reputation in cluster development in the water sector. All players contribute to the realization of a common objective: to stimulate and facilitate regional economic development.

The Leeuwarden cluster is described a serving the function of an anchoring milieu, which is a cluster that specializes in specific segments and focuses on the development and delivery of dedicated, intermediary products and services (Ebbekink & Lagendijk, 2017). The local state plays a critical coordinating role in relevant fields of policy-making such as education, training, infrastructure, and business support; and the policies and practices of the local state are aligned to the needs of the cluster. Leeuwarden is aiming for a critical mass of partners with a focus on knowledge-intensive water process technology, as opposed to becoming a large-scale production facility and exporter of water-related infrastructure (watercampus.nl, 2014). The city's planners and policy makers are putting public resources behind promoting greater innovation and entrepreneurship in an existing cluster, and this is seen to both maintain an existing competitive position in the market, and further create a competitive advantage in emerging technologies (Di Palma & Huizinga, 2012.). In this conception of cluster-based economic development, the dynamics of innovation and entrepreneurship are driven by finding a balance of supply and demand: purposely increasing the supply of people with technological expertise and the resources for R&D; against an increasing demand for sustainable water innovation that is driven by both growing demand for more fresh water, and pressures to meet increasingly stringent water quality standards (Di Palma & Huizinga, 2012; Ebbekink & Lagendijk, 2017). Leeuwarden is not the only water technology innovation cluster in the Netherlands: Delft also has a cluster anchored by the Delft Technical University.

B. The Water Campus.

The Leeuwarden Water Campus is expected to play a leading role in positioning Leeuwarden, and the Netherlands, as a global provider of innovative solutions and new techniques to address the growing global demand for fresh water in the face of stressed supplies, pollution, and climate change. The role of the WaterCampus is to organize cooperation between water-and-wastewater companies, knowledge institutes, and public authorities in the water technology sector to create synergy for the innovation, education, and entrepreneurship that is necessary to build and sustain a globally competitive water technology cluster. The WaterCampus is expected to become the physical core of the Dutch water technology sector and it has been designated as a 'United Nations Innovating City for Water Technology' (watercampus.nl, 2014).

The Water Campus is built from several existing pillars of the Leeuwarden water technology cluster: Wetsus, or the Center for Sustainable Water technology, previous located nearby at the University of Applied Sciences; the John the Baptist Church, now a business center and incubator; the Water Alliance; the Foundation for Water, Energy, and Life Sciences Leeuwarden; the Center of Expertise Water Technology (CEW); the Water Application Center; and a specialized water fund, Wetsus. The CEW and Water Alliance are the managing partners of the campus which provides partners with unique infrastructure to support innovation and entrepreneurship: it has a demo-site and laboratories, it provides a meeting place for scientists and businesses from across Europe, and its hosts pitching events for its partners to promote their technology (watercampus.nl, 2017). Located beside the campus is a business estate that will provide additional space if the campus outgrows its physical capacity. The total investment in the Water Campus is estimated at €36 million, with most of the financing coming from the public partners, and the facility is described as a 'club good' designed to improve relational assets, which will strengthen the cluster's network of stakeholders (Ebbekink & Lagendijk, 2017). The Water Campus also aligns with the sustainable development focus of the regional and local governments. The WaterCampus is an innovative ecosystem that facilitates the entire innovation chain: it facilitates moving technologies from idea to research & development to field-testing and demonstration to launching and, ultimately, to tangible business with companies worldwide.

C. Wetsus.

Wetsus is a not-for-profit foundation established in 2003 but now located at the Water Campus in Leeuwarden. The vision of the institute is to become the “European Centre of Excellence for Sustainable Water Technology”; and the Mission is to facilitate breakthrough technological innovations for water treatment by serving as a facilitating intermediary for public and private water organizations engaged in multidisciplinary collaboration at all stages of the innovation-to-commercialization process (Wetsus, 2016, 2017). Wetsus' objectives are broadly two-fold: to create a consortium of companies, universities and institutions which work together to develop innovative and sustainable water technologies that are process-based, emission free, and part of an endless cycle; and to introduce these technologies into society through entrepreneurs. Wetsus' philosophy is that research must be demand-driven if it is to serve society and be commercially viable. To this end, the institute is seeking to increase its interaction civil society to gain insights and ideas and ease implementation of technologies. In 2007 Wetsus was designated by the Dutch government as a 'Technological Top Institute' for water technology, and it is part of the Dutch Innovation Program established by the Ministry of Economic Affairs. Wetsus also performs a brokerage role since its inception in 2003 where the objective is to boost creativity through multi-disciplinary collaboration which leads to the development of state-of-the-art water treatment (Di Palma & Huizinga, 2012).

To achieve its Vision, Mission and objectives, Wetsus' main activity is the coordination of a world leading research program whose broad network of partners include public and private companies, universities, scientific chairs, and European policy makers at all political scales (Wetsus, 2016, 2017). Westsus describes their innovation model as “jointly implemented, market-driven, application-oriented, multidisciplinary, (pre)competitive scientific research in the field of sustainable water technology” (Wetsus, 2016, 2017). Westsus also believes that physical co-location, the sharing of laboratory facilities, and multi-disciplinary research teams have high potential to develop important innovations in water technology which today often requires the combined input from different disciplines from biology to chemistry, and from mechanical and electrical engineering to material science (Wetsus, 2016, 2017).

The institute has received funding of about €70, half of which comes from the Dutch Department of Economic Affairs, with the other half coming equally from the business community and knowledge institutes in the Netherlands (Wetsus, 2016, 2017). Full participating companies pay a membership fee of between €17,000 and €28,000 per research theme per year (Wetsus, 2017). Platform participating companies pay an annual membership fee of between €3,400 and €7,900 but only have access to Wetsus' intellectual property and privileged access to certain information (Wetsus, 2017). Along with fees, a total budget of around €15 million per year is available until 2021 (Wetsus, 2016, 2017). Wetsus also intends to eventually establish an investment fund, with the financial support of banks and other investment entities, of between €50 and €100 million, to finance water technology-driven startups that have the potential to create new market segments and which show a clear path to commercialization and profitability (Di Palma & Huizinga, 2012).

The current Wetsus international network has about 125 public and private partners from all over the world who join forces to solve the global water problems. This includes about 100 water companies that actively participate in the research through paying memberships, which gives them the right to define the research program, and about 22 participating research institutes and universities known as 'know-how participants' (Wetsus, 2016, 2017). There are also about 50 scientific chairs from nine European countries who oversee execution of research projects (Wetsus, 2016, 2017). The result is a concentration at the Water Campus of a pool of know-how and talent that crosses disciplinary boundaries, who share research and office facilities, and develop a multi-disciplinary community of practice in water.

The Wetsus research project model involves a team of 5-8 participating private and public water companies which assemble under a research theme and jointly determine the research program; and the project is executed in the Wetsus' laboratory under the supervision of the 3-4 of the participating research institutes and universities (Wetsus, 2017). Each research project is typically carried-out in four-year-long time-frames, primarily by PhD students and their supervisors; and the results from these pre-competitive research projects are commercially implemented by the funding and defining companies and made accessible to third parties through patents and scientific publications (Wetsus, 2017). The research undertaken at Wetsus involves about 15 scientific disciplines but focuses on five main research areas in clean water production and waste water treatment: new water sources, sustainable water supply, waste water treatment and reuse, reuse and production of components and energy from water, and the detection of pathogens and micro/nano-pollutants (Wetsus, 2017). One of the most significant bottlenecks in the water technology innovation chain is field-testing and scale-up. Wetsus, together with Water Alliance and several partners in a radius of 50 kilometers around the Wetsus laboratory, provide demonstration sites where new concepts can be scaled-up, tested and demonstrated (Wetsus, 2017).

In addition to Wetsus' research role, the institute also develops human capital for the water sector through a talent and education program and supports entrepreneurship and the development of spin-offs to stimulate the commercialization of water technologies (Wetsus, 2017). Since 2003, Wetsus has helped to create 30 spin-off companies of the 110 new water technology companies started in the Netherlands during that period (Wetsus, 2016). Entrepreneurs and innovators are often in need of financial support for their research and startups and Wetsus also plays the role of matchmaker between financiers and water technology companies in need for capital (Wetsus, 2017).

Wetsus places a high value on its researchers and students publishing their research in peer-reviewed journals, and the institute is rated in the category of "very high impact" for its success with publications. Since 2010, the annual publication rate has been about 60 articles - in journals such as *Progress in Materials Science, Energy & Environmental Science, Water Research, Environmental Science & Technology, Bioresource Technology, ChemSusChem, Journal of Membrane Science,* and *Desalination* – with a rate of citation on average 2.2 times higher than the world average (Wetsus, 2017). Wetsus has a large cohort of PhD students on its doctoral program, about 65 at any time from all over the world; and the program, with its specialization on water technology, has grown in the 10 years of its existence to be internationally respected for its rigor and its strong connection between research institutes and industry partners in Europe (Wetsus, 2017). Wetsus is also building an extensive knowledge network that extends beyond the Water Campus which currently numbers 5,000 persons. These members are kept abreast of developments at Wetsus through regular newsletters and periodic events (Wetsus, 2017).

D. The Water Alliance.

The Water Alliance is a non-profit, membership-based industry association, located at the Leeuwarden WaterCampus, whose role is to help its members create tangible business opportunities through matchmaking, networking, and business development. Its diverse membership of 85 organizations represent all facets of the water-and-wastewater industry, and the network is designed to inspire, stimulate and support members to accelerate innovation around sustainable water technology solutions (wateralliance.nl, 2017). The Alliance's Vision is to turn the Leeuwarden water cluster into the water innovation hub of Europe, with the WaterCampus at its core; its Mission is to promote economic development and employment by turning innovative water technologies into sustainable economic growth; its strategy is to bring together a complete value-chain of innovation in water technology, and to take technologies from concept to commercialization (wateralliance.nl, 2017). The membership of the Alliance is open only to Dutch public and private companies, government agencies and knowledge institutes involved in water technology, but many of these businesses do operate internationally.

E. The Water Application Center (WAC).

The WAC is a fully equipped testing center, located on the Water Campus in Leeuwarden. The WAC recognizes that the hardest part within the innovation process is often the step from laboratory-testing to pilot-scale applications to implementation with the launching-customers. The center therefore provides researchers, innovators, and entrepreneurs in water-and-wastewater access to both in-house and external facilities to test their water technology on both small and large scales, or have the tests performed for them by competent researchers (waterapplicationcenter.com, 2017). The Water Alliance has established relationships with several organizations within the local water industry to offer their facilities as demonstration sites that cover a wide range of water technologies including potable water technologies, municipal and hospital waste water treatment technologies, desalination technologies, and sensor technologies.

F. Criticisms of the Leeuwarden Cluster.

The cluster vision for Leeuwarden, as articulated by the proponents of the Water Campus, has its critics. Many water technology companies located in and around Leeuwarden – especially the small and medium enterprises - see no need to relocate to the Water Campus and they are concerned that the planners and policy-makers are out-of-touch with reality. These companies do not feel as if they have been adequately consulted by the Water Cluster's planners and policy-makers; they believe that the focus is too external and comes at the expense of local engagement; they believe that the projected economic growth of the cluster is exaggerated; they believe that the primarily top-down strategy is flawed, that the Water Campus has not been marketed in a substantive way, and that policy-makers have failed to grasp the actual value-adding mechanisms of the cluster; they believe that the selection criteria is flawed and does include the ideal mix of organizations; they suspect that many supporters of the cluster are attracted by the promise or prospect of public subsidies rather than by a compelling business case for the Water Campus; and they perceive that the management of the cluster's development is too fragmented or uncoordinated (Ebbekink & Lagendijk, 2017). One of the perennial challenges faced by water technology companies are high barriers to entry, particularly in terms of access to venture capital, technical requirements, and long lead time to commercialization; and these issues are not receiving the priority they deserve as planners and policy makers focus on filling the real estate (Ebbekink & Lagendijk, 2017). The pursuit of symbolism, such as the signaling of a commitment to sustainability through the pursuit of Breaam Excellence Certification for the built infrastructure of the

Water Campus, may be an important goal of policy-makers; however, there are concerns that such financially costly strategies might dilute the economic focus of the cluster (Ebbekink & Lagendijk, 2017).

These concerns by some Leeuwarden stakeholders mirror the concerns often raised about public intervention in clusters: that policy-makers lack the information and cognitive capacity to properly understand the complexity of a cluster; that the state should avoid picking winners and exercise caution in how it uses scarce public resources as subsidies; that cluster intervention can denigrate into a 'race-to-the bottom' or 'smoke-stack chasing'; and that politicians and policy-makers lack the strategic patience for building and sustaining a cluster which is an inherently a long-term activity (Ebbekink & Lagendijk, 2017). These concerns by some Leeuwarden stakeholders also seem to suggest that the Leeuwarden cluster lacks the robust 'relational assets' that facilitate the flow of information or knowledge sharing that could be translated into specific and targeted policies and practices (Ebbekink & Lagendijk, 2017). Many of the water technology businesses in Leeuwarden do not feel a sense of ownership for the cluster (Ebbekink & Lagendijk, 2017). The development of a cluster in a peripheral region of the Netherlands, as opposed to Delft in the heart of the country, is also seen as possibly weakening the relational role of a cluster (Di Palma & Huizinga, 2012). Despite these concerns, however, the long-term strategic, reputation and symbolic value of a project such as the Water Campus should not be discounted, especially if it is targeted at a nascent or emerging cluster in an industry with growth potential (Ebbekink & Lagendijk, 2017).

IX. Competitiveness of Dutch Water Cluster

A. Overview

The Dutch water economy is one of the best developed and most sophisticated in the world, and it is one of the pillars on which the rest of the Dutch economy secures its globally competitive position. The Dutch water sector has been selected by the national government as one of nine 'Top Sectors' because of its potential to support continued growth in employment and output, and to protect the environment (OECD, 2014; Janssen et al., 2016). The Dutch water technology sector is globally recognized for its expertise in two broad but important areas: delta technology, which involves the protection of land and the built environment from floods and storm-water; and water-and-wastewater, which involves the delivery of adequate quantities of high quality fresh water to domestic and industrial consumers, and well as the ability to treat and re-use water which protects the environment and makes the water economy more sustainable. Dutch water knowledge and technology is sold worldwide in places as far afield as New Orleans, Russia, Bangladesh and Vietnam. The Dutch water sector has several water technology clusters and different regions of the Netherlands have different types of expertise: the South is noted for a higher concentration of companies with expertise in delta technology, while the North is noted for its companies with expertise in water quality, recycling, and re-use. Dutch economic development is significantly influenced by its abundant natural endowment of water, its proximity to the sea, and its low and flood prone topography; however, its competitive advantage in water technology flows from solving the challenges that water has posed to the health, safety, and economic security of its people rather than a passive reliance on this inherited natural factor.

B. Factor Conditions.

In The Netherlands, water is a key economic factor and the country is generally well endowed with this inherited, basic, natural resource. Water in its natural state is a major input into a limited number of sectors in the Dutch economy, such as agriculture or energy; expertise in water resource management and water technology, which are advanced and specialized factors that are consciously and proactively created, are key to productivity in wide areas the Dutch economy (Porter, 1990; Geels, 2005; Marques, 2010). Dutch expertise in delta technology is unique in the world and is built on the county's historic struggle to manage its rivers, hold back the sea, and preserve land from an ocean which has the power to reclaim it at any time. Water resource management and water technology are advanced and specialized factors that have taken considerable time to develop, have required heavy and sustained investment, and in the case of delta technology are hard to duplicate (Lintsen, 2002; Metz & van den Heuvel, 2012; Lonnquest et al., 2014).

To develop and sustain its specialized and advanced factors the Dutch economy is supported by public and private funding for venture capital and R&D; its universities produce many competent scientists and engineers; its researchers are highly productive in publishing peer reviewed journal articles and in securing patents; and its entrepreneurs and innovators have an outstanding track-record in commercializing technologies (Geels, 2005; Marques, 2010; Hisham, 2015). Despite its relatively small size and population the Netherlands has a significant history of invention, innovation, discovery, exploration, and contribution to the arts and to ideas, going back to at least the 1500s. The Netherlands may have joined the industrial revolution later than some other nations; however, this does not mean that it was an economically or technologically unsophisticated country as it was a major seafaring, colonial, trading, and financial power by the mid-to-late 19th Century when it began to industrialize (Mokyr, 2000). The contribution to GDP from manufacturing is slightly less than 20%, a little lower than the European average; the contribution from high-technology manufacturing is about 2%, compared to 2.5% for the rest of Europe; and employment in high-technology manufacturing is about 2.5% of the workforce, compared by about 5% in the rest of Europe (Janssen et al., 2016). The Netherlands has historically had an economy dominated by the service sector, and this sector is becoming increasingly knowledge-intensive (Janssen et al., 2016).

The Dutch invest less than 2% of their GDP in R&D which is in line with the United States, Singapore and the rest of Europe, but about half that of Israel, and this totals about €5 billion annually, or a little over €750 per capita (Janssen et al., 2016). The comparatively low level of R&D intensity in the Netherlands is because of the comparatively large share of GDP taken up by the service sector, the comparatively small size of the Dutch high-technology sector, and the high share of large firms that are in low-to-medium technology industries (van der Veen, 2010). The government covers about one-third of the investment in R&D, while almost half of the private sector's share of R&D is made by the top 2% of firms, with more than 500 employees (Janssen et al., 2016). Firms with 10-50 employees, which make up 78% of all Dutch firms, contribute only about 13% of R&D but represent about 30% of innovation; while half of innovation is made by the top 4% of Dutch firms (Janssen et al., 2016). This situation with R&D and innovation has implications for water technology firms and water technology startups which tend to be small. The nine 'Top Sectors' accounted for more than 80% of R&D

expenditure between 2013 and 2016, representing about €1 billion, and about 36% of the production and about 25% of added value to GDP in 2012; but the water and the environment sector received less than 1% of public R&D provided to the top sectors (UNESCO, 2014; Janssen et al., 2016). This suggests that despite the important contribution of the water-and-wastewater sector to economic development, human health, and environmental protection its ability to command R&D support falls far short of other more commercially attractive sectors.

The Dutch have one of the strongest venture capital markets in Europe; the national government offers incentives to the startups through matching capital injections and tax breaks; and in 2016 startups accessed almost €1 billion of funding from the market. Although small firms are the largest component of employment growth and are more innovative, they have difficulty accessing venture capital; most of the venture capital is concentrated in central and southern regions around Amsterdam, Rotterdam and Eindhoven; and only a small fraction of venture capital goes to water, wastewater or the environment because these have long commercialization periods and investors prefer more general purpose technologies that serve a wider market and have faster commercialization periods (Janssen et al., 2016; Aquatech, 2015).

The Netherlands has 13 research universities whose focus is basic research, and 37 technical and vocational universities whose focus is more towards applied sciences. Dutch research universities are heavily involved in R&D, at a rate almost twice the EU average, and are also ahead of private research facilities; but most of this R&D is concentrated in a small number of the research universities (Janssen et al., 2016). To support entrepreneurship, innovation, R&D, and the commercialization of technology, many Dutch cities are becoming actively involved in cluster programs and provide incubators for startups (Janssen et al., 2016). The Netherlands published almost 35,000 scientific publication in 2014, placing it sixth in the EU, and it was particularly strong in the biological sciences and engineering (UNESCO, 2014). Its average rate of publication per million inhabitants between 2008 and 2014 was 1,894, which was ahead of the EU average of 1,085 and far ahead of the United States average of 998; but the Netherlands was behind the Nordic average and far behind top performing Denmark whose publication rate stood at 2628. Dutch scientific publications are also among the most cited, at 1.48 per publication, compared to the EU average of 1.09 citations (UNESCO, 2014).

C. Related & Supporting Industries

The spatial concentration and proximity of upstream and downstream firms within an industry creates an organizational structure which facilitates or hinders the exchange of ideas and information, determines roles and responsibilities, reflects the relative power and influence of member, and depends on as well as reflects the objectives and strategy of firms in the cluster (Porter, 1990; Markusen, 1996). The resulting organizational structure facilitates or hinders continuous innovation and determines the degree of competitiveness of the cluster and its key firms (Porter, 1990). The evolving Leeuwarden water technology cluster consists of businesses, research institutes, educational institutes, and governments agencies within the water technology sector which have been purposely brought together to create synergy for world class innovation, education and entrepreneurship related to water technology. Given that the driver for the Leeuwarden cluster is a public-private partnership, the Leeuwarden cluster would be best described as an anchored cluster where a non-profit organization dominates the cluster and the economic relations between cluster members (Markusen, 1996).

The anchor of the Leeuwarden cluster is the Water Campus which consists of three managing partners - Wetsus, the Center for Expertise in Water (CEW), and the Water Alliance – other key permanent partners – the City of Leeuwarden, the Friesland Province regional government, Centre for Innovative Expertise Water (CIV) and Water Application Centre (WAC) – and about 70 companies and institutions that are connected as a member or partner to the managing partners. The Water Campus uses a model called the Water Technology Innovation Chain to support water technology firms to accelerate the time to commercialization and increase the rate with which technologies are successfully commercialized by bringing together all the supportive institutional elements which entrepreneurs and innovators would require throughout the whole commercialization process, from idea to business. The Water Campus provides a single focal point for education, scientific and technological knowledge, business support, and match-making related to water-and-wastewater; Westsus helps firms with demand-driven scientific research; the CEW helps firms with applied research to accelerate innovation and reduce the time to market for water technologies; the Water Alliance helps with business facilitation; and the WAC helps firms test their technologies in sophisticated laboratories, and identifies and coordinates with sites across the province to facilitate field testing and demonstrations (Water Campus, 2017).

D. Demand Conditions

Demanding customers and intense local competition puts pressure on firms to constantly innovate and improve the quality and functionality of their products which increases the competitiveness of these firms (Porter, 1990). The Dutch water economy, over several centuries, has been driven to address water hazards and water quality issues – this demanding environment provided fertile ground for the rise of technologically capable water technology firms that would be pushed to become internationally competitive once local demand was largely satisfied (Lintsen, 2002; Geels, 2005; Lonnquest et al., 2014). The Netherlands is a now net-exporter of water and related environmental technologies and is the global leader in some water sub-sectors, such as delta technology, and shares global leadership in several other water sub-sections, such as water-and-wastewater treatment, recycling, and reuse (van der Veen, 2010). About 40% of the world market for water management is in Dutch hands (Holland Trade & Invest, 2017).

Water and the environment directly account for a small but important part of the Dutch economy. High population density, a high degree of urbanization, and significant economic activities have created significant environmental pressure in The Netherlands making water critical for public and environmental health and national economic competitiveness and performance. In 2010, the Dutch spent about €3.8 billion on treating drinking water, managing sewer systems and treating waste-water; turnover for the entire Dutch water sector in 2008 was about was € 16.4 billion, of which 57% was earned by water technology companies; exports for the sector in 2008 amounted to € 6.5 billion, with over €2 billion for water supply and water purification alone; environmental services accounts for about 0.66% of gross added value; energy and water utilities companies account for about 2.3% of gross added value; and the water economy employs about 180,000 people (van der Veen, 2010; Holland Trade & Invest, 2017). The indirect impact is far greater than these figures would suggest as water is an input into almost all other economic activities. Many leading Dutch industries, such as petrochemicals and agriculture, are water intensive or water enabled industries that demand large volumes of water (Holland Trade & Invest, 2017).

Public procurement and the domestic utility industry are an important source of domestic demand. In the 1970s, the Netherlands introduced a levy on water pollution which became a financial driver to invest in water treatment facilities. The resulting huge investments created a market for new and improved water technologies and sparked an upsurge in R&D and innovation which positioned the Netherlands as a leading water technology nation (van der Veen, 2010).

E. Firm Strategy, Structure and Rivalry

Firms operate in a dynamic environment and this encourages firms to increase productivity and innovation (Porter, 1990). This dynamic environment is usually created by competition with other firms; however, it can also be stimulated in the Dutch case by the need to solve important or pressing social or environmental problems, such as flooding and storm surges, or by government regulation to improve water quality or reduce water use. In The Netherlands science, technology, innovation, and the environment have always influenced each other to shape how Dutch society addresses water resource management and water hazard risk (Bijker, 2002). For much of Dutch history the water economy was managed such that different players and different scales of government had specific areas of responsibility: local governments managed local water resources, while the regional and national governments managed national and regional projects; policy and technical design was determined by the Rijkswaterstaad, while construction was often done by private contractors; and operations or service provision was carried out by independent public agencies, public corporations, or private firms (Bijker, 2002). Although the balance of power over the water economy shifted briefly in favor of the national state following the Second World War, the private sector and civil society have historically played a large role along many dimensions to include defining problems, identifying solutions, implementing projects, and operating and maintaining the resulting water systems (Bijker, 2002).

The presence of many technically capable and well-established water technology firms does not automatically translate into a competitive or profitable market structure. The Dutch water economy has the largest number of water technology firms of any of the six clusters studies; however, the Dutch water economy is primarily characterized by firms operating under market structures that can be characterized as monopolistic, oligopolistic and monopolistic competition, depending upon their segment of the water economy. Therefore, at the local, regional and national scales the Dutch water sector is generally not characterized by intense inter-firm competition or rivalry; however, at the global scale where there are firms from other countries serving similar market segments there is more likelihood for Dutch water technology firms to face competition and rivalry.

The Dutch have tended to operate an open economy for most of their modern economic history, their firms have usually been forced to adapt to external economic and political circumstances beyond their control, and the Dutch have been able to build internationally competitive firms at various scales (Sluyterman, 2013). There was a brief experiment with a protected and managed market-economy in the middle of the 20th century; however, by the start of the 21st century the Dutch economy had again become a decidedly open, liberal market-economy (Sluyterman, 2013). This environment means Dutch technology firms, many of which are small by international standards, have an international outlook and the experience to compete in the international market.

Firm structure in the water technology sector is characterized by many small firms which in some ways encourages innovation through the independence of the entrepreneurs; however, this type of structure creates a fragmented industry with small firms not capable of bearing large amounts of risk, or the costs associated with long periods of commercialization (van der Veen, 2010). The Dutch water sector consists of about 1500 firms, most of which are small-and-medium in size, with only 270 firms employing more than 100 persons; and more than 60% of these firms engage in exporting (van der Veen, 2010). The increase in popularity of public-private partnerships and the rise of contractual arrangements such as Design-Build-Own-Operate (DBOO) favors large, multinational water-and-wastewater firms who can build a consortium and carry the risk of a large, long-term investment (van der Veen, 2010). This has been a stimulus to the creation of facilitation and cooperation mechanisms such as the Water Alliance, Wetsus, and the Netherlands Water Partnership which allows small technology firms to network and showcase their technologies and capabilities.

Firm strategy in the water technology sector is built largely upon a very strong scientific and technological position, home demand which is strong and technically demanding, and decades of international experience; firm strategy is hampered by a paucity of entrepreneurs, a weak entrepreneurial spirit, a cultural reluctance to take risks, and a regulatory regime which does not reward risk taking – these issues are generic to the Netherlands, weakens the national and sector innovation systems, and makes it difficult to translate the knowledge and experience to commercially successful business ventures (van der Veen, 2010). The scientific and technical capacity to develop technologies must be balanced by the entrepreneurial and innovative capacity to commercialize these technologies, or investors and venture capitalists will not enter the market (van der Veen, 2010). Water technology clusters are ecosystems and they cannot function competitively if important elements, like financial intermediaries or trade associations, are absent (Moore, 1993, 1996).

F. Government & Chance

Government and chance can, and often does, serve as a catalyst for innovation, entrepreneurship, and competitiveness (Porter, 1990). The Dutch government did this by encouraging firms through incentives, pushing them with regulations, by acting as a demanding customer through setting high standards for government procurement, or intervening in markets to overcome market failure; and chance can do this; while chance played a significant role in creating a globally competitive water sector as a byproduct of an urgent need to address water quality issues, as well as manage water hazard risks. Water as a Dutch 'Top Sector' receives considerable public support through a range of tax benefits, innovation credits, and grants that encourage businesses to develop innovative products and services (Ministry of Economic Affairs & Climate Policy, 2017). The Dutch government also works to raise the profile of the water sector: water technology firms may receive national honors and awards for excellence in science, technology, and innovation, technological through the biennial National Icons Competition; through the biennial Innovation Expo which has become a network comprising 3,000 representatives from the private sector, public bodies and knowledge institutions that works together on innovations and technological breakthroughs; through the creation of national data bases, blogs, and vlogs to promote the water sector; and through its embassies and business attaches; and through its policies, such as the National Science Agenda (Ministry of Economic Affairs & Climate Policy, 2017). Here the state is attempting to overcome deficiencies in the water economy such as the bounded rationality of economic actors - where firms misunderstand market signals or are more risk averse than is socially desirable - or imperfect information – where asymmetric or incomplete information narrows the range of strategies choices or impeded profitable market transactions (Lescop & Lescop, 2013).

Policy making and regulation in the Dutch water economy has a long history, but it became a significant stimulus for innovation with the introduction in the 1970s of a levy on water pollution. This levy was used to finance investments in water purification which resulted in cleaner surface water as well as a leading global position for the Dutch water purification industry (van der Veen, 2010). Between the 1970s and 1990s the Netherlands became a leader in environmental policy making with policies and regulations that were considered as highly transparent and flexible; and although regulations remain stringent and environmental standards remain high, political and policy attention for the environment at the national scale has been superseded by a shift in attention to the supranational and global scales which may not be as beneficial to the Dutch water technology sector (van der Veen, 2010).

X. Conclusion

The Dutch water technology sector is a product of a long relationship between Dutch society and a water dominated environment that has at various times supported and sustained that society and at other times threatened its existence. The Dutch water challenge has generally not been too little water, like Singapore or Israel, but too much water: extensive tracts of farmlands and the built environment must be protected either from storm surges along the coast or flood waters from its many rivers. Many Dutch water challenges relate to its geography, geology, low lying topography, and large tracts of land that have been reclaimed from former bodies of water that must be constantly protected against flooding and subsistence. Another Dutch water challenge relates to water quality and environmental protection which is driven by the country's small size, high population density, and high level of urbanization. The Dutch have therefore learned how to manage water resources through both trial-and-error, and systematic intellectual and scientific inquiry; they have come to the realization that it should be driven by a continuous process of innovation that is adaptive and capable of meeting evolving challenges; and they have come to understand that it should involve multiple stakeholders from the public sector, the private sectors, and civil society rather than being managed exclusively by technocrats. This process of learning has fostered a philosophy towards water technology that it should be practical, efficient, cost-effective, and sustainable; that its development and diffusion benefits from forging mutually beneficial collaborations with international partners and experts; and that it should be made available to a global water economy that is facing a growing demand for fresh water - for domestic, industrial, and agricultural purposes - that is driven by population growth, urbanization, economic expansion and climate change. The Dutch have an intimate understanding of many of the water challenges facing the planet as The Netherlands has for generations been a densely populated, high-urbanized, highly industrialized, and agriculturally intensive society whose natural and built environment faces multiple risks from water-related hazards. What started out as a strategic vulnerability for The Netherlands has been turned into a strategic advantage with the country now recognized as a global leader in many water technology fields from flood control, to chlorine-free potable water supply, to recycling, to reuse, and desalination.

This long history of addressing complex water challenges, and the maturity of the Dutch water utility sub-sector, means that the Dutch water technology sector is currently in the paradigm of an innovation-driven growth strategy. Most of the 20th century saw massive public investments in water infrastructure and complex hydraulic engineering projects; while the last three decades of that century saw a shift to addressing water quality and water efficiency issues largely related to environmental protection. The current innovation driven paradigm is driven by a need to solve emerging problems, and old and persistent problems, in new and better ways that are more cost-effective and more financially and environmentally sustainable. The Netherlands has developed a globally competitive, innovation-driven, and diverse water technology sector with several globally competitive clusters spread across The Netherlands, each area having a dominant technological specialization or focus. The water technology cluster that is the object of this case study, Leeuwarden, specializes in technologies to produce fresh water and treat of waste-water. While the delta technology cluster in the south of the country could be considered a mature cluster with many large and experienced hydraulic engineering firms, the cluster in Leeuwarden could be considered a growing cluster with many smaller and newly emerging water technology firms.

The Dutch water technology sector is one of the largest in the world with much of its current business derived outside The Netherlands. The sector, however, owes much of its business to decades of public investment and public initiatives which provided an important launching platform for entry into the global water economy. Solving collective needs and challenges from flood protection, to navigation, to providing the domestic economy with a reliable and affordable water-and-wastewater services through world-class water utilities became the primary drive behind the Dutch water technology sector. Spillover effects meant that Dutch water-enabled and water-intensive industries and agriculture also benefitted from an innovative water sector. Although the national government took the decision to position water as a 'Top Sector' this decision came after there were emerging and mature water technology clusters in The Netherlands. The creation of this sector was historically the indirect effect of public activities in the Dutch water economy; however, given the continued importance of this sector to The Netherlands and the export potential of water technologies, the state is seeking to nurture and sustain this sector by consistent investment in world-class public water infrastructure, a broad-based technological infrastructure, appropriate science and technology policies, a network of public and private research organizations, and supportive government institutions. Dutch governments at all scales are working to ensure that R&D and commercialization take place by the creation of a supportive and facilitative economic, technological and institutional landscape along the entire value chain of the water industry. Dutch governments and industry associations at all scales participate in the process of learning, the diffusion of water innovations, and the acceleration of commercialization in several ways: by hosting events which build network and act as fora for the exchange of ideas and knowledge; through collaborations and partnerships; and by providing test-bedding opportunities for testing technologies in real-life operating conditions at water-and-wastewater works. In this way local competences were built up incrementally and systematically. The structure of the Leeuwarden cluster is that of an anchor centered around the WaterCampus, which is a public-private partnership organized to bring businesses, educational institutes and governments together to stimulate innovation and entrepreneurship. Despite public interest in the water technology sector, the long history of private sector involvement in the water economy, and the considerable global experience of private firms in water technology, ensures that The Netherlands has been a net exporter of water technology for several decades, and makes the sector ultimately less reliance on government contracts, government funded R&D, and government subsidized venture capital. If the Leeuwarden Water Cluster can become less dependent of state support this cluster has a high probability of transitioning to a mature cluster in the coming decade given the high global need for water technologies.

CHAPTER 9

WATER TECHNOLOGY CLUSTERS IN SINGAPORE

I. Introduction: Water in Singapore

Water has always been both a key strategic resource and an economic asset in Singapore: first as a constraint on development, when the deficit in water supplies threatened to limit economic growth; and second as an enabler of development. The creation of an innovative water sector has resulted in a globally competitive industry that generates exports of technologies and expertise, raises the diplomatic standing of Singapore in the international community, and re-brands the city-state as a well-managed, efficient, aesthetically pleasant, and environmentally responsible city (Wong, 2006; Tortajada, 2006a, 2006b; Caballero-Anthony & Hangzo, 2012; Braak et al., 2017; Dhalla, 2017; Joo & Heng, 2017). This transformation of the Singaporean water economy can be traced to good governance, robust institutions, and the application of technology; and these three pillars of transformation were the result of a concerted and consistent effort by an innovative and entrepreneurial Singaporean government as it addressed a key development challenge (Tortajada, 2006a, 2006b; Low, 2012; Tortajada, Joshi & Biswas, 2013). Singapore has won many awards for its success at water resource management, and the Third World Centre for Water Management identifies the city-state as one of the best examples in the world of urban water supply and management from which both developed and developing countries could draw lessons which could be adapted to their contexts (Tortajada, 2006a, 2006b).

Singapore strategy for transforming its water economy required numerous specific enablers: (1) a strong political will to create an enabling environment by ensuring institutional effectiveness; (2) an effective and efficient legal and regulatory framework; (3) an ability to conceive of all sources of water supply in their totality; (4) a concurrent emphasis on supply and demand management, and on waste-water and storm-water management; (5) an ability to find the right balance between water quantity and water quality, between efficiency and equity considerations, and between public sector and private sector participation; (6) an ability to find ways to lower production and management costs while keeping service quality high; (7) an ability to raise sufficient capital to finance necessary infrastructure and to prioritize those projects; (8) a commitment to developing a technologically skilled, managerial competent, and highly motivated workforce; and (9) its ability to learn from experience and adapt to changing circumstances (Tortajada, 2006a, 2006b; Chew, Watanabe & Tou, 2010). The development of strategies, the creation of enablers, and the ability to integrate and coordinate them in the relatively short time-frame of 40 years, is an indication of the existence of a robust governance and institutional framework; while the number of strategies and enablers is an indication of the complexity of the challenges that all water resource managers must face. The Singapore case also suggests that political will and public support often seems to require a crisis driver to create a sense of urgency to solve water challenges. Singapore's example is therefore a sobering warning to other countries that the creation of a modern water economy, and a competitive water technology sector, cannot take place amid mediocre institutions, weak and uncommitted public and private leadership, and unclear priorities (Tortajada, 2006a, 2006b).

This chapter will show the following: (1) Singapore's historical relationship with water and how its political leaders recognized that the development of a national water economy was critical for underpinning all aspects of political independence and economic development; (2) Singapore's governance and institutional framework and how the country's political leaders eventually developed policies and institutions that transformed the country from a water-scarce country to a water independent country; (3) Singapore's water resource management strategy and how the country's technocrats employed science and technology to close the 'water loop' from collection, to treatment, to disposal, to reuse; (4) Singapore's innovation and economic development strategy and how it created indigenous expertise in water resource management and water-related technologies; and (5) Singapore's competitive position in relations to its water technology sector and how the country is a major global exporter of urban storm water, recycling, and desalination technologies. Singapore is now an internationally recognized name in the global water community where it is perceived as a model for urban water management and environmental conservation which supports its desire to become a global HydroHub for innovations in water (Caballero-Anthony & Hangzo, 2012).

II. History of the Singapore Water Economy

A. Overview

Singapore is a city-state which gained independence twice: from Britain in 1959, after 135 years of colonial rule, and then also from the Malay Federation in 1965. The history of its water economy can be divided into roughly five periods: (1) the colonial period prior to 1959; (2) the immediate post-independence period from 1965 to 1972 when the new nation was politically stabilized, the initial development vision established, and its water supplies from Malaysian were secured; (3) the period between 1972 and 1992 when the legal, regulatory and institutional foundations of the water economy were established, and natural local sources exploited to the maximum; (4) the period between 1992 and 2003 when attention shifted to exploiting unconventional sources; and (5) the period since 2003 when the water economy was opened up to the private sector and the decision made to make the water sector into a globally competitive HydroHub.

B. Colonial & Pre-Independence Singapore.

Singapore was founded in 1819 by Sir Stamford Raffles of the British East India Company as a free port to capitalize on its strategic location along major Far East maritime trade routes. The colony was variously administered by a Municipal Commission, established in 1887, with eventual responsibility for piped water, gas, and electricity; between 1951 and 1957 by a City Council - which took over from the Municipal Commission – and a Rural Board; and between 1957 and 1959 by the Ministries of Local Government and National Development as part of major bureaucratic reforms to prepare the city-state for independence and reduce red-tape, bureaucratic inefficiency, and corruption (Tortajada, Joshi & Biswas, 2013). In 1963 the Public Utilities Board (PUB) was formed to take over implementation and operational responsibilities for water, electricity, and gas services: given the developmental significance of the PUB's portfolio it was placed under the Prime Minister's office where it largely remained until 1971 (Tortajada, Joshi & Biswas, 2013). Singapore's long struggle to establish high quality institutions, governance arrangements, and technical and managerial capacity would eventually prove central to its ability to address water resource management and every other development challenge (Yew, 2012; Tortajada, Joshi & Biswas, 2013).

Initially, Singapore was able to supply all the water needs of its small population from local sources and the first reservoir was constructed in 1822. By the 1890s well water had become contaminated and many were closed down (Tortajada, Joshi & Biswas, 2013). A second reservoir was constructed - and several times upgraded - between 1867 and 1922, and a third commissioned in 1910: total supply capacity was now 17.5 million gallons per day from a storage capacity of 2,100 million gallons but by 1922 this was inadequate for the 400,000 people who lived in the colony (Tortajada, Joshi & Biswas, 2013). This led to the 1927 agreement with the Sultan of Johor for the construction of two reservoirs which were to eventually supply an additional 18 million gallons of water per day to Singapore by 1932 (Tortajada, Joshi & Biswas, 2013). The constantly increasing volume of regional and global trade ensured the economy flourished and that rapid development took place, but this was placing a strain on the water resources of the small colony above that for which the authorities made provision: there was essentially an absence of long-term planning and it was not until 1950 that the first serious water resources study was commissioned (Tortajada, Joshi & Biswas, 2013). In the 1950s several water projects were initiated both in Singapore and Johor to expand water supply; however; all these projects proved inadequate and during 1961 and 62 Singapore suffered severe water shortages from prolonged droughts (Tortajada, Joshi & Biswas, 2013). In 1961 and 1962 critical water agreements with Malaysia were signed to secure additional water from Johor and to secure this supply until 2061; while the government of Singapore, with help for the World Bank, was driven to commission another water study because of rapidly increasing demand (Tortajada, Joshi & Biswas, 2013). By independence Malaysia controlled 80% of Singapore's fresh water supply

C. 1965-1972.

The priority in this period was for newly independent Singapore to achieve political and economic stability and water played a critical role in achieving these goals. In 1965, daily per capita water consumption among the approximately 1.8 million Singaporeans was 75 liters and the most immediate impediments to economic growth were insufficient water supply, droughts and flooding. The main emphasis of water strategy in the 1960s was therefore to secure additional water from Malaysia under the Water Agreements - this was the least expensive and most readily available source at the time – and to address flooding from which about 13% of Singapore was at risk (Tortajada, Joshi & Biswas, 2013). The government also began the process of putting in place enabling elements what would become a comprehensive institutional and regulatory framework for water resource management: the Environmental Public Health Act of 1968 and the Clean Air Act of 1971 were passed, and a Water Planning Unit was established in the Prime Minister's Office in 1971 (Tortajada, Joshi & Biswas, 2013). This unit began to study various options to address Singapore's long-term water problems and in 1972 produced the city-state's first 20-year Water Master Plan (Tortajada, Joshi & Biswas, 2013). The Water Planning Unit initially sought the assistance of Tahal Consultants from Israel, but their input was limited: Israeli expertise was based on conditions very dissimilar to Singapore's and the city-state realized that it would have to quickly develop indigenous expertise (Tortajada, Joshi & Biswas, 2013). In the early years there was considerable continuity in policies and plans as most of the water supply projects implemented in this period were a continuation of plans which were developed by the

British in the pre-independence period, in particular the expansion of supply from Johor (Tortajada, Joshi & Biswas, 2013). The severe financial constraints during this period meant that projects had to be carefully prioritized and resourceful city engineers had to come up with innovative, low-cost solutions (Tortajada, Joshi & Biswas, 2013).

D. 1972-1992.

In this period the emphasis of the water strategy initially shifted to self-sufficiency and later to environmental remediation, with the cleaning of rivers and waterways. Whereas the focus of the previous period was on securing additional supplies from Johor, the 1970s focused on increasing local sources of water supply (Tortajada, Joshi & Biswas, 2013). It was also the period when comprehensive and centralized planning by the state became well-established: in 1971 a Concept Plan with a 40-year time horizon was produced whose vision would be implemented by a series on 10-year sector-specific Master Plans (Tortajada, Joshi & Biswas, 2013). Three Master Plans were of critical importance for the water sector – the Water Master Plan, the Sewerage Master Plan, and the Drainage Master Plan – although other Master Plans – such as for housing – would also impact water and would have to be coordinated between the agencies responsible for water. The 1972 Water Master Plan contained two broad strategies: exploit existing sources of water resources more efficiently and effectively; and keep under surveillance unconventional sources of water until they become technically and economically feasible (Tortajada, Joshi & Biswas, 2013). Because of Singapore's small size and high level of urban development, it was recognized that unconventional sources such as storm-water runoff, recycling and reuse, and desalination would eventually have to be exploited (Tortajada, Joshi & Biswas, 2013).

The priority water development strategy was to exploit surface water sources, through extensions of water catchment areas, as this was the quickest and most cost-effective strategy in the short-to-medium term, although Johor water was still cheaper. Many potential catchment areas were heavily polluted and required extensive remediation before their potential could be exploited (Tortajada, Joshi & Biswas, 2013). Contrary to findings from the 1950 Water Study, the 1972 study determined that ground-water potential was very limited due to Singapore's soil and geology, while cloud seeding proved unsuccessful (Tortajada, Joshi & Biswas, 2013). The Water Master Plan also included plans to extend the city-state's catchment areas from 11% to 75% of land area, and to implement pollution controls to improve the quality of water being collected in those catchment areas (Tortajada, Joshi & Biswas, 2013).

After 1986, when local catchments had been fully exploited, Singapore began to seriously examine the unconventional sources of water; by this time some experience at recycling wastewater had been developed, as the Ministry of the Environment (EVN) had established a pilot plant as far back as 1974, and experience with inter-agency coordination on water quality issues had been built-up (Tortajada, Joshi & Biswas, 2013). Exploratory work on the possibility of damming the Marina Bay, to create what would later become the Marina Barrage, was begun, and negotiations were started with Indonesia to import water from that country through an undersea pipe. Recycling and desalination would have to wait a few more years before full-scale projects would be technically and economically feasible (Tortajada, Joshi & Biswas, 2013).

Improved drainage, pollution control and sewerage also began receiving more attention from planners and policymakers: pollution affected the quality of water being collected in the expanded catchment areas and stored in reservoirs, as well as the cost of treating water to make it potable. In 1972 a Drainage Department was set up under the ENV to protect people and infrastructure from flooding, improve public health, and produce a Drainage Master Plan. Over the course of 25 years it would invest S$2 billion in drainage infrastructure, in upgrading waterways to facilitate storm-water runoff, and in reducing flood prone areas by 95% (Tortajada, Joshi & Biswas, 2013). The Drainage Department also became responsible for enforcing several pieces of legislation and for issuing development permits relating to drainage.

The dominant sanitation method traditionally employed in Singapore was the night-soil bucket collection service which would remain in use up until the 1980s when it was finally superseded by a comprehensive sewerage system (Tortajada, Joshi & Biswas, 2013). To address sanitation, a Sewerage Master Plan, later renamed Used Water Master Plan, was produced in the late 1960s which outlined the creation of a sewerage system which was separate from the storm-water system which channeled surface runoff directly to rivers and reservoirs. The building of a comprehensive sewerage system was very costly, but is made feasible because capital, operating and maintenance costs were ultimately recovered from consumers using a cost-recovery mechanism (Tortajada, Joshi & Biswas, 2013). To complement the efforts to improve water quality through drainage and sanitation, the government in the 1980s also embarked on a concerted effort to clean up Singapore's rivers and waterways. This laid the foundation for a shift in emphasis to aesthetics in the next period, and this was articulated in the updated 1991 Concept Plan.

E. 1992-2003.

In this period the emphasis shifted to providing Singapore's citizens and visitors with access to recreation and amenities in both the natural and build environment (Tortajada, Joshi & Biswas, 2013). The success of the early supply strategies was demonstrated by the water system's capacity to support domestic water consumption of 173 litres in 1993, and to meet ever increasing industrial demand (Tortajada, Joshi & Biswas, 2013). Policy now shifted to how to contain domestic demand and water planners therefore began serious consideration about adding recycled and desalinated water to the portfolio - in 1996 consultants were contracted to carry out feasibility studies for desalination (Tortajada, Joshi & Biswas, 2013). Storm-water from roads and housing estates was also now being tapped, rather than channeled into the sea, and urban areas were brought into the catchment system (Tortajada, Joshi & Biswas, 2013).

A new recycling demonstration plant using the latest technology was constructed at a cost of S$14 million, and a decision was taken in 1999 for the PUB to build one small desalination plant and invite the private sector to bid to design, build, operate and own (DBOO) a large desalination plant, exploiting recent advances in desalination technology (Tortajada, Joshi & Biswas, 2013). Between 2000 and 2002 the demonstration recycling plant proved the technical and economic feasibility of the recycling water and plans were put in place to add recycled water to the water portfolio of the PUB: thus NEWater was born and waste-water was re-branded as used water (Tortajada, Joshi & Biswas, 2013).

F. 2003 and Beyond

In this period Singapore committed itself to exploit unconventional sources of supply, strengthen sustainable environmental management practices, reduce domestic consumption, engage the private sector to leverage their competencies, and make the water sector into a globally competitive, high-technology industry with high investment, export and job creation potential (Wong, 2006; Khoo, 2009; Chew, Watanabe & Tou, 2010; Tortajada, Joshi & Biswas, 2013; Han, 2014). The latest approach to water supply is encapsulated in a strategy launched in 2005 known as the 'Four Taps Strategy' which focuses attention on the four main sources of water – imported, rain and storm-water, recycled, and desalinated – and seeks to find the optimal balance between these sources. Success was achieved on all fronts: most of Singapore's land area is used as a catchment, the supply from unconventional sources has significantly increased, daily per capita domestic water consumption was reduced to 153 liters in 2011, and dependence on Johor water has been reduced (Tortajada, Joshi & Biswas, 2013). With regards to unconventional sources, the city-state opened two desalination plants, in 2005 and 2013 respectively, which together meet about 25% of Singapore’s current total freshwater needs; there are plans for three additional desalination plants by 2020; and the PUB has identified five coastal sites for future plants with the goal for desalination to meet 30% of the estimated daily freshwater demand by 2060 (PUB, 2016). Singapore opened its first full-scale water reclamation plant in 2003 to produce NEWater, primarily for the commercial and industrial sectors which value high-quality water for many industrial processes (PUB, 2016). NEWater can also be added to reservoir water where it can undergo additional treatment to produce drinking water. Four more NEWater plants were commissioned in 2003, 2004, 2007, and 2010 respectively (PUB, 2016). All the desalination and NEWater plants are public-private partnerships with design-build-own-operate (DBOO) contracts (PUB, 2016). NEWater and desalination meet up to 40% and 25% of Singapore's daily water demand, and plans are under way to boost capacity to increase this to 55% and 30% of water needs respectively by 2060, before the second water agreement with Malaysia expires.

Several more storage facilities were commissioned in this period. The Marina Barrage, Singapore's 15th and most urban reservoir, was commissioned in 2008; and the 48 kms of phase one of the Deep Tunnel Sewerage System (DTSS) was completed in 2008, with the remaining 12 kms of Phase 2 scheduled for completion in 2025 (PUB, 2016). Two additional reservoirs were opened in 2011 at Punggol and Serangoon (Tortajada, Joshi & Biswas, 2013). Singapore's total water infrastructure currently stands at 17 raw water reservoirs, 9 treatment works and 14 storage or service reservoirs with a capacity to supply the city-state about 1,360 million liters of water per day; and two-thirds of Singapore's land area is now used as a catchment with plans to increase this to 90% by 2060 (PUB, 2016). At independence Singapore only had three reservoirs. Although Singapore still imports water from Malaysia the city-state is now, theoretically at least, capable of self-sufficiency in the supply of fresh water. Singapore is now fully connected to sewers, the PUB collects and treats all wastewater; and the PUB has constructed separate drainage and sewerage systems to facilitate wastewater reuse on an extensive scale (PUB, 2016). There is universal access to drinking water and sanitation, 100% of consumers are metered, unaccounted for water as a percentage of total production is 5%, and there are no illegal connections (Tortajada, 2006a & 2006b). These performance results exceed most of the developed world, and far outstrip all of the developing world, and represent a sea change from the performance results at independence in 1965.

III. Singapore's Water: Overcoming a Deficit

Although Singapore is located in the tropical-monsoon region of South-east Asia and receives one of the highest levels of annual rainfall in the world, the country has very limited natural water resources. This is due to its small size, low-lying topography, extremely small rivers, absence of natural aquifers, and soil characteristics which result in a low rate of absorption of rainwater, limits the surface area available for natural catchments and the storage of water (Dhalla, 2017). The UN has ranked Singapore 170th among 190 countries in terms of fresh water availability (UNESCO, 2006). With a current population of about 5 million citizens in about 700 km^2, Singapore water and urban planners must reconcile competing land uses such as housing, commerce, industry, transport, education, and recreation (Dhalla, 2017). Limited land for water collection and storage placed a serious ceiling on the prospects for economic development, good public environmental health, and a high quality of life (Wong, 2009; Dhalla, 2017).

Prior to independence, and the city-state's economic takeoff, water consumption levels were much lower than at present, and the inadequate infrastructure and poor water supply management sparked water rationing in 1961 and 1963. Singapore's economy in the 1960s was dominated by low-end agriculture – pig and poultry farming – and services – shipping and trade related services – that were highly polluting and, when combined with the lack of sanitation infrastructure, resulted in the city-state's limited bodies of fresh water being largely open cesspools (Dhalla, 2017). These industries offered little value-added and thus little prospect for meaningful and sustainable economic development. In the half-century since independence, Singapore has transformed its agricultural-and-trade-based economy to one that exports high-technology manufactured products, advanced producer services, and tourism (Wong, 2009; Dhalla, 2017). This transformation, however, comes at a price: these high-value industries are energy-and-water-intensive. As the economy and population of the city-state expanded the demand for fresh water only kept rising; although increases in overall domestic demand is now tapering off, and per-capita domestic consumption is falling because of conservation and demographic changes, industrial demand is expected to continue to rise from the continuing shift to high-value, water-intensive industries (Wong, 2009; Dhalla, 2017). Singapore has had to purposively transform and align its water economy in step with the restructuring of the wider economy, but the deployment of recycling and clean production technologies would also support the upgrading of the wider economy making it more sustainable and competitive.

Singapore's current domestic water storage capacity historically only satisfies about 50% of the demand for water, with the rest of that demand being met from water imported from neighboring Johor state in Malaysia (Wong, 2009). The combination of local and Johor storage caters for about two years supply at the normal levels of usage, but in the absence of the Johor supply that buffer is reduced to only about 4 months supply from local sources (Wong, 2009). This risk to its water supply has encouraged Singapore to diversify its sources of supply to include securing a 100-year S1.5 billion agreement with Indonesia to import water; and to make up for the deficit in its storage capacity it employs reclamation of used water, desalination, strict demand management through full-cost pricing to reflect water's scarcity, and by encouraging conservation (Wong, 2009).

Solving the many challenges facing the water economy was a high priority for

Singapore's government from the earliest days. Political commitment at the highest level, and the inculcation of a sense of crisis in the public to secure their support, ensured that comprehensive water and waste water infrastructure was given priority in the allocation of scarce financial resources (Wong, 2009; Yew, 2012; Dhalla, 2017). Strict zoning laws were used to relocate people and industries, public housing used to resettle people in estates with water-and-wastewater infrastructure, and carefully spatial planning segregated land uses to create green-and-blue spaces to collect storm-water and offer recreation to its citizens (Wong, 2009; Yew, 2012; Dhalla, 2017). Political commitment and the nurturing of public support also ensured that Singapore approach to a complex problem could involve a long-term multifaceted, and holistic approach to water resource management. Singapore's strategy was accomplished incrementally, through a process of learning and adaptation over several decades (Wong, 2009; Yew, 2012; Dhalla, 2017).

Singapore is now in advance of many other countries in the capture, treatment, and reuse of waste-and-storm water. Currently, two-thirds of the country now serves as a catchment area for drinking water supply, among the highest in the world, and the country is almost water independent. This determination to efficiently and effectively manage its scarce water resources has also helped create the foundation for a globally competitive, high-technology water sector with companies and research facilities that are now among the most scientifically and technically capable, and innovative and entrepreneurial, in the world. A natural deficit in water became a driver for both public and private innovation and entrepreneurship; Singapore has been successful in building a diverse, sustainable, and resilient range of water sources; and an internationally competitive industrial sector was developed over four decades which where there was initially none (Wong, 2009; Menkhoff & Evers, 2011; Tortajada, Joshi & Biswas, 2013; Dhalla, 2017).

IV. Governance of the Singapore Water Economy

A. Overview

The sustainability of Singapore's national economy and the competitiveness of its industries are contingent upon the sustainable supply of fresh water (Wong, 2006). The first two pillars of Singapore's success in solving its water deficit were good governance and robust institutions (Low, 2012). These pillars were realized by an integrated strategy of long-term comprehensive planning, strong political will, effective laws and regulations, efficient institutional arrangements, and practical and effective approaches to problems which facilitated reconciling the trade-off between economic development and environmental protection (Tortajada, 2006a, 2006b; Wong, 2009; Menkho & Evers, 2011; Tortajada, Joshi & Biswas, 2013; Dhalla, 2017). The commitment to these strategies is demonstrated by the fact that the government of Singapore allocates approximately 1% of its annual GDP to protecting public and environmental health (Tortajada, Joshi & Biswas, 2013).

Singapore's water authorities over time, and through a process of learning and adaptation, developed an extensive suite of innovative policies, regulations, and practices for the sustainable management of scarce water resources, protection of the environment, and support of economic development (Chew, Watanabe & Tou, 2010; Menkho & Evers, 2011). Singapore's governance philosophy to water and the environment can be summed up by the principles of Engineering, Economics, Education, Enforcement, and Engagement: engineering represents the hard infrastructure; economics represents the careful use of scarce resources and market pricing; education represents changing people's behavior for the common good; enforcement represents sanctions for irresponsible behavior; and engagement represents making the average citizen accept ownership for achieving sustainable environmental outcomes (Tan, Lee & Tan, 2009). This governance approach is both holistic and integrated and includes policy instruments and regulations, management, technology, and human capital development.

One strategy for achieving the universal provision of affordable, sustainable and resilient water supply services to both domestic and commercial customers employs the concepts of 'addition' and 'multiplication.' This two-pronged strategy addresses both supply and demand: addition is a supply strategy which involves the capture and storage of storm-water and desalination of sea water; multiplication is both a supply and demand strategy which involves the reclamation of used water and the reduction of demand through pricing, behavior changes and the deployment of more efficient technologies (Wong, 2006). The 'Four Taps Strategy' introduced in 2005 to diversify sources of water is an important component of this framework.

The Singapore philosophy supports the goal of managing water resources as a 'closed loop' because policymakers and planners concluded that the solution cannot rely on indefinitely expanding supply, which is ultimately fixed (Wong, 2006; PUB, 2016). The new water paradigm of a 'closed loop' works toward balancing supply with demand through sustainable conservation practices and the employment of advanced technologies (Wong, 2006; PUB, 2016). Such a paradigm, however, shift requires the highest level of water governance, which in the case of Singapore is achieved through the high steering power and efficiency of government, the technical and managerial competence of elite groups, and the outstanding planning and organizing competencies of public sector agencies tasked with realizing water and environmental goals (Menkho & Evers, 2011).

B. Institutional & Regulatory Framework

The government of Singapore has gradually developed, and regularly updates and amends, a comprehensive framework of policies, legislation, regulations, codes of practice, and best-practices to govern the water-and-wastewater sector; it carefully allocates roles and responsibilities between public and private partners; and it provide an enabling environment for sustainable economic development (Wong, 2006; Tortajada, Joshi & Biswas, 2013). Planners and policymakers from across agencies regularly and systematically work together to update regulations to reflect the latest scientific knowledge, technologies or management practices, and land is rezoned and re-purposed to higher-value uses in a timely manner (Tortajada, Joshi & Biswas, 2013).

The institutional framework is underpinned by a collection of technically competent public agencies which developed comprehensive and integrated policies, carefully implemented them, and rigorously monitored and enforced regulations to protect Singapore's water resources and her environment (Tortajada, Joshi & Biswas, 2013). The Ministry of the Environment and Water Resources (MEWR) which was formed out of the Ministry of the Environment in 2004 to manages water as a strategic national resource; the Public Utilities Board (PUB) manages the country’s water supply, water catchments, and used water in an integrated way that support economic development; the National Environment Agency is responsible for implementing environmental policies established by the MEWR; the Environment and Water Industry Development Council (EWI), which was formed in 2006, is charged with turning the environment & water industry into a strategic growth area; local public universities train personal and carry out basic and applied research; the Agency for Science, Technology and Research (A*STAR) has the primary mission of raising the level of science and technology competency in Singapore; the Economic Development Board (EDB) helps grow local companies, encourage R&D to develop cutting-edge technologies, and then helps export Singapore’s capabilities to growing markets around the globe; and the Singapore Water Association (SWA) promotes Singapore as a point of reference for all water technologies and services (Menkho & Evers, 2011). The work of these agencies is well coordinated, and their plans carefully integrated, and occasional conflicting goals and a lack of consensus between these agencies are resolved at the level of the Cabinet (Tortajada, Joshi & Biswas, 2013). The success of these agencies demonstrates that Singapore's policymakers and planners have successful integrated the work of these agencies along horizontal and vertical dimensions (Marques, 2010).

As early as 1965 the government declared that water, sanitation, and environmental protection would be high priorities and demonstrated its commitment in 1968 with the Environmental Public Health Act, in 1971 with the Clean Air Act, and in 1975 with the Water Pollution Control Act: water, sanitation, and environmental considerations were to be an integral part of economic and spatial planning; the development, infrastructure, and environmental agencies coordinate their planning and decision-making; and policy and practice requires pollution prevention strategies over environmental remediation (Tortajada, Joshi & Biswas, 2013). The Water Pollution Control and Drainage Act of 1975 was an important step in rationalizing an increasingly complex and fragmented legislative and regulatory framework affecting water quality

(Tortajada, Joshi & Biswas, 2013).

Anti-pollution units were formed in 1970 and 1972 respectively and they carry out rigorous inspections and strictly enforce regulations using command-and-control processes: Singapore does not permit moderate levels of pollution like many other countries, it requires industries to adhere to strict norms, and it understands that water quality is significantly impacted by poor sanitation, pollution, and littering practices (Tortajada, Joshi & Biswas, 2013). In the early years thousands of people were prosecuted and fined for breaches of the environmental laws; however, over time, the number of prosecutions has been minimal, or even none at all, as compliance with pollution regulations became the national norm (Tortajada, Joshi & Biswas, 2013). Strict enforcement is complemented by public education and information provision and as early as 1969 the government initiated the 'Keep Singapore Clean' campaign to change norms around littering and the discharge of pollution into waterways (Tortajada, Joshi & Biswas, 2013). By 1992, Singapore has managed to reduce pollution to WHO accepted levels, completed the remediation of all its major polluted sites, and reduced regulatory breaches by potential polluters to a small fraction of its early levels, despite undergoing massive urbanization and industrialization and becoming a developed country (Tortajada, Joshi & Biswas, 2013; Braak et al., 2017).

Important recent updates to legislation were made in 1999 with the Wastewater and Drainage Act and the Environmental Pollution Control Act, which together replaced or consolidated several earlier pieces of legislation such as the Environmental Public Health Act of 1968, the Clean Air Act of 1971, and the Water Pollution Control and Drainage Act of 1975 (Tortajada, Joshi & Biswas, 2013). From the Wastewater and

Drainage Act (2002) come several codes of practice: the Code of Practice on Wastewater and Sanitary Works, the Code of Practice on Surface Water Drainage, and the Code of Practice for Water Services. These codes contain information on the minimum requirements and best-practices for planning, building and operating water-and-wastewater infrastructure, and for the provision of water-and-wastewater service. The Environmental Pollution Control Act of 2002 sets standards for water quality in terms of the acceptable temperature, the concentration of organic compounds, the concentration of suspended and dissolved solids, the pH values, and numerous other parameters for effluents. In 2008 the Wastewater and Drainage Act of 1999 was replaced by the Environmental Protection and Management Act which provides a more comprehensive legislative and regulatory framework for environmental pollution control and the promotion of resource conservation (Tortajada, Joshi & Biswas, 2013).

Collectively this comprehensive legal and institutional framework for water-waste-and-stormwater management and environmental protection is designed to re-brand Singapore as the 'Garden City,' and despite the high standards foreign direct investment has not been deterred (Tortajada, Joshi & Biswas, 2013). In fact the high environmental standards have encourage the establishment, by entrepreneurs and innovators, of many water-and-wastewater management, research, testing, consultancy, and technology manufacturing businesses; the pristine environment which replaced the slums and degraded environment sends a strong signal to investors about the competence of the state; and high standards of public and environmental health in the present reduce future costs for remediation (Tortajada, Joshi & Biswas, 2013). The government of the city-state over the years has closely followed the development in water, sanitation, and environmental policy and regulations in other jurisdictions – namely the United States, United Kingdom, and New Zealand - but the process of policy transfer was tempered with learning and adaptation to local conditions (Tortajada, Joshi & Biswas, 2013).

Despite the comprehensive legal and institutional framework that has been put in place to govern the water economy, there is no sector-specific, independent regulatory agency explicitly responsible for setting tariffs, ensuring the quality of public service, and for meeting service obligations, except for the high priority area of water quality which is the responsibility of the NEA (Marques, 2010; Tortajada, Joshi & Biswas, 2013). The primary means for guaranteeing these service obligations is self-regulation, although the Singapore water sector does have a professional association which plays a very important role in self-regulation and in disseminating best practices by keeping the sector appraised of the latest international developments in water technology and management (Marques, 2010). Although the levels of water tariffs are high by international standards the cost of water-and-wastewater services is a small portion of the average person's budget; and given that the quality of service is very high and consistent, there is little public or political pressure for independent regulatory oversight. Singapore's water policy makers and managers have also enthusiastically and faithfully employed economic tools and techniques to develop water and environmental policies and legislation, to guide decision making in the face of financial constraints, to set fair and equitable prices for consumers, to set prices which also reflect full environmental and production costs, to address market failures and introduce competition, and to create incentives for conservation and pollution control (Tan, Lee & Tan, 2009). This rational approach to water resource planning, though not perfect, is disciplined, consistent, and transparent which ensures a high degree of faith in public policy, public decision-making, and the credibility of water governance (Tortajada, Joshi & Biswas, 2013).

The city-state currently operates an institutional framework with a mixed system where the relative core competencies of both the private and public sectors determines whether direct public management or delegated private management is used (Tortajada, 2006b;). (Wong, 2009; Chew, Watanabe & Tou, 2010; Menkho & Evers, 2011; Tortajada, Joshi & Biswas, 2013; Dhalla, 2017). Since the government officially introduced public-private partnership (PPP) schemes in 2003, private sector participation in service provision is increasingly important in a sector previously the preserve of the public sector (Wong, 2009). Delegated public management is the preferred arrangement for new water-and-wastewater facilitates, usually taking the form of 15-30-year Build-Design-Own-Operate (BDOO) contracts, as the government moves from a public utility model for the water sector to an industry ecosystem model. Through PPPs, the public sector is seeking to deliver the most cost-effective services, and rather than directly owning and operating assets the government focuses on accountability for the services (Wong, 2006). Through PPPs, the public sector is also seeking a means to overcome technological, economic, financial, and management constraints within the public sector, leverage private sector expertise, and open business opportunities for the private sector so that the private sector can exploit economies of scale in applying new high-tech water technologies for service delivery (Wong, 2006).

C. Public Utilities Board (PUB).

Water-and-wastewater services were historically provided by the public sector exclusively through publicly owned and managed facilities using direct public management. The public sector agency responsible for providing these water services is the publicly owned PUB, which over the period of about 30 years was able to provide Singaporeans with universal coverage in water-and-wastewater services - one of the highest rates of coverage in the world – and offer its citizens one of the highest levels of service quality (Marques, 2010). This is a remarkable achievement in a relatively short time and a great improvement from the situation at independence: then there was an almost total absence of a sewerage system, waterways were highly polluted with human and industrial waste, the majority of citizens accessed water from public stand-pipes, and much of the city was at risk from flooding (Totarjada, 2006a, 2006b; Tan, Lee & Tan, 2009). The level of sophistication and innovation of the PUB's programs and projects is impressive.

The Public Utilities Board (PUB) was formed in 1963 as a statutory authority to take over the provision and supply of electricity, water and piped gas from the Singapore City Council (Khoo, 2009; Low, 2012). The PUB also adopted its first Water Master Plan in 1972 and aggressively developed several water supply schemes so that by the late 1970s water rationing was consigned to the past: a reliable and clean water supply system was created which was less dependent on the vagaries of weather (Khoo, 2009; Low, 2012). At the same time, stringent pollution control strategies and measures were adopted and enforced. In 2001, the PUB underwent a major transformation where it fully relinquished its energy portfolio but assumed responsibility for sewerage and drainage in addition to water supply: the PUB was therefore reconstituted to become the national water agency overseeing the holistic management of Singapore's entire water system – from fresh, used, storm, NEWater, to desalination - thereby 'closing the water loop'

(Irvine, Chua and &. Eikass, 2014). Since 2003 there has been an increase in private sector activity in water services - largely in treatment, NEWwater, and desalination - which represents a shift to delegated private management. The organizational structure of the PUB is therefore characterized by both horizontal and vertical integration of both water-and-wastewater services (Marques, 2010).

The PUB approach to water resource and environmental management is both comprehensive and holistic and comprises two dimensions – the hardware and the software – and is also encapsulated in the PUB’s corporate tag-line: 'Water for All: Conserve, Value, Enjoy' (Khoo, 2009). ‘Water for All’ is an example of the hardware dimension and refers to the supply strategy to ensure a diversified and sustainable supply of water for Singapore. ‘Conserve, Value, Enjoy’ is an example of the software dimension and describes water demand management that consists of appropriate water pricing, mandatory water conservation measures, public education and efficient management of the water distribution system. 'Conserve' specifically refers to several strategies, both mandatory and voluntary, to promote water conservation through good water-saving habits and measures, and regulations such as those which require the use of low-capacity flushing cisterns and constant flow regulators. Conservation strategies have been successful as between 2003 and 2015, households cut their daily per-capita water use from 165 litres to 151 litres, which the PUB plans to lower further to 140 litres by 2030 (PUB, 2017). The current daily level of about 150 litres of treated water every day, which is well above the 50-100 liter minimum recommended by the World Health Organization (PUB, 2016).

Guided by a long-term Water Master Plan, the PUB has taken an integrated water management approach: managing water, used water and drainage as an interconnected system, with the aspiration to collect every drop of water, reuse water endlessly and desalinate more seawater (Low, 2012; Irvine, Chua and &. Eikass, 2014). With this strategy, PUB “closed” the water loop and established a diversified and sustainable water portfolio comprising four National Taps, it strengthened Singapore’s water resilience and bolstered it against extreme weather events such as droughts and floods, and it used technological developments to increase water availability, improve water quality management and steadily lower production and management costs (Irvine, Chua and &. Eikass, 2014; Braak et al., 2017). The PUB also has world-class in-house research and development support with about 50 expert staff members in its Centre for Advanced Water Technology, which ensures that the agency and country has local knowledge and expertise (Tortajada, 2006).

Maintaining a high quality, world-class service is a critical component of the mission of the PUB. The PUB employs performance management to maintain the quality of service and has a robust system for monitoring and evaluating performance through the collection of performance data and the development of performance indicators (Marques, 2010). There are two important aspects of quality of service: one relating to operational efficiency, effectiveness, and reliability; and another relating to customer service (Khoo, 2009; Marques, 2010; Low, 2012). High quality customer service fits into an emerging Singaporean governing philosophy of public education and consultation that is designed to build public trust in public services and public institutions and to gain public support for key complementary strategies such as conservation. The result is that the level of public awareness about water management and environmental issues among the citizens of the city-state is very high by international standards (Khoo, 2009; Marques, 2010; Low, 2012). The customer service system used by the PUB is known as the CARE model - Call, Action, Response, and Evaluation – which merges customer relationship management with the latest information and communication technologies to address service problems and to maintain a relationship of trust and confidence with the public (Marques, 2010). Unlike most countries for which water-and-wastewater systems are hidden infrastructure, the emerging strategy in Singapore is to render waterworks visible to the public, resulting in a sense of attachment between people and the infrastructure and involving civil society in its protection.

The operational efficiency, effectiveness, and reliability of the PUB's system is world-class with current water losses being less than 5%, down from about 10% in the mid-1980s (Khoo, 2009). This level of unaccounted for water is one of the lowest rates in the world, better than many developing countries where water systems can lose as much as 60% of the water produced, and better than most of the United States; and it is achieved by universal and accurate metering and an aggressive program to keeps leaks in the pipe network to a minimum (Tortajada, 2006). The PUB has successfully developed a model for accurate water demand forecasting serves two main purposes: capacity planning and cost and revenue projections. The water demand forecast model requires active consultation with other national agencies in Singapore - such as the Economic Development Board, Ministry of Trade and Industry and the Urban Redevelopment Authority – to draw on their expertise in land-use planning and economic development, and to get the most accurate possible inputs for the model (Khoo, 2009).

D. Pricing & Cost Recovery.

The strategy employed by Singapore's government to price water, and the motives behind that strategy, has undergone several changes since independence in 1965. Pricing has variously been employed as a tool for cost recovery - to ensure the financial resources for expanding supply and operating the water-and-wastewater system at the highest levels of efficiency and reliability – and as a tool for demand management – to encourage conservation to reduce the need to expand supply indefinitely (Tortajada, 2006a, 2006b; Marques, 2010; Tortajada, Joshi & Biswas, 2013). For much of the 20th century most countries, to include Singapore, have concentrated on expanding supply and many observers have taken increased water demand by domestic and industrial consumers as a sign of economic growth and an improvement in welfare (Tortajada, Joshi & Biswas, 2013). The governments that have traditionally been the owners and managers of public utilities and suppliers of water-and-wastewater services to the public often supplied those services at a reduced price, practiced cross-subsidization with industrial and commercial consumers paying a higher tariff than domestic consumers, and in extreme cases even failed to collect tariffs at all (Tortajada, Joshi & Biswas, 2013).

The official motivation behind these pricing and cost recovery strategies has been to protect the welfare of the poor; however, the primary motivation is political with tariff regimes controlled by elected officials who mostly resist increases to advance various vested interests (Tortajada, Joshi & Biswas, 2013). These practices have been self-defeating and shortsighted, especially since water-and-wastewater services are one of the few public services that are capable of financial self-sufficiency by generating their own revenues (Tortajada, Joshi & Biswas, 2013). Low levels of tariffs are incompatible with metering, cannot cover the cost of service provision, have little impact in managing demand, usually end up subsidizing the middle and upper-classes who consume more water than the poor, and ensure that the poor receive an inadequate quantity and quality of water (Tortajada, Joshi & Biswas, 2013). Providing water-and-wastewater services that are efficient and reliable is costly: the annual cost to the PUB to run Singapore's system - collecting used water, treating water, producing NEWater, desalination, and maintaining water pipelines - was about S$500 million in 2000, but by 2015 this had risen to S$1.3 billion (Yangchen, 2017). As the demand for fresh water from naturally occurring sources has fallen behind the supply from those sources, those pricing and cost recovery strategies are being called into question and some countries have adopted pricing and cost recovery strategies guided by sound economic principles (Tortajada, Joshi & Biswas, 2013; Yangchen, 2017).

The current cornerstone of Singapore's water pricing policy is Long Run Marginal Cost (LRMC) pricing, where the water tariff is set at the level of the highest cost of production, which in the case of Singapore is desalination (Yangchen, 2017). Marginal cost pricing sends the strongest signal about the value of water, has the greatest impact on demand, and ensures that the water utility raises the level of revenues needed to cover the cost, and provide supply, from the most expensive source. Singapore's did not always employ marginal cost pricing, and for many years its tariff was set at a level to cover the cost of building and maintaining the infrastructure and covering operations (Tortajada, Joshi & Biswas, 2013). While this policy ensured that the PUB had the financial resources to build out the water-and-wastewater system, it did little to manage demand and influence conservation. The result was that demand for water rose with expanding economic activity and as the standard of living increased; and it also meant that when droughts occurred rationing was the strategy employed to manage demand (Tortajada, Joshi & Biswas, 2013). The drought of 1971, and the later exhaustion of potential sites for reservoirs, changed the outlook of the government on pricing policy and gradually, over two decades to 1997, the tariff structure was adjusted until it reached its current regime (Tortajada, Joshi & Biswas, 2013).

The government of Singapore revised the water tariff ten times between 1965 and 2012. During the 1960s consumers were charged a flat rate based on volume with a fixed monthly charge for meters and one-time charges for connections to the water supply system (Tortajada, Joshi & Biswas, 2013). The first revision since the rate was set in 1954 came in 1966. Domestic rates were increased from S$0.13 to S$0.18 per thousand litres, government rates were increased to between S$0.22 to S$0.33, while commercial and industrial rates were increased from S$0.29 to S$0.33 (Tortajada, Joshi & Biswas, 2013). Higher rates prevailed for supplies to ships and water re-sellers. The public position of the government in 1966 was that the increase in the tariffs was largely for cost recovery as the production cost per thousand liters had moved from approximately S$0.16 in 1962 to S$0.17 in 1967 (Tortajada, Joshi & Biswas, 2013). In 1969 the decision was taken for the universal provision of sanitation and the domestic tariff was raised again in 1970 to cover the cost of the loans (Tortajada, Joshi & Biswas, 2013). These increases meant that the monthly water bills for domestic consumers would rise between S$0.20 to S$2.00, which was a small proportion of the average household budget.

In 1973 a new pricing regime was introduced. The domestic tariff rate was adjusted from a flat volumetric rate to an increasing cost block tariff rate, and conservation was now added as a goal of the pricing strategy (Tortajada, Joshi & Biswas, 2013). In 1975 both the domestic and non-domestic tariff rates were revised upwards to address both rising demand and rising costs (Tortajada, Joshi & Biswas, 2013). After the 1973 and 1975 tariff revisions the rate of increase in demand for water was reduced. In 1981 the domestic increasing block tariff was simplified from four to three blocks; while the flat volumetric non-domestic rate was revised to an increasing block tariff (Tortajada, Joshi & Biswas, 2013). By this time the government adopted the position that rationing by price was a more effective and efficient strategy than traditional rationing in the face of rising demand and continuing constraints on supply (Tortajada, Joshi & Biswas, 2013). In 1983 both the domestic and non-domestic tariff rates were again increased to cover the costs of constructing new reservoirs and treatment plants while the tariff structure was again adjusted. In 1986 the number of categories were simplified to four – domestic, non-domestic, shipping, and water producers - and the non-domestic tariff rates simplified with all non-domestic consumers charged at the rate of the highest block (Tortajada, Joshi & Biswas, 2013).

In 1991 a conservation tax was added to water bills as an explicit attempt to encourage conservation: the government now actively sought ways to encourage and facilitate continued economic growth without higher water use, especially imported water (Tortajada, 2006a, 2006b; Tortajada, Joshi & Biswas, 2013). The most significant restructuring of the tariff regime came in 1997 when the government adopted water pricing based on principles of economic efficiency, and the tariffs and conservation tax became a uniform flat rate for all consumers (Tortajada, Joshi & Biswas, 2013). This strategy was phased in over three years and saw the tariff set to reflect the higher cost of alternative supply sources. In addition, the water conservation tax is charged on all water supplied; domestic blocks were reduced from three to two; and volumetric sewerage fees aligned with the volume a wastewater generated (Tortajada, Joshi & Biswas, 2013). The domestic tariff in 2000 was S$1.17 and S$1.40 per thousand liters and the non-domestic tariff was S$1.17 per thousand liters (Tortajada, Joshi & Biswas, 2013). The Conservation Tax on domestic consumption in 2000 was an additional S$0.30 and S$0.45 per thousand liters, while the tax on non-domestic consumption was S$0.30 per thousand liters. This tax is collected by the PUB but is paid over to the Consolidated Fund. The water pricing and cost recovery measures are designed to eventually close of the water loop and get consumers to see potable and used water as a single product by moving towards charging the same price for both potable water and used water in the longer term (Khoo, 2009).

The conservation measures, which consist of a combination of pricing, public education, and technical measures have been a moderate success: per capita daily domestic consumption which was 172 liters in 1995 was reduced to 153 liters in 2011 (Tortajada, 2006a, 2006b; Tortajada, Joshi & Biswas, 2013; Yangchen, 2017). The government, however, intends to take this down further: many European countries have daily domestic water consumption rates of 100 liters so continued savings are still possible. The impact of these reductions can be seen at the macro scale in total annual water demand, which increased steadily from 403 million m^3 in 1995 to 454 million m^3 in 2000 but declined to 440 million m^3 in 2004. The impact of the pricing strategy can also be seen in the average monthly water bill which has about doubled, from about S$15 to S$30 per month, during the period 1995 to 2000 (Tortajada, 2006a, 2006b; Tortajada, Joshi & Biswas, 2013; Yangchen, 2017). This still represents less than one percent of the average household budget which is affordable for most consumers and in line with international rates.

To protect low-income consumers the government offers rebates on water bills, which are usually credited to the customers' utility account, but are designed to be decoupled from water consumption to prevent over consumption through the creation of a perverse incentive to consume water (Tortajada, 2006a, 2006b; Tortajada, Joshi & Biswas, 2013). This represents a move away from 'lifeline' tariffs where the first block of water use is subsidized under the assumption that the poor cannot afford to pay normal tariffs. The main disadvantage of 'lifeline tariffs' is that instead of providing a targeted subsidy only to those who cannot afford to pay, these subsidies also subsidize water consumers who can afford to pay for the quantity of water they actually consume (Tortajada, 2006a, 2006b; Tortajada, Joshi & Biswas, 2013). Singapore's current tariff structure is considered efficient and effective in socio-economic terms: the poor do not subsidize the rich, and commercial and industrial users do not subsidize domestic users (Tortajada, 2006a, 2006b; Tortajada, Joshi & Biswas, 2013).

The water pricing and cost recovery strategy of the Singapore government has been successful in providing the considerable financial resources required over the past four decades to build out the city-state's water-and-wastewater infrastructure. Between 2000 and 2015, for instance, the PUB invested S$7 billion in water infrastructure and expects to double this by 2021 to strengthen the third and fourth Taps, to build, repair, and upgrade pipes and pumps, to meet higher costs of manpower, materials and chemicals, and to carry out increasingly expensive engineering works, such as having to dig deeper underground to lay pipelines (Yangchen, 2017).

IV. Four Taps Strategy

A. Overview

Singapore’s drive for water self-sufficiency - and a sustainable and resilient water economy that can support economic development - are underpinned by synergy between effective governance, an appropriate institutional, legal and regulatory framework, and engineering and technological solutions that supports economic development and ensures water security (Wong, 2006; Chew, Watanabe & Tou, 2010; Tortajada, Joshi & Biswas, 2013; Joo & Heng, 2017). The current guiding framework for achieving the universal provision of affordable, sustainable and resilient water supply services to both domestic consumers and businesses is known as the 'Four Taps Strategy.' This new strategy was introduced in 2005 and the 'Four Taps' represent Singapore's four current sources of water: water received from Johor in Malaysia, water collected in storm-water reservoirs, water obtained from recycling, and water received from desalination (Khoo, 2009; PUB, 2016). Singapore's dependence imported water has been reduced from 80% of its water needs at the time of its independence to its current level of about 40%, but the city-state's current storage capacity can only satisfy about 50% of the current demand for water and this drives the effort to increase the total land area used as a water catchment, and the proportion of water that comes from recycling and desalination (Khoo, 2009; PUB, 2016). By 2060, Singapore plans to supply 80% of its water from recycling and desalination, and 20% from local catchments; and, were it not for unusually low rainfall in several recent years, the city-state from 2011 could theoretically have been able to supply all its water needs from the three national taps, the same year the 1961 water agreement with Malaysia ended (Khoo, 2009; PUB, 2016).

B. Singapore-Malaysia Water Treaty.

Singapore's first tap is water from Malaysia. In 1927 the British colonial government's solution was to establish an agreement with the neighboring British colony of Johor (Malaysia) for the supply of water to Singapore which was delivered from 1932 through pipes which ran under the causeway bridge that connected Singapore to Malaysia. The supply of Johor water was further guaranteed by two agreements signed with Malaysia in 1961 and 1962, which were to terminate in 2011 and 2061 respectively. Based on the agreements, Singapore was required to build and maintain waterworks in Johor, it had "the sole and absolute right" to a fixed amount of raw water at a fixed price of 3 Malaysian cents per 1,000 gallons until the agreements expired, and was obligated to sell back some of the treated water to Johor (Wong, 2006; Caballero-Anthony & Hangzo, 2012). Singapore registered the two agreements in the United Nations Charter Secretariat Office in June 1966, they are therefore governed by international law, they contain specific provisions on when the price can be revised and how the revisions should be computed, and they cannot be unilaterally renegotiated (Wong, 2006).

Long-term water security has therefore been an important consideration for the newly independent nation, in their ensuing relationship with Malaysia, and on water policy and planning (Tortajada, Joshi & Biswas, 2013). The economic development and social stability that Singapore achieved in the immediate post-independence would not have been possible without the guaranteed supply of Johor water (Menkho & Evers, 2011). Re-negotiations of the contracts have proved difficult, and although both countries always honored the agreements Malaysia has issued several veiled threats about curtailing supplies - the Government of Singapore allowed the 1961 agreement to lapse when it expired in 2011 and sought alternative solutions to its water supply risk (Wong, 2006; Caballero-Anthony & Hangzo, 2012). Because of the uncertainty over Johor water, Singapore aggressively developed new plans for increasing water security and self-sufficiency during the post 2011-period. These included increasingly more efficient water management, the formulation and implementation of new water-related policies, heavy investments in desalination, extensive reuse of wastewater, improved catchment management, and other similar actions (Tortajada, Joshi & Biswas, 2013).

C. Rainwater Harvesting & the Catchment System

Singapore's second tap is from catchments, the collection of rain and storm-water, and its conversion to potable water. Despite having one of the highest levels of rainfall in the world the geography and geology of Singapore limits the available amount of ground and surface water. This has led the PUB to develop additional new sources of water, including through an improved ability to collect and store raw water. This is done by harvesting rainwater through a comprehensive network of drains, canals, rivers and storm-water collection ponds and then channeling this water into the city-state's 17 reservoirs. In 1970 the total land area utilized for water catchment was 11%, but by 2011 this was increased to 60% with plans to utilize 90% of Singapore's total land area for water catchment by 2060 (Khoo, 2009; PUB, 2016). Singapore was among the first cities in the world to obtain drinking water from estuary reservoirs and urban catchments in the 1970s and 1980s, and one of the few countries in the world to harvest storm-water on a large scale. The recent completion of the the Punggol and Serangoon reservoirs, the Marina Barrage and the Deep Tunnel Sewerage System were significant additions to reserve capacity (Khoo, 2009; PUB, 2016).

The Marina Barrage, which was commissioned in 2008, is Singapore's 15th reservoir and it was formed by building a dam at the confluence of five rivers and across the mouth of the Marina Channel. It is the result of earlier efforts to clean up the Singapore River and it now serves as an unpolluted source of rainwater that can be harvested for drinking, as a tidal barrier for flood control purposes, and as a place for recreation (Khoo, 2009; PUB, 2016). The Marina Barrage is in the heart of the city and at 10,000 hectares (100 km^2) is the equivalent to one-sixth of Singapore land area: it is the city-state's largest and most urbanized reservoir (Khoo, 2009; PUB, 2016).

The Deep Tunnel Sewerage System was conceived by the PUB in the 1990s as a cost-efficient and sustainable long-term solution to Singapore's used-water needs and an integral part of Singapore's strategy to manage the entire water loop as a closed system (Khoo, 2009; PUB, 2016). Phase one of the DTSS, which was completed in 2008, is a 48 km long network of two tunnels that crosses the entire city-state 20–50m below ground. It is used to divert used water from the eastern, northern and central parts of Singapore and channel this water by gravity to one of three coastal water treatment and reclamation plants (WRPs) at the south-eastern end of Singapore where it can be turned into NEWater. Phase 2 is scheduled for completion in 2025 and will see the network increase to about 60 kms. The DTSS system will streamline how Singapore collects, treats, disposes, or reclaims used water, it will improve environmental management, it will shrink the land occupied by used water infrastructure by 50% due to the closing of some plants, and it will free up this precious land for higher value uses (Khoo, 2009; PUB, 2016).

D. NEWater.

Singapore's third tap is NEWater, the conversion of waste-water to potable water. In 1974 the PUB developed a pilot plant to turn waste-water into potable water but did not scale up the project at the time because the cost of reclaiming water was found to be prohibitive and the technologies unreliable (Khoo, 2009; PUB, 2016). By 1998, however, the technology had advanced to a stage where production costs had become low enough to make the reclamation of used water economically and technologically viable. In 1998 the PUB and the MEWR conducted the Singapore Water Reclamation Study to determine the suitability of using reclaimed water to supplement Singapore's water supply and a full-scale demonstration plant was commissioned in 2000 to undertake extensive studies on the quality of reclaimed water and the reliability of membrane technology. Singapore subsequently opened its first full-scale water reclamation plant in 2003 and named the product from that plant NEWater. By 2010 the number of NEWater plants had increased to five - two plants were commission in 2003, a third in 2004, a fourth in 2007, and the fifth in 2010. The first four plants have a combined capacity equivalent to 15% of Singapore's total water demand, while the fifth brings that capacity up to 30% of Singapore's total freshwater water demand, with that figure projected to increase to 50% by 2060.

The first three plants were designed, built and operated by the PUB; however, the fourth and fifth plants were design-build-own-operate (DBOO) contracts awarded to the private sector. The first three factories were built using foreign technologies; however, the government intended that future plants should reflect indigenous technological capacity. The opening of the fourth plant represented the successful shift to both indigenous technology and public-private partnerships (PPPs), with Singapore's Keppel Integrated Engineering being the private partner. The contract for the fifth plant was awarded to Sembcorp as a DBOO project. These PPPs are considered as examples of delegated private management. The dominance of Singapore's water technology sector by international firms such as Veoila and Suez was gradually and systematically replaced by local firms such as Hyflux, Keppel and Sembcorp (Chew, Watanabe & Tou, 2010).

NEWater is a reliable source of high-quality water supply which is targeted at the commercial and industrial sectors. It is ideal for certain types of industrial manufacturing processes, like semiconductors or pharmaceuticals, which require ultra-pure water, although it can also be added to reservoir water where it can undergo additional treatment to produce drinking water. Quality and public safety is maintained through rigorous and comprehensive physical, chemical and microbiological testing (Khoo, 2009; PUB, 2016). During development, an international panel of experts in engineering, biomedical science, chemistry and water technology was formed to provide independent advice on the water reclamation study and to evaluate the suitability of NEWater as a source of water for potable use; and the media was a key partner in the successful acceptance of NEWater by the public (Khoo, 2009; PUB, 2016).

NEWater is currently the jewel of Singapore's water supply diversification strategy, and the pride of its engineering, scientific and technological strategy (Khoo, 2009; PUB, 2016). NEWater requires high levels of engineering, scientific, and technological sophistication in water; but it must also be supported and complemented by other industries, such as the information and communication technology sector (Khoo, 2009; PUB, 2016). The successful implementation of NEWater is the result of an important paradigm shift in public policy, public relations, and water resource management: re-branding waste-water as used water as an important renewable resource, to be recycled and re-used rather than treated for discharge into the sea (Khoo, 2009; PUB, 2016).

E. Desalination.

Singapore's fourth tap is desalination, the conversion of sea water to potable water. The city state's first desalination plant opened in 2005, and its second in 2013, and these two sources meet about 25% of Singapore's current total freshwater needs. By 2020 three additional desalination plants will be added to the national system, and the government has identified five coastal sites for future plants with the projection for desalination to meet 30% of the estimated daily freshwater demand by 2060 (PUB, 2016). As a small, water-scarce island surrounded by the sea, desalination is a natural option for Singapore; however, it only became an economically and technologically viable option because of advances in membrane and reverse osmosis technology.

The first desalination plant, Singspring Desalination Plant in Tuas, was built by Hyflux and Ondeo of France through a competitive 20-year DBOO contract at a cost of S$200 million. With a daily production capacity of 30 million imperial gallons (140,000 m^3) it is largest reverse osmosis seawater desalination plant in the tropics, and the second largest in the world, it is one of the most energy efficient, and it meets 10% of Singapore's water needs (Wong, 2006; Khoo, 2009). The contract to design, build, own and operate Singapore's second desalination plant, the Tuaspring Desalination Plant plant also located at Tuas, was also won by Hyflux in 2011, and the plant was put into operation in 2013. Tuaspring has a capacity of 70 million imperial gallons (320,000 m^3)

per day. These contractual arrangements are an example of delegated private management. The five NEWater plants and two desalination plants together have the capacity to supply more than half the city-state's water demand reducing dependence on rainfall and importation and boosting the resilience of the national water system (PUB, 2016).

Desalination is the most expensive and energy-intensive of the Four National Taps: the cost to produce desalinated water is about S$0.78/$m^3$ compared to S$0.30/$m^3$ for NEWater. The first-year cost to produce water for the latest plant in Marina East, set to open in 2020, is estimated at $1.08/$m^3$ - an increase of some 40 per cent. (Yangchen 2017). Because Singapore is a net energy importer, the city-state must continue to invest in R&D to find better and less expensive ways of desalting seawater: PUB's goal is to cut in half desalination's energy use (PUB, 2016). The employment of technology has reduced Singapore's dependence on external water sources, and increased its internal supply through reclamation and desalination, but it has made the city-state more energy dependent: NEWater production requires about five times, and desalination about 20 times, as much energy as conventional treatment. As the demand for freshwater grows with economic development, and as Singapore shifts towards reclamation and desalination, the energy required for water treatment in 2060 could be as much as four times the current demand with current technology. The current process of reverse osmosis process pushes seawater through membranes that filter out dissolved salts and minerals, resulting in pure drinking water; however, the PUB and its partners are currently experimenting with electric-deionisation, and have pilot-tested this technology, which could significantly reduce desalination's energy use and cost. Containing the cost of water is necessary to continue to keep Singapore a competitive place to do business and open up major opportunities for export earnings.

V. HydroHub – Singapore's Water Technology Innovation Cluster

A. Overview

In 2004 the government of Singapore announced the launching of three initiatives together - the HydroHub, the Singapore Water Association (SWA) and the Water Network - as part of an economic development strategy to capture 3 to 5% of the global water industry market, worth an estimated S$430 million annually, and another 5 to 10% of the global membrane market, worth an estimated S$500 million annually (Wong, 2006). In Asia alone, the market for water infrastructure to 2020 is estimated at S$500 billion and Singapore also intends to capture a share of this market (Han, 2014). Between 2003 and 2015, Singapore's water sector grew from S$0.5 billion, or 0.3% of GDP, to S$1.7 billion, or 0.6% of GDP; and the number of professional and skilled people employed in the sector is expected to reach 11,000, or 0.5% of employment (EWI, 2011; Han, 2014). The number of water companies has grown from 50 to about 180; the number of public and private R&D centers conducting research in various areas of water technology is currently 28; and the accumulated value of international projects involving Singaporean companies since the launch of the HydroHub totals around S$10 billion (Han, 2014; PUB, 2016).

To support the growth of the water-and-wastewater sector and help establish the HydroHub the Ministry of Environment & Water Resources (MEWR) established the Environment and Water Industry Programme Office (EWI) in 2006 as an inter-agency body led by the PUB, the national water agency. The EWI also includes the Economic

Development Board (EDB), International Enterprise Singapore (IES), and SPRING Singapore (EWI, 2011). The EWI received an initial grant of S$100 million to support its institutional facilitation role (Chew, Watanabe & Tou, 2010). Its mission involves attracting foreign water companies to Singapore, providing R&D funding, and helping Singapore-based companies and research institutes develop and commercialize water technologies for the global marketplace (Chew, Watanabe & Tou, 2010; Caballero-Anthony & Hangzo, 2012). The WaterHub is based in the Water Center of Excellence, which is located beside the Ulu Pandan NEWater factory, and it is home to the IWA, the SWA, the Centre for Advanced Water Technology (CAWT), and the research arms of several international water companies such as Siemens, Konzen, and Nitto Denko (Chew, Watanabe & Tou, 2010; EWI, 2011). As part of the HydroHub's overall ecosystem, the Lee Kuan Yew School of Public Policy at the National University of Singapore established an Institute of Water Policy in 2008

The EWI's strategy to develop the HydroHub involves three components: capability development, cluster development, and internationalization (EWI, 2011). The first strategy, capability development, involves building a strong scientific and technology base through investing in R&D, developing talent, assisting companies in marketing and building networks with potential partners, and making water facilities available for testing technologies (Chew, Watanabe & Tou, 2010; EWI, 2011). With regards to networking, the SWA gathers local water companies and related organizations to work closely with government agencies - such as PUB, EDB and Institute of Engineers of Singapore - on water technology development, skills acquisition and industry missions; while the Water Network is a platform for the people, private and public sectors

(3Ps) to meet, network, share information and give views to the PUB on policies and programs concerning all aspects of the city state's water.

With respect to R&D investment and talent development, Singapore commitment is based on the belief that water technology serves as a driver for economic growth and as a foundation for the city-state's long-term competitiveness (EWI, 2011). The water industry has core capabilities that are common within and across industries and an investment in the water sector creates synergies at the firm and industry levels (Wong, 2006). To support R&D, the government established the National Research Foundation (NRF) in 2006 to drive R&D efforts in Singapore and approved initial funding of S$5 billion to undertake its work between 2006 and 2010, of which S$330 million was to promote R&D in the field of environmental and water technology (Khoo, 2009). In 2011 the NRF allocated a further S$140 million to promote R&D to this sector (EWI, 2011). This public investment in R&D is part of an ongoing strategy aimed at raising Singapore's technology development capability: between 1991 and 1995 S$2 billion was provided through the National Technology Plan (1991-1995) and between 1996 and 2000 S$4 billion was provided through the National Science and Technology Plan. The EWI oversees two competitive R&D project funding schemes: one for the public sector, the Incentive for Research & Innovation Scheme (IRIS); and one for Singapore-based private sector companies, the Innovation Development Scheme (IDS) (EWI, 2011). Singapore's two major universities are globally recognized leaders in water technology and are key players in the HydroHub. These universities have established several international partnerships to advance science and technology in the water sector: Nanyang Technical University, for example, established a partnership with DHI; and Singapore National

University established a partnership with Delft Hyudralic (Chew, Watanabe & Tou, 2010). The EWI also helps to develop local talent by providing scholarships for scientists, technologists, and water managers to pursue Masters and PhD degrees and often places these individuals in research facilities (EWI, 2011).

With respect to testing and commercialization, the CAWT, a wholly-owned subsidiary of the PUB, helps water companies develop commercially viable technologies and conducts training courses with the HydroHub for both public and private organizations. Between 2007 and 2011, PUB facilities were made available for over 107 new test-bedding projects (EWI, 2011). EWI's Technology Pioneer (TechPioneer) scheme assists with accelerating the commercialization of new environment and water technologies through their early adoption in Singapore; while start-up companies can compete for a publicly funded incubation grant known as the Fast-Track Environmental and Water Technologies Incubator Scheme (Fast-Tech) (EWI, 2011).

The second strategy, cluster development, involves the development of the industry by attracting major international water companies to locate headquarters, manufacturing, consultancy, engineering, and R&D facilities in Singapore, and to use the city-state as a test-bedding and piloting base for new water technologies and for expansion into the region (Chew, Watanabe & Tou, 2010; EWI, 2011). The EWI, EDB, and the PUB have worked to attract major players from the US, such as GE and Black & Veatch, from Japan, such as Nitto Denko and Toray, from Germany, such as Siemens, from France, such as Veolia and Suez, and from Israel, such as Desalitech (Khoo, 2009). GE Water will invest S$130 million over 10 years and employ 100 top-tier researchers; Siemens Water Technologies will invest in a S$50 million global water R&D and engineering center over 5 years and work with PUB on three R&D projects; and Nitto-Denko will invest S$6 million to set up a water R&D center, the first such Japanese venture to be set up in Singapore (Khoo, 2009). The government also actively works to develop local water technology companies to include Hyflux, Keppel, and SembCorp Industries. Public-private, public-public, and private-private partnerships are a key feature of the Hydrohub and so the government actively cultivates a strong private sector component (Chew, Watanabe & Tou, 2010; EWI, 2011).

The third strategy, internationalization, involves the IES and the PUB working to help Singaporean water companies export their technology and expertise (Chew, Watanabe & Tou, 2010; EWI, 2011). These agencies facilitate the internalization process by the creation of networks through trade missions, conferences and bilateral agreements for water research and consultancy projects. Singapore, for example, hosts international water events such as the Singapore International Water Week (SIWW) which has grown from 8,500 participants in 2008 to 20,000 participants from 118 countries in 2014. Internationalization represents the economic re-positioning of water from a survival challenge to be overcome to an international growth industry motivated by profit, and built on a proven track record of solving urban water problems in Singapore that many other countries share (Joo & Heng, 2017); it represents the normative re-positioning of Singapore with respect to environmental sustainability, sustainable economic development, sustainable urban planning, and climate change; and it represents the diplomatic re-positioning of the small city-state by increasing its standing in the international community through the sharing of its technology and expertise with international agencies, and through its humanitarian work (Caballero-Anthony &

Hangzo, 2012). With respect to humanitarian work, Singapore assisted the Maldives with water filtration equipment when it was hit by a tsunami in 2005, and Thailand and Cambodia when it was hit by flooding in 2011, and it supplied water to Johor state in Malaysia when that region was hit by a drought in 2015 (Wong, 2006; Caballero-Anthony & Hangzo, 2012). Through processes of entrepreneurship and innovation, efficient and effective governance, good water resource management, and sustained investment in infrastructure and R&D, a water shortage and national security risk has been transformed by government intervention and private sector participation into a tool of economic development, environmental stewardship, and international diplomacy (Caballero-Anthony & Hangzo, 2012).

B. Separation Technologies.

Singapore's consistent and focused investments in infrastructure and in R&D for water-and-wastewater have made it a global leader in separation technologies. Separation technologies are crucial mechanical and chemical processes that have wide industrial and medical application and a significant impact on efficiency, cost, waste reduction, and waste reuse (National Research Council, 1998; Dhalla, 2017). Separation technologies have the potential to increase productivity of firms and industries and thus national competitiveness (National Research Council, 1998). The government of Singapore is helping to address the commercialization challenges faced by the firms and research facilities involved in developing separation technologies and the full-scale deployment of technologies. One way the government achieves this is through support for testing at pilot scales in actual application settings. To this end it has established the S$30 million Separation Technologies Applied Research and Translation (START) Center at Nanyang

University as a national-level, public-private testing facility to develop and commercialize innovative separation and filtration technologies (Nanyang Technological University, 2016). START will pull together the pool of scientists, technologists, industry experts, and intellectual property which has been built up over the decades in Singapore's water-and-wastewater ecosystem.

C. Hyflux.

Hyflux is a Singaporean water technology company that represents the emergence of an indigenous water industry as well as the success of the government's efforts to foster indigenous innovation and entrepreneurship in the private sector. Since its establishment in 1989, Hyflux now competes on an equal footing with other internationally recognized water treatment and desalination firms and this is evidenced by its partnership with more than 200 clients in Asia, Africa, and the Middle East (Wong, 2006). Since 2004 Hyflux has been a major player in the Chinese market for both treatment and desalination technologies (Wong, 2006); it has been awarded major contracts in Dubai and Oman, and in Saudi Arabia where in 2015 Hyflux signed a US$48 million contract to build a desalination plant (Chew, Watanabe & Tou, 2010); and it is currently building the world's largest seawater desalination plant in Algeria worth US$468 (Chew, Watanabe & Tou, 2010; EWI, 2011). The internationalization of Hyflux's business was critical to cushioning the firm's sales during the 1997 Asian recession which also affected the firm's domestic market in Singapore (Wong, 2006).

Because of both domestic and international business, the scale of Hyflux's growth has been impressive - between 2000 and 2004 the firm's revenue rose five-fold from S$17 million to S$88.7 million – and so has been the scope of its growth – and in 2000 it extended its businesses beyond water treatment to involvement in related industries such as life sciences and pharmaceuticals (Wong, 2006). Hyflux offers filtration and purification technologies that caters to the domestic water consumption market; however, the water treatment and recycling technologies also offered by Hyflux are important to the cost-effective and environmentally sound operations of a range of high value-added, water-intensive industries – such as wafer-fabrication, paper and pulp, petrochemical, pharmaceuticals, textiles and dyes - which are the future of the emerging Singaporean economy and the main source of Singapore's ever increasing demand for water (Wong, 2006; PUB, 2016). The expansion of Hyflux into overseas markets has necessitated a change in the firm's structure with respect to its regional division of labor: it has relocated the manufacturing of peripheral components to China while keeping production of the core technologies in Singapore. Hyflux has demonstrated its ability to identify and acquire the relevant technologies and apply them where demand arises, as well as the ability to move up the value-chain to the development of its own technologies and processes as it learns (Wong, 2006); and it now has the second largest R&D facility for membranes and materials in Asia outside Japan (EWI, 2011).

IX. Application of Porter's Diamond to Singapore's Water Technology Cluster

A. Overview

The Singapore water economy is one of the best developed and most sophisticated in the world, its governance and institutional arrangements are held up as an example for other countries, the water technology sector is positioned as a key pillar supporting Singapore's national competitiveness, it is being developed specifically as a globally competitive industry, and it is being used as a tool for global diplomacy (Wong, 2006;

Tortajada, 2006a, 2006b; Caballero-Anthony & Hangzo, 2012; Joo & Heng, 2017; Dhalla, 2017). The Singapore water technology sector is globally recognized for its expertise in several areas: recycling and reuse, urban catchments and storm-water management, desalination, and separation technologies (Khoo, 2009; Low, 2012). The Singapore water economy is globally recognized for its ability to reliably deliver high quality water at an affordable price, for its absence of illegal connections and nonrevenue water, for is low level of losses to leaks, and the ability of its utilities to operate in a financially sustainable manner (Khoo, 2009; Low, 2012). Singapore is also globally recognized for its successful environmental transformation from a polluted city to a clean city filled with 'green and blue' spaces, and for its expertise in environmental engineering and sustainable urban design in which water plays a leading role (Tan, Lee & Tan, 2009; Tortajada, Joshi & Biswas, 2013). Singapore water knowledge and technology are increasingly sold worldwide in places as far afield as North Africa, the Middle East, and China. Singapore's resilient and increasingly sustainable water economy has been built despite a severe water deficit, and it has seen the city state transformed from water dependency to increasing water independence based primarily on both technological innovation and institutional restructuring (Low, 2012; Yew, 2013; Tortajada, Joshi & Biswas, 2013).

Singapore's knowledge base and expertise in water resource management, and its competitive advantage in water technology, flows from solving severe and urgent water related challenges that have at various times posed a risk the public health and safety, national security, and economic security; it does not arise from a passive reliance on an inherited natural factor. Singapore is one of the few countries that has successfully closed the water loop, and the whole water cycle is managed as a system: there is the collection of rainwater from catchments, drains, canals and ponds that is stored in 17 man-made reservoirs from where it is treated and distributed as potable water; and there is an island-wide sewerage system which collects all used water for treatment and reuse (Low, 2012; Irvine, Chua & Eikass, 2014). This holistic and integrated management of water is supplemented by one of the most advanced seawater desalination programs in the world (Low, 2012; Irvine, Chua & Eikass, 2014).

B. Factor Conditions

In Singapore water is a key economic factor despite the country not being well endowed with this normally inherited, basic, natural resource. Singapore is so deficient in natural resources that it must import almost all its food and energy and half its water; yet despite this deficit the country has become a post-industrial society with an economy focused on advanced manufacturing, finance, and tourism. Beyond domestic demand, the growing number of these water-enabled and water-intensive industries means that water is a major input into a growing number of sectors in the Singaporean economy where its reliable supply increases productivity, lowers costs, reduces waste, and protects the environment (Wong, 2006; Khoo, 2009; Dhalla, 2017; Joo & Heng, 2017). The city-state has invested heavily in developing expertise in integrated water resource management which has become vital to ensuring a reliable supply of potable water and for treating waste-water. Singapore's water resource management and water technology are both advanced and specialized factors that have been consciously and proactively created; and Singapore has developed global leadership in holistic and sustainable urban storm-water management, in the design and construction of urban 'green' and 'blue' infrastructure, and in low-impact and water sensitive urban development (Tan, Lee & Tan, 2009; Irvine, Chua & Eikass, 2014; Lim & Lu, 2016). These advanced and specialized factors have been developed in a relatively short time by visionary leadership, and through heavy and sustained public investment in both infrastructure and people (Yue, 2001; Koh & Wong, 2005; Tan, Lee & Tan, 2009; Chew, Watanabe & Tou, 2010).

The basic statistics that provides a picture of a country's technological capabilities are the expenditure on R&D as a percentage of GDP, the number of research scientists per 10,000 labor force, the number of scientific articles published, as well as the number of patents filed and granted. While investment in R&D is an important factor in the development of innovation capabilities, innovation performance also depends critically on conditions that foster technology entrepreneurship, the availability of technical talent, and well-functioning product and capital markets (Koh & Wong, 2005). The appropriate policies and infrastructure that stimulate technological creation and innovation are a mixture of human capital, technical talent, institutions, incentives, hardware, policies, and investments. Collectively, they shape a nation's capacity to create and maintain its competitive advantages in innovation and technology creation; and Singapore has worked hard to build the institutional and technological infrastructure to support these indicators.

To develop and sustain its specialized and advanced factors the Singapore water economy is supported by considerable and sustained public funding for R&D; its world-class universities produce a large number of competent scientists and engineers; its researchers are becoming increasingly productive in publishing peer reviewed journal articles and in securing patents; and its entrepreneurs and innovators have a short but outstanding track-record in commercializing technologies (Yue, 2001; Chew, Watanabe &

Tou, 2010). Despite its relatively small size and population, Singapore in a single generation became a scientifically and technologically capable society because of a public focus on training and developing scientists, engineers and technologists to support economic development (Low, 2001; Koh & Wong, 2005; Yew, 2012). Singapore is exploiting its excellent human capital in combination with its central location and history of integration into the global trading system to propel and sustain its economic development (Low, 2001; Yew, 2012).

Singapore is increasingly becoming a knowledge-based economy with many globally competitive technology firms. High-technology startups already contribute a small but rapidly growing portion of GDP that could soon rival accommodation and food services; however, the city state is yet to produce a global leading startup in any area of technology (Yue, 2001; Chew, Watanabe & Tou, 2010; PWC, 2016; Dhalla, 2017). The contribution to GDP from manufacturing is about 18%, or S$270 billion, which is roughly in line with Israel, the Netherlands, and the United States; while utilities directly contribute about 1% to GDP, which is again roughly in line with these three countries (PWC, 2016; Singapore Department of Statistics, 2017). Manufacturing also employs about 15% of the workforce, or almost 400,000 people (PWC, 2016; Singapore Department of Statistics, 2017). The manufacturing sector is quite diversified and currently about half of this sector consists of high-technology industries including petro-chemicals, semi-conductors, consumer electronics, machinery, transport equipment, and ships. The government is attempting to support the ongoing restructuring of manufacturing by shifting manufacturing towards increasingly high value-added sectors such as aerospace, precision engineering, and the life sciences, particularly biotechnology, medical equipment, and pharmaceutics. Many of these industries have a high demand for high quality water.

Singapore's government views R&D as a key driver for economic growth and a strategic investment in the city state's long-term competitiveness. Singapore's government has supported high-technology sectors, to include water technology, with strong, sustained, and increasing public R&D investment and the institutional framework to allocate this support in a targeted and strategic manner. Singapore invests about 2% of its GDP in R&D, which is in line with the United States and the rest of Europe, but about half that of Israel; and in 2015 this totaled about S$9.5 billion annually, or about S$2,000 per capita (A*STAR, 2016; Singapore Department of Statistics, 2017). The 2015 level of R&D investment is a significant increase from S$6.5 billion in 2010 (Singapore Department of Statistics, 2017). A significant portion of R&D is funded by the Government of Singapore, at about 0.9% of GDP, which translates to about S$16 billion for the first half of the current decade; while the government has committed another S$19 billion between 2016 and 2020 (A*STAR, 2016). Much of the private sector investment in R&D is a result of the presence of multi-national firms which Singapore has actively attracted to strengthen the local technology sector (UNESCO, 2015; Singapore Department of Statistics, 2017; Sagar, 2017). The R&D, innovation, and entrepreneurship landscape has implications for water technology firms, but this sector remains highly dependent on R&D support from government and purchases from public utilities.

Singapore has five public autonomous universities, two of which are world-class research universities, and one comprehensive private university; there are five polytechnics providing specific skills for the workplace; there are ten branch campuses of foreign higher education institutions offering industry-specific courses of study; and there are two private institutions that provide post-secondary education in the arts. The largest proportion of students graduate with degrees in math, science, technology, engineering, and medicine providing Singapore a large pool of scientifically and technologically competent workers, which is vital in a country with a relatively small labor pool and looming labor shortages (UNESCO, 2015). Singapore has about 50,000 scientists and researchers, or 11 per thousand employees, which is ahead of the United States and the Netherlands, but behind Israel (UNESCO, 2015). Around 880 private domestic and multinational companies report R&D activity, and this is complemented by several public organizations involved in research which can roughly be grouped in institutions of higher learning and other public research institutes (Partners in Science, 2015). A*STAR is a key institution in public research: it is both a major research funder and a major research performer, and it overseas a consortium of 18 institutes (A*STAR, 2016). In 2015 Singapore's scientific publication output was 16,351 journal articles and the city state registers about 1,000 patents per year (Partners in Science, 2015; Singapore Department of Statistics, 2017).

Venture Capital activity in Singapore was a miniscule US$20 million in 1983 but it has increased rapidly over the past 10 years into a multibillion industry (Ahlstrom & Bruton, 2006; PWC, 2016). Venture capital is a small fraction of the amount invested in R&D, but it may be two to three times more effective in helping to get technologies patented and commercialized than other forms of capital: this makes it an important complement to other forms of capital (Kortum & Lerner, 2001). The venture capital industry in Singapore is different from this industry in much of the rest of Asia in its willingness to fund high technology startups; however, there is a need for more growth-stage capital as funds are not properly spread across the startup lifecycle (PWC, 2016). Singapore's surge in venture capital fundraising reflects growing interest in Southeast Asia's startups as international investors seek opportunities beyond the United States and China (Ahlstrom & Bruton, 2006; PWC, 2016). Singapore's government has invested heavily in the upgrading its startup ecosystem by strengthening the institutional framework, by providing incentives to attract entrepreneurs and venture capitalists, by cutting regulatory red tape, by helping to protect intellectual property, and by allocating public money for early investments.

C. Demand Conditions

More than four decades of successfully addressing pressing and challenging domestic water resource management issues has enabled Singapore to strategically position itself to become a 'hydrohub,' which is an international center for water technology and integrated urban water resource management where technologies are researched, tested, commercialized, and marketed globally (Schnoor, 2010). Domestic demand conditions form the second broad determinant of national competitive advantage, and the growing international success of Singaporean water technology firms is a direct result of domestic demand conditions, which in turn has a direct impact on the formation of specialized and advanced factor conditions and on the pace and direction of innovation and technology development (Porter, 1990). While the size of Singapore's domestic market is small, the need to urgently address a severe water deficit, polluted waterways, and flooding forced the city-state to develop sophisticated skills in integrated urban water resource management, to learn how to adopt and integrate foreign water technologies, and more recently to develop and commercialize indigenous water technologies (Khoo, 2009; Tan, Lee & Tan, 2009; Chew, Watanabe & Tou, 2010; Low, 2012; Dhalla, 2017; Sagar, 2017; Joo & Heng, 2017). The growing export success of Singaporean water expertise and water technology demonstrates that the city-state's water technology is becoming internationally competitive (Wong, 2006; Yangchen, 2012; Han, 2014).

The complexity of the water challenges facing Singapore rather than the size of the domestic market were the drivers for the development of a sophisticated and demanding local market. Addressing these challenges gave Singaporean innovators and entrepreneurs - first public and later private sector - an early market lead in integrated urban water resource management that would eventually provide Singaporean water technology firms the knowledge and experience to compete internationally. The initial domestic market base was largely domestic public water utilities, and the main suppliers of engineering and technical services were initially public; however, as the domestic water sector evolved the state actively encouraged and supported the growth of domestic water technology firms, and as the wider economy evolved the demand for water technologies by water-intensive and water enabled firms has also grown to diversify the domestic market (Khoo, 2009; Wong, 2009; Dhalla, 2017; Sagar, 2017; Joo & Heng, 2017; Braak, 2017; Yangchen, 2012). The public sector was initially instrumental in developing Singapore's water sector and water technology industry; nevertheless, in the long-run, the dominance of the water sector by public sector and public utilities could become a hindrance to the long-term international competitiveness of the sector (Low, 2012). Given the relatively small domestic market Singapore's water technology industries will need to earn most of their revenues overseas and face stiff competition from foreign firms if they are to continue to innovate, remain competitive, and meet the goal of capturing 3% of the global water market.

D. Firm Strategy, Structure & Rivalry

The strategy and structure a firm adopts and the domestic rivalry it faces, helps to explains how a sector forms and evolves, and how it is structured and managed, which ultimately offers insights into how the sector achieves sustained competitive advantage (Porter, 1990). The degree of competition within a sector or industry, especially domestic competition, is extremely important to competitiveness because rivalry forces firms and industries to raise productivity to compete, and competitiveness is especially important for international success (Porter, 1990). The degree of cooperation within a sector and industry also affects how knowledge is diffused, and how costs and benefits of public goods are shared, which also determines both firm and industry success (Porter, 1990). The aims, strategies, appetite for risk, and methods of managing and organizing firms vary widely among nations, and national advantage emerges from a good harmony between these factors rather than firms adopting a universal approach or standard (Porter, 1990). The Singaporean water technology industry, at less than 200 firms, is small; many of the domestic firms are new and the international firms newly located to Singapore; the sector does not face intense domestic rivalry; and given the small size and population of Singapore it is unlikely to ever face significant domestic rivalry. The sector also tends to be largely an outgrowth of public sector initiatives to address water scarcity and water quality, is heavily dependent on government procurement for sales and government resources for R&D, is highly regulated and monitored by the government, and is now characterized by significant public-private partnerships for the supply of potable water

(Wong, 2009; Low, 2012; Dhalla, 2017). Although Singapore's public sector has been remarkably innovative and entrepreneurial, these public entities still have a tendency towards conservatism and risk aversion (Low, 2012). Given that the major risks from water scarcity and pollution have been addressed, the pressure on the public sector for innovation may be potentially waning, making the need to increase the private sector role in the water sector ecosystem more critical. The sector can, therefore, be best classified as emerging.

Experience suggests that a competitive market environment is crucial for stimulating and supporting entrepreneurship and innovation, and this competitive environment encourages firms to invest in efficiency-enhancing technology, provided they can expect sufficient returns from their investment (OECD, 2000). In the case of Singapore, the driver for an efficient water sector was the need to support the competitiveness of the rest of Singapore's economy; and the process of continually upgrading the economy stimulated and justified significant public investments in technologically advanced water infrastructure and water technology R&D (Koh & Wong, 2005; Low, 2012; Tortajada, Joshi & Biswas, 2013; Yangchen, 2012 & 2017). The PUB has developed deep knowledge in water resource management, world-class expertise in hydraulic engineering became a corporate strength; and the public utility sub-sector of the water economy has been restructured so that the entire water cycle and water value chain is managed as a closed loop by the PUB, under the Ministry of Environment and Water Resources (Low, 2012). Innovative and entrepreneurial public policies, innovative and entrepreneurial management practices by public utilities, and the development by the public sector of a robust water sector ecosystem have enabled Singapore to move from an investment-driven to an innovation-driven water industry that is increasingly exporting innovative technologies and best practices in water management (Koh, 2005; Koh & Wong, 2005; Wong, 2005; Dhalla, 2017).

Although the public sector has taken a leading role in Singapore's water economy, and the water economy is dominated by public utilities for water-and-wastewater, companies from the United States and Europe have been active in Singapore for several decades (Schnoor, 2010; Braak, 2017). The Environment and Water Industry Programme Office (EWI) – the public sector, inter-agency body for driving the water technology industry – has been leading the effort to develop Singapore's water cluster through three strategies: technology development, cluster development, and internationalization which supports local companies and attracts high-technology foreign firms and highly skilled foreign workers to build the critical mass to create a dynamic water cluster. The foreign firms that been established in Singapore span the value chain from R&D to equipment suppliers to system integrators to project developers and financiers, and their presence is expected to create synergies and foster partnerships which would allow firms to develop and deliver integrated water solutions to a global water marketplace (Dhalla, 2017; Joo & Heng, 2017; Lide, 2017). Initially these multinational companies were involved in the transfer of foreign technologies into Singapore - which the city-state absorbed and adapted to their local needs - which was typical of the investment-driven growth strategy of the early years; more recently these multinational water firms have opened global research or business technology centers in Singapore and are increasingly involved in water R&D and technology commercialization within the water ecosystem (Koh, 2005; Schnoor, 2010; Chew, Watanabe & Tou, 2010; Dhalla, 2017; Braak, 2017). Although these foreign firms are an important part of the Singaporean water ecosystem, the eventual goal is the development of an indigenous water technology capability, and domestic water technology firms such as Hyflux, Keppel, Seghers and Sembcorp Utilities owe much of their success to the willingness of public utilities to enter with them into public-private partnerships for water supply.

E. Supporting & Related Industries

The nature and strength of the relationships between supportive and related industries and water technology firms in a water technology cluster create synergies that are crucial to the competitiveness of that cluster (Porter, 1990). Building competitive advantage requires firms to manage the horizontal and vertical dimensions of the entire value system which includes networks of suppliers, buyers, trade associations, universities, and research centers that jointly create or share knowledge, transfer technology, and create positive spillovers that increases innovation and accelerates commercialization (Porter, 1990). Vertical relationships within a water technology cluster exist between trading partners involved in successive stages of production, including suppliers that provided specialized inputs such as trained technologists, and customers that buy water technology such as water-and-wastewater utilities, (Wong, 2006; Chew, Watanabe & Tou, 2010; Tortajada & Joshi, 2013; Joo & Heng, 2017: Dhalla, 2017). Robust vertical relationships give water technology firms early access to inputs that may represent the latest technology or lowest cost, such as desalination and recycled water in Singapore, and it tends to encourage improved product quality (Wong, 2006; Tortajada, 2006a; Yangchen, 2012; Low, 2012; Lide, 2017). Horizontal relationships exist between firms at the same stage of production that sometimes compete but may also cooperate in joint ventures. Examples of horizontal relationships include firms with different specializations collaborating to build a desalination plant, or in the supply of capital to finance water projects (Koh & Wong, 2005; Koh, 2005; Wong, 2006; Chew, Watanabe & Tou, 2010). Dynamic horizontal relationships strengthen water technology clusters - such as through the presence in Singapore of strong computer, electronic, software, bio-technology, and chemical industries - as these industries complement the water technology sector with related technologies whose integration helps to solve water complex problems, which produces spillovers for other sectors of the economy, and which strengthens competitiveness.

Fewer firms today have large internal markets and many firms now outsource or subcontract non-core functions to specialist firms (Porter, 1990). Competitive water technology firms thus require close linkages among a diverse range of organizations within the sector to ensure that new technologies are commercialized into marketable products that can find a global market. Government, universities and technical colleges, research institutes, infrastructure providers, utilities, standard-setting agencies, and a host of other organizations are critical components of the ecosystem required for technology creation, and these are all present in the Singapore water technology ecosystem (Koh & Wong, 2005; Wong, 2006; Yangchen, 2012; Lide, 2017; PUB, 2017; Dhalla, 2017; Joo 7 Heng, 2017). A dynamic water innovation ecosystem with globally competitive firms requires strong linkages between universities, industry, and government which creates synergies that are crucial in fostering an innovative and entrepreneurial culture; and the Singapore government, through public policy and targeted investment in R&D and venture capital, has built an emerging ecosystem (Low, 2012; Menkhoff & Evers, 2011;

Lide, 2017; Sagar, 2017). The PUB is an example of a government agency that operates simultaneously at multiple point along the value chain and along both horizontal and vertical dimensions (Low, 2012). The PUB conducts research, it fosters and supports startups, it provides testing facilities, it organizes networking opportunities to connect the local and international water technology community, it enters into public-private partnerships, and it collaborates with the private sector to improve water supply efficiencies, explore new approaches to water resource management, and export Singapore's water technologies (Low, 2012; Lide, 2017). The government in its 2005 National Science identified the water industry as one of the key sectors in the new knowledge economy; and the PUB used its considerable knowledge and experience in the search for alternative sources of water, and strong research culture into water technology, to play a key role in growing the emerging water industry (A*STAR, 2005; Khoo, 2009; Low, 2012; Lide, 2017). The extended interaction which the PUB encouraged with the private sector was designed to make the utility more efficient as well as facilitate access each other's expertise and experience (Low, 2012; Lide, 2017). The work of the PUB is closely coordinated with other government agencies - such as EWI and NERI - that also affect the water technology sector at multiple points along the value chain by facilitating rather than just regulating, by providing funds for R&D, and by nurturing Singaporean startups (Low, 2012; Lide, 2017).

F. Government & Chance

Government and chance are exogenous to Porter's Diamond but have the capacity to either positively or negatively influence how the diamond functions, with the government influencing primarily through regulations and the overall institutional framework (Porter, 1990). The government of Singapore has acted as both catalyst, through its investment in infrastructure and R&D, and as challenger with its regulations requiring the country to meet high environmental standards (Tortajada, 2006a & 2006b; Tan, Lee & Tan, 2009; Khoo, 2009; Low, 2012; Lide, 2017). The Singapore government has actively and proactively taken steps to stimulate innovation, entrepreneurship, and technological progress in the water technology sector in several ways: attracting foreign water technology firms to locate their regional manufacturing and research facilities in Singapore, particularly in the high-tech sector; attracting high quality professional talent, by implementing regulatory and fiscal changes to make it easier to start a businesses; setting up venture capital funds to encourage startups; funding R&D at universities and research centers across the entire water value chain; establishing a network of public agencies to support innovators and entrepreneurs; applying and integrating water technologies into its domestic water management practices; ensuring a strong intellectual property protection regime; strong state involvement in labor, land, and industrial development policies; ensuring fair competition for both local and international firms; and providing a stable macroeconomic environment with steady growth and low inflation (Low, 2001; Koh, 2005; Khoo, 2009; Low, 2012; Lide, 2017). This significant public role can be justified because of the existence of market failure in the water economy: the application of new ideas or technologies may also take a long time to be realized, thus raising the level of commercialization risk; private enterprises often fail to invest sufficiently in water R&D because social returns may exceed potential private returns, and private enterprises cannot capture all the private gains from R&D; and many water technology firms are too small to individually make a large capital-intensive investment with an uncertain outcome and a long gestation period (Koh, 2005; Koh & Wong, 2005).

Under a series of science and technology plans where water technology has been identified as a key growth sector, Singapore's development model is being adapted from the traditional model of technological catch up to one where the economy can compete close to the technological frontier of the global knowledge economy based on its ability to engage in technology creation (Koh & Wong, 2005; A*STAR, 2015).These strategies have also enabled the government to deliver an efficient, safe and sustainable water supply; deliver a clean, healthy, and pleasant environment; and create a vibrant water technology cluster (Tan, Lee & Tan, 2009; Tortajada, Joshi & Biswas, 2013; Lim & Lu, 2016). These strategies were part of the Government of Singapore's key drivers in supporting a shift from an investment and efficiency-driven growth strategy to an innovation-driven growth strategy, of which clean technologies such as water were to play an important role.

The strategy to build an economically sustainable water cluster is still, however, incomplete because of the following: the private firms in the water technology cluster are still dominated by international companies; local water technology firms are mainly still at the stage of acquiring and improving on existing technology, or importing and adapting foreign technologies; and local firms remain highly dependent on support from Singapore's public sector to grow and sustain their firms (Koh, 2005; Koh & Wong, 2005; Lide, 2017). The Government of Singapore government is taking steps to remake the institutional and technological infrastructure of the water economy to foster an environment conducive to innovation and technology creation; and they were careful to avoid the mistakes of other countries by tailoring its policies to local realities and inherent advantages (Koh & Wong, 2005). Despite the success of public policy towards the water economy of Singapore the government must guard against undermining decades of work in building its water sector by failing to wean the private sector off public support which could stifle private sector initiative and creativity as the water industry matures.

X. Conclusion

Economic development in Singapore has been significantly shaped by the resource constraints that the city-state has faced, water scarcity being the most significant of these constraints. Resource constraints meant that a growth strategy driven by factors such as raw materials was simply not an option for Singapore, and the city-state was forced to move quickly from an investment-driven growth strategy, through an efficiency-driven growth strategy, to an innovation-driven growth strategy. Securing a reliable supply of fresh water from limited local sources, ensuring flood protection from high levels of rainfall and monsoons, and protecting the densely populated city-state from waste-water and pollution required considerable innovation and entrepreneurship, with the public sector of Singapore leading the way. Singapore's severe water constraints forced the government to look to institutional and technological solutions that improved supply, increased the efficiency of water use, and reduced pollution. In a period of approximately four decades from independence in 1965, Singapore was able to solve its water-and-wastewater challenges; and in the process developed the foundation for a globally competitive water technology cluster. This decision led to the water economy becoming an important source of competitive advantage for Singapore, with world-class water utilities providing the domestic economy with a reliable and affordable water-and-wastewater services, and the water technology sub-sector through the HydroHub providing an important launching platform for entry into the global water economy. What started out as a strategic vulnerability for Singapore has been turned into a strategic advantage with the city-state now recognized as a global leader in all aspects of the water technology value-chain from catchment, to storage, to recycling, to reuse, and desalination.

The Singapore water economy is largely a creation of state planning, investment and management to build a suitable institutional framework and encourage the development and diffusion of innovative water technologies. It was established, nurtured, and sustained by significant and consistent investment in world-class public water infrastructure, a broad-based technological infrastructure, appropriate science and technology policies, a network of public and private research organizations, and supportive government institutions. The technological infrastructure encompasses a world-class public education and research system, a legal framework that supports contract enforcement and protects intellectual property rights, and a technology policy that provides the incentives to develop and diffuse technologies and encourage innovation and entrepreneurship. This business-friendly environment encouraged foreign investment in the water economy. The diffusion of foreign technologies into Singapore stimulated and supported a process of learning by the indigenous players in the water sector, first by public sector utilities and later by private sector firms. Singapore's government ensured that this diffusion and learning took place in a very specific economic, technological and institutional landscape, and that it also took place along the entire value chain of the water industry. Singapore's public agencies, and the utilities they manage, participate in the diffusion of water innovations and the acceleration of commercialization in several ways: by hosting events which build network and act as fora for the exchange of ideas and knowledge; through collaborations and partnerships; and by providing test-bedding opportunities for testing technologies in real-life operating conditions at water-and-wastewater works. In this way local competences were built up incrementally and systematically and Singapore thus moved up from being a net importer of water technology to a net exporter of water technology. The next challenge for Singapore's water policymakers as the HydroHub goes global, is to wean the private sector in the emerging water technology cluster from a reliance on government contracts, government funded R&D, and government subsidized venture capital. If the HydroHub can become more independent of state support Singapore's water technology cluster has a high probability of transitioning to a growing cluster in the coming decade given the high global need for water technologies.

CHAPTER 10

WATER TECHNOLOGY CLUSTERS IN ISRAEL

I. Introduction

Israel is at the forefront of water resource management, water policy, and water technology. It has been able, in the face of a severe scarcity of fresh water resources, to deliver clean and safe water to a rapidly growing population and economy in the 60 years following its independence. Its water economy has benefited over many decades from the existence of a series of public and private innovators and entrepreneurs who have transformed the institutional environment, developed complex infrastructure, sophisticated technologies, and effective policies and management practices (Feitelson, 2013; Siegel, 2015; Marin et al., 2017). Israel's journey to water security and sustainable water resource management has not been without its challenges, and its fair share of policy and engineering mistakes. For several decades its water policies and practices were correctly criticized as outdated, inefficient, ineffective, economically unsustainable, detrimental to the environmental, and unfair to its Arab neighbors (Tal, 2002, 2006, 2007; Feitelson, 2013). Entrenched economic and political interests and a Zionist-socialist ideology which privileged a narrow form of economic development divorced from a wider and more sustainable model of development retarded the pace of reform of the water economy, particularly between 1964 and 2000 (Rouyer, 1996; Tal, 2007).

Israel's water economy has evolved through several discernible periods which can be differentiated by a set of evolving issues, goals, discourses, approaches, and actors which have interacted to shape policy and practice (Rouyer, 1996; Tal, 2007; Feitelson, 2013; Siegel, 2015). Institutional and technological developments often coevolve. In each period the development and diffusion of water technologies has played a central role in the water economy, often enabling change institutional change. Technology was first employed on large and complex engineering projects to find, extract, and move large volumes of water from natural sources to water deficient regions in the south (Tal, 2002, 2006, 2007; Siegel, 2015). Technology was later employed to increase the efficiency of water use, improve water quality, and reuse wastewater (Tal, 2002, 2006, 2007; Siegel, 2015). Technology more recently has been used to again expand supply, but this time from unconventional sources (Tal, 2002, 2006, 2007; Siegel, 2015). Israel's water resource portfolio now includes recycled sewage and desalinated seawater. In each period several social, economic, and climatic drivers influenced how water resources were exploited, where the distribution network was built, and who received this scarce resource (Raphaeli, 1965; Sadan & Ben-Zvi, 1987; Menahem, 1998; Tal, 2006, 2007; Feitelson, 2013; Siegel, 2015; Marin et al., 2017). Each driver was met by a different response, but each successive driver also required increasingly complex solutions which raised the marginal investment cost for each additional unit of water produced (Raphaeli, 1965; Sadan & Ben-Zvi, 1987; Tal, 2006, 2007; Feitelson, 2013; Siegel, 2015; Marin et al., 2017). Addressing increasingly challenging problems with increasingly complex solutions also required an appropriate institutional framework: legislative, administrative, and regulatory measures had to be devised to assure the regular supply of safe water at reasonable prices (Raphaeli, 1965; Sadan & Ben-Zvi, 1987; Tal, 2006, 2007; Feitelson, 2013; Siegel, 2015; Marin et al., 2017).

Israel's water economy has been significantly restructured over the last 60 years: the contribution from various water sources has significantly changed; the philosophies around the relative importance of water to economic development and environmental conservation have shifted in favor of conservation; the relative power of key stakeholders in Israel's water sector have shifted towards those who favor market-based solutions; water security and resilience is now much more dependent on employing technology than exploiting sources; and water has started to become a potential tool of diplomacy for building better relationships with neighbors, and less a trigger for conflict (Tal, 2006, 2007; Feitelson, 2013; Siegel, 2015; Marin et al., 2017). Trial and error and conscious, comprehensive planning have both played a role in helping Israel to finally put its water future on a more sustainable path thanks to a combination of 'hard' engineering and technological innovations, and 'soft' regulatory programs and economic tools that produce better incentives for the water sector (Sadan & Ben-Zvi, 1987; Tal, 2006, 2007; Feitelson, 2013; Siegel, 2015; Marin et al., 2017).

This chapter will show the following: (1) Israel's historical relationship with water and how development of a national water economy was critical for underpinning all aspects of political independence and economic development; (2) Israel's governance and institutional framework and how the country's political leaders and technocrats eventually developed policies and institutions that transformed the country from a water-scarce country to a water independent country; (3) Israel's water resource management strategy, how it evolved exclusively from a supply orientation to include demand management, and how the country's technocrats employed science and technology to diversify its water resource portfolio; (4) Israel's innovation and economic development strategy and how it created indigenous expertise in water resource management and water-related technologies; and (5) Israel's competitive position in relations to its water technology sector and how the country is a major global exported of drip irrigation and desalination technologies. The Israeli experience suggests that sustainable national water economy requires planners and policy makers to consider the following: (1) the mix of policies and strategies needs to be carefully selected and complementary; (2) the policies, strategies, and technological prescriptions are to a great extent determined by unique local factors; (3) the policies and strategies need to be tailored to local social, economic and environmental conditions; (4) water reformers need to overcome conservative tendencies to maintain a status quo that may no longer be relevant; and (5) policies and strategies need to be properly supported with financial resources, and technical and institutional capacity (Raphaeli, 1965; Sadan & Ben-Zvi, 1987; Menahem, 1998; Tal, 2006, 2007; Feitelson, 2013; Siegel, 2015; Marin et al., 2017).

II. History of Israel's Water Economy

A. Pre-independence.

The modern Israeli water economy predates the State of Israel and started in the period between the First and Second World Wars when the British ruled Palestine. During this period the British authorities used the region's shortage of water as one justification to curtail Jewish immigration to the territory, pacify an increasingly restive Arab population who were increasingly opposed to Jewish immigration, and with war imminent in Europe avoid tying down large numbers of troops (Rouyer, 1996; Siegel, 2015). The water economy of Palestine was characterized by limited water resources and virtually non-existent water infrastructure, and what infrastructure had been built by the

Romans had been allowed to deteriorate by the former Ottoman rulers (Rouyer, 1996). The British policy was articulated in a White Paper on the conditions in Palestine which was published in 1939. To counter Britain's restrictive policy towards Jewish immigration, Zionist leaders needed to demonstrate that British estimates of the demographic and economic carrying capacity of Palestine's water economy were incorrect, and that the regions waters had great economic potential if there were significant changes in the way in which the water economy was governed, and how water was exploited. The Zionists did not change British policy, but they did change the way they conceived how water would be managed when they eventually founded the Jewish state (Siegel, 2015).

The Zionist agenda to settle Jewish immigrants in Palestine depended on access to water and large-scale irrigation, and Zionist representatives at the 1919 Paris Peace Conference attempted to extract formal access to northern sources of water from the victorious European powers who now ruled the Middle East (Thomas, 2009). It was recognized that the survival of any future Jewish state depended on access to the waters of the Jordan and Litani Rivers and the Sea of Galilee: this would guarantee any future Jewish state a water resource base for a strong economy, but it also accommodated historic and geographic considerations which were important to Zionist ideology (Rouyer, 1996). Despite the lack of success in Paris, the Zionist movement proactively began creating or expanding pre-state institutions in Palestine. One important institution was the Jewish National Fund (JNF), an organization founded in 1901 to help establish Jewish communities in Palestine. The JNF supported water, agricultural and environmental projects; it became a major land owner in Palestine-Israel, which would help to evolve a pattern of collective rather than private land ownership in the new state; and it would grow from a small-scale operation to have a deep and lasting impact on Israeli land, water, and natural resource policy and practice (kkl-jnf.org, n.d. a; Rouyer, 1996). Between the wars 96% of the wells and most other water infrastructure developed in Palestine were built by Jews and funded by the JNF (Rouyer, 1996). Another important institution was Mekorot, the future water supply company, which was conceived in 1935 and founded in 1937, and was partially owned by the JNF. Merkorot was responsible for water exploration, well drilling, and water transportation to ensure that an adequate supply of water would exist for new immigrants and the growing number of farming communities. As the demand for water increased, and the scale and scope of Mekorot's operations grew, greater innovation was required from its engineers and planners. The water system that emerged prior to independence was small-scale, fragmented and located close to easily accessible supplies along the Mediterranean coast and in the north, which was a pragmatic response to limited financial resources and the absence of centralized political authority. The Zionist vision, however, also included incorporating the larger Negev desert in the south into the wider economy and society.

Simon Blass produced the first Water Plan in 1939 and would update it regularly for 20 years (Siegel, 2015). Blass' draft would eventually become Israel's Water Master Plan, but his first draft contained all the elements of the future Israeli Water Economy. Blass proposed a three-phase approach to national self-sufficiency: (1) searching for water beneath the Negev desert, (2) pumping water from central Israel to the Negev in the south, and (3) building an underground water conveyance that would bring water from the north to the rest of Israel, including the Negev in the south. During the Second World

War Blass surveyed all of Palestine's water resources and continued to refine his plans with ideas gleaned from water projects in the United States. He considered using storm-and-waste water and proposed bringing water from the Mediterranean to the Dead Sea whose drop would also generate hydroelectric power. Blass also considered untapped sources at the edge of the Palestinian territory – the Yarmouk River on the border with Trans-Jordan and the Litani River on the border with Lebanon – which at that time drained into the Jordan River and Mediterranean Sea respectively. These rivers would eventually come under Israeli control as prizes of Arab-Israeli wars.

In 1947 Blass' water plan would also prove useful in presenting the Zionist case for an independent Jewish state to a United Nations committee whose mission was to examine the division of Palestine into Jewish and Arab states. Blass' water plan challenged the British claims regarding the economic and environmental carrying capacity of Palestine which were used to justify restricting Jewish immigration to the territory. In the end the UN committee was persuaded by Blass and his associates and they recommended the partition of Palestine and the creation of a Jewish state. By the time of independence for the Jewish state in 1948, the Zionist leadership had conceived of a comprehensive water framework from which they could begin supporting the development of the new state (Siegel, 2015).

The Zionists also got support from an unlikely source, an American water expert, Walter Lowdermilk. Lowdermilk surveyed the region's water resources and its agricultural potential in the late 1930s and in 1944 he published a book based on his findings, *Palestine, Land of Promise.* Lowdermilk challenged the findings of the 1939 British White Paper on several points and suggested that the region's water challenges could be solved with the application of science, technology, and sound water resource management (Siegel, 2015). The basis of the Lowdermilk plan was a regional approach to the problem of water scarcity with holistic management of all the region's water resources (Rouyer, 1996). The Lowdermilk Plan was followed in 1948 by a detailed engineering study prepared by an American engineer and consultant, James Hays. This plan, entitled *T.V.A. On the Jordan*, provided an eight-stage blueprint to realize Lowdermilk's overall conception for a Jordan Valley Authority based on the Tennessee Valley Authority (Rouyer, 1996).

A key strategy of the Zionist leadership was the settling of the sparsely populated Negev desert in the period leading up to independence (Rouyer, 1996). This was done with the financial support of the JNF. The Negev was strategically important for both defensive depth and its potential economic value. Three experimental settlements were constructed in the Negev in 1943, 11 more in 1946 and five in 1947 (Rogers, 2003). Blass, who was also the Director of the JNF's Hydrology Department, successfully drilled wells at Gvar Am and Nir Am and devised a plan to connect several other farming communities to this source of ground water through a network of pipes eventually built in 1946. The innovative and entrepreneurial Blass acquired high-quality steel pipes as war surplus from London where they were installed during the Blitz to supply water for firefighting (Siegel, 2015). The money for this expensive procurement came from the JNF (kkl-jnf.org, n.d.).

B. 1948-1964.

The State of Israel received its independence on 14 May 1948 and was immediately attacked by six Arab armies. The conflict lasted for about one year. When the armistice was signed the State of Israel had extended its borders by about 30% beyond the 1947 UN Partition Resolution and increased its water resources, a fact which remains a source of conflict between Israel and many of its Arab neighbors to the present day (Isaac & Shuval, 1994). These expanded boundaries would ultimately permit Israel to implement much of the Lowdermilk-Hays Plan, but on a largely unilateral basis (Rouyer, 1996).

The immediate need for defense and resettling refugees consumed considerable financial resources of the new state; however, water and agriculture remained a national priority as food was in short supply. Agriculture would provide a source of employment for the growing number of refugees, and a rural-agrarian life fit the Zionist-socialist ideology of the Jewish leadership (Rouyer, 1996; Tal, 2007). In 1953 Israel started receiving reparations from Germany and one of the priority areas for these reparations was water infrastructure (Siegel, 2015). Water and water infrastructure became decisive elements in nation building and in building the national character of the people of the new state.

Water would play a central role in both conflict and peace between the State of Israel and its neighbors. The War of Independence meant that many key sources of regional water now fell in demilitarized zones, legal access to which would have to await a future peace treaty (Thomas, 2009). Although efforts by the United Nations and the United States for the joint development and control of the water resources of the Jordan Valley was unable to realize wide international agreement, both Israel and Jordan undertook in 1955 to abide by their allocations under the Johnston Unified Water Plan as a treaty of allocation rights (Bailey, 1985; Thomas, 2009). Israel began to exploit the water resources of what was now northern Israel within the framework of the agreement until the June 1967 war brought the Golan Heights and West Bank under Israeli control (Rogers, 2003). Although Jordan and Israel have managed to work together on water issues of mutual concern, Israel and its other Arab neighbors have also employed a range of military and diplomatic strategies to address their strategic water concerns from 1948 to the present.

Blass' water plan was systematically implemented during the 1950s with considerable donations from American Jewry (Siegel, 2015). The key components were the supply of water to the Negev from the Yaron River in central Israel, inaugurated in 1955, and the construction of the National Water Carrier which would bring water from the North of Israel to the Negev (Siegel, 2015). The National Water Carrier was a major undertaking for the young state because of its technical complexity, its high cost, and its demand on scarce resources: it remains to this day the largest and most costly development project executed in Israel at about 420 million Israeli Pounds (IL) in 1964 values (Cohen, 2008; Siegel, 2015). The planning for the project began in 1953, the detailed plans were approved by the government in 1956, construction began in 1959, and the 130 kilometers system was completed in 1964. The National Water Carrier was designed by Tahal and constructed by Mekorot. The National Water Carrier remains the centerpiece of Israel's water supply system as most of the water works in Israel are combined with this network (Cohen, 2009).

The 1950s also saw other important developments in the water economy of Israel, especially in terms of the legal, regulatory and institutional framework. A series of water laws were passed in the 1950s which were to become a central part of Israel's water supply and water-conservation success (Siegel, 2015). In 1955 two laws were passed: one law prohibited any drilling for water anywhere in the country, even by the owner on his private land, without first obtaining a license to do so; and the second law prohibited any distribution of water unless that supply was done through a meter. In 1957 a law was passed to control all surface water, rainwater and sewerage. None of these types of water could be diverted without government permission. The Water Law of 1959 consolidated these emerging legal principles and confirmed water as public property subject to state control and compelled all citizens to use water sparingly and efficiently. Even with the entry of private companies into the water economy, water remains common property highly regulated by the state (Siegel, 2015). In 1953 Israel drafted the world's first set of standards for wastewater reuse, and effluent recycling would eventually emerge as a central element of Israeli domestic water policy. In 1962 the Knesset passed the Local Authorities (Sewerage) Law to allow local authorities to build and own sewerage works within their jurisdictions (Laster & Livney, 2009).

C. 1964 to 1990.

This period was dominated by two developments: (1) the recognition that all potential sources of natural water supply in Israel were fully exploited, and (2) the politico-hydraulic consequences of Israel's victories in the Six Day War of 1967 which brought the sources of much the region's surface and ground water under Israeli control (Menahem, 1998; Feitelson, 2013). Given that the limit of further exploitation of Israel's natural sources had been reached, and the reality that desalination was not yet technically and economically feasible, attention gradually shifted to improving the management of existing resources (Menahem, 1998; Tal, 2007; Feitelson, 2013). The state of water resources was provided in a 1972 report to the Minster of Agriculture by an international team of renowned water experts (Menahem, 1998). Recycled water and drip irrigation technology now became more attractive and in combination saved both water and fertilizer. Nevertheless, the use of recycled water and water from the Sea of Galilee, increased the salinity of water used for irrigation with negative environmental consequences. Increasing concerns over water quality led to a 1971 amendment of the Water Law of 1959 to require the Water Commission to also take water quality issues into consideration (Feitelson, 2013).

Despite evidence of the unsustainable nature of Israel's existing water policy, the increasing use of recycled water may well have reduced the urgency to substantially reform the water economy to protect and preserve natural sources (Menahem, 1998; Tal, 2002, 2006; Feitelson, 2013). Planning became increasingly short-term, the fiscal space became increasingly tight, policy change was reactive and characterized by incremental decision-making (Menahem, 1998). None of the long-term plans prepared by Tahal in the 1960s and 1970s were implemented and Tahal began to shift its planning services to the private sector and international clients (Menahem, 1998). Even the Water Master Plan which was produced following a water crisis in 1985 was intentionally suppressed.

There was, nevertheless, a gradual shift in agricultural policy away from food self-sufficiency, water intensive crops, maximizing agricultural exports, centralized state-led water planning, and subsidizing the agricultural sector towards more market-based approaches (Tal, 2007; Feitelson, 2013). The traditional model of collectivist and family farms was replaced by commercial farming driven by profits. New farms were larger, employed fewer people, applied more capital and technology, and achieved increasing economies of scale (Tal, 2007; Feitelson, 2013). These changes in agriculture were part of a restructuring of the wider Israeli economy, and a shifting of economic power, which allowed the economy to grow while maintaining the overall output of the agricultural sector (Tal, 2007; Feitelson, 2013). The agricultural sector, however, continued to place unsustainable demands on natural water sources and this period thus ended with the first major drought crisis in 1989.

D. 1990 to 2005.

This period was dominated by a re-evaluation of Israel's water policies and the institutional framework for water resource management; and it saw the public becoming increasing involved in the water discourse that was traditionally the preserve of politicians, water technocrats, and agricultural interests (Tal, 2007; Feitelson, 2013; Siegel, 2015). The drivers for this shift were three major water crises, which were the result of increasingly severe droughts, the huge influx of Russian Jews, and the prospects of a peace deal with Arab neighbors which would undoubtedly lead to greater water allocation demands from Palestinians, Jordanians and, perhaps, Syrians (Starr, 1991; Menahem, 1998). The droughts led severe water shortages and rationing which affected agricultural, industrial, and domestic consumers; (Feitelson, 2013; Siegel, 2015). The Water Commission continued to allow the water reserves to reach critical levels as demand outstripped the rate of replenishment and a report by the State Comptroller which was critical of the Water Commissioner led to his dismissal (Feitelson, 2013). These events provided a window for political action that finally triggered far-reaching policy reforms.

Around this time concerns for the environment also came to the forefront of the discourse around water (Tal, 2006 & 2007; Feitelson, 2013; Siegel, 2015). Natural systems to include waterways and nature reserves were increasingly discovered to be under stress. The reality was that the codex of the four key water laws developed in previous decades did not explicitly recognize ecological and environmental concerns outside the context of securing the supply of water (Tal, 2002, 2006, 2007; Feitelson, 2013). There were also no specific laws protecting the natural environment, those which had been proposed were never passed by the Knesset (Laster & Livney, 2009). A 2004 amendment of the Water Law of 1959 recognized ecological support as a legitimate purpose to which water could be allocated (Laster & Livney, 2008; Feitelson, 2013). Secondary and advanced level treatment of waste-water increasingly became standard after 1990 and the increase in recycled water made more water available for substitution in agriculture and for stream rehabilitation (Feitelson, 2013). By 2000 almost all cities and towns were connected to at least secondary levels of treatment.

The drought crises of the 1980s and 1990s had exposed fissures within the policy community with some committed to the traditional socialist model of water resource development and allocation, and others committed to more market-based approaches to resource allocation and utility management (Feitelson, 2013; Siegel, 2015). Those who advocated for more market-based and neo-liberal approaches to water resource management argued that traditional policy encouraged over-extraction beyond the natural rate of replenishment; what was required was the adoption of price as a demand-management mechanism, and full-cost recovery to ensure high-quality service, reliable infrastructure, and financially sustainable utilities (Tal, 2007; Feitelson, 2013; Marin et al., 2017).

Until 1996 the Ministry of Agriculture was the lead ministry for the water sector and this set the policy tone: the ministry's priority was to supply natural water resources to meet all water demands; agriculture remained the main user of water; and the agricultural lobby wanted to keep the tariff for agricultural water artificially low (Feitelson, 2013). By the start of the 2000s, the agricultural sector produced less than 5% of Israel's gross national product but still drained more than 70% of the country's water. The Ministry of Finance in contrast wanted to stop water subsidies as a precondition for supporting desalination (Feitelson, 2013). It was not until about 2000 that some level of consensus on the way forward was achieved by the various actors and Israeli farmers were forced to accept a one-third reduction in water for certain crops (Feitelson, 2013; Siegel, 2015).

The drought of 1999 to 2000 shifted the positions of both the finance and agriculture lobbies and a compromise on key issues was reached to facilitate the development of desalination (Feitelson, 2013; Siegel, 2015). The changes brought about by events in the 1990s led to a surge in entrepreneurial and innovative activity relating to desalination technology, and ultimately to breakthroughs which reduced production costs and energy usage (Siegel, 2015). It also accelerated a trend in irrigation where sprinklers, which used to irrigate over 80% of Israel's irrigated land, were replaced as the primary source of irrigation by drip technology, which used to irrigate 10% but now represents almost 80% of irrigated land (Davis, Maks & Richardson, 1980; Reisman, 2005).

In 2000 the Government of Israel began the process of gradual change in the policy for water sector management to transition the country to a more sustainable approach to water resource management which guaranteed Israel's water security. A

Parliamentary Investigation Committee of the Water Sector was established and its findings, which were published in 2006, led to the gradual establishment of a more modern and relevant institutional framework for water resource management. The era of cross-subsidization by sectors was to come to an end, and some on the policy fringes even advocated that Israel should get out of agriculture given that the economy was evolving from an industrial to a post-industrial stage (Tal, 2007; Feitelson, 2013).

E. 2005 to Present.

This period begins with the inauguration of the first large-scale desalination plant at Ashkelon in 2005, and this represents the single most decisive shift towards a more sustainable supply system for water (Tal, 2006; Feitelson, 2013; Siegel, 2015; Marin et al., 2017). Desalination signifies the emergence of a third pillar in Israel's water portfolio, and this new source strengthens the country's position as a global player in water technology beyond the confines of drip irrigation and recycling. In addition to providing a reliable, climate independent source of water, desalination helps to solve one of the most important environmental problems facing Israel's water resource managers – the salinity of the country's water supply (Tal, 2006; Feitelson, 2013; Siegel, 2015). In addition, higher standards for wastewater, combined with the higher quality water from desalination entering the waste stream, will improve the quality of recycled water supplied to agriculture which reduces some of the environmental problems of recycled water (Tal, 2006, 2007; Feitelson, 2013; Siegel, 2015). No advance is, however, without its drawbacks: desalination increases the energy requirements of Israel, the country's carbon footprint, and it requires that brackish water be discharged back into the sea (Tal, 2006; Feitelson, 2013; Siegel, 2015).

This period also signifies the continued shift in governance towards more neo-liberal policies in the water economy through pricing, ring-fencing, the creation of quasi-markets, and the use of public-private partnerships (PPPs) for implementation and operations (Feitelson, 2013; Siegel, 2015; Marin et al., 2017). As part of the neo-liberal turn in Israel's water economy, most water-and-wastewater services are now supplied through local public corporations or PPPs. By 2009, most Israeli communities are served by these restructured service providers and the intention is to have all communities served by this business model rather than directly by municipalities (Feitelson, 2013; Siegel, 2015; Marin et al., 2017).

The passage of the Water and Sewerage Corporation Law of 2001 was instrumental in signaling this shift in the governance and management of a major sub-sector of the water economy, and it facilitates increased entrepreneurship and innovation in the related water technology sub-sector. The new governing regime was further strengthened in May 2006 when the Knesset enacted a further fundamental change to the governance and management structure of the water sector: the establishment of the Israel Water Authority (IWA) to replace the Water Commission (Siegel, 2015; Marin et al., 2017). Since the Water Law of 1959 the management of water resources was primarily entrusted to the Water Commissioner; however, as water's governing framework evolved through the passage of additional legislation and the establishment of practices, the level of competing and conflicting political claims on water prevented the Water Commissioner from independently exercising his functions (Feitelson, 2013; Siegel, 2015; Marin et al., 2017).

III. Israel's Water: Overcoming a Deficit

Israel is one of the most water-scarce countries in the world; it is also part of the most water-scarce region of the world with the greatest water disparity between neighbors; and within its pre-1967 borders there are no further unexploited natural water resources (Roudi-Fahimi, Creel & De Souza, 2002). Water scarcity has been fundamental in shaping the development of the Israeli water economy over the last six decades, forcing the country to develop a series of innovations in water governance, managerial practices, technologies, and institutions.

Subtropical Israel is located on the southeastern coast of the Mediterranean between relatively wet Lebanon to its north, and relatively dry Egypt to its south. Its area of 20,000 kms^2 is spread across four distinct geographic regions that vary in elevation and topography: the Mediterranean coastal plain, the western and central hills, the Jordan Rift valley in the east, and the Negev desert in the south. This makes for considerable climatic variation within a small geographic space with a radius of only about 200 kilometers (Cohen, 2008). Most of Israel has a semi-arid climate; however, the country has climatic transition characteristics which range from wet sub-tropical in the north, with an average annual rainfall of 600 millimeters, to dry sub-tropical desert in the south, with an average annual rainfall of 150 millimeters (Cohen, 2008). Extreme variations in precipitation between years are normal, and multiple years of drought are not uncommon. Annual rainfall in Galilee in the north can reach 1,100 millimeters; the range in the desert south is between 30 millimeters in the Arava and Iehuda deserts and 200 millimeters in Beer Sheva; while the mountains around Jerusalem and the Mediterranean coast fall in between (Cohen, 2008).

As is characteristic of the Mediterranean, the rainy season lasts for 3 to 4 months of the year during winter, with 75% of annual precipitation falling between December to February. Occasional heavy rains during this period can produce short but intense floods that contain up to 9% suspended solids, making it difficult to store and reuse flood waters (Cohen, 2008). Of the quantity of precipitation that reaches the soil, 60% evaporates, 10% to 25% infiltrates the soil and gets to the aquifers or remains in the soil to support vegetation and crops, and 5 to 10% drains into the valleys (Cohen, 2008). All the major water resources of Israel depend on local rainfall, and most are concentrated in the northern regions of the country around the Mount Hermon basin where the single most important water resource is the Sea of Galilee and the Jordan River and its tributaries. These sources are the only natural fresh surface water in the region, and it provides approximately 20% to 30% of the Israel's total fresh water supply and one-third of its renewable supply (Tal, 2006; Cohen, 2008).

Israel has a water resource deficit with annual water resources potential of under 2000 million cubic meters a year while current annual demand exceeds 2150 million cubic meters (Cohen, 2008). Israel's water resources are divided roughly as follows: 52% from underground and seasonal sources, 31% from surface sources, 12% from used and recycled waters, and 5% from flood waters (Rogers, 2003; Cohen, 2008). With respect to groundwater resources, Israel has access to three major aquifers, two renewable and one non-renewable: the Yarkon-Taninim Aquifer that lies beneath north central Israel and the West Bank territory of the Palestinian Authority; the Coastal Aquifer that lies beneath the west central coastal plain along the Mediterranean Sea down to an including all of the Gaza Strip; and the fossil water aquifers of the Negev Desert, where the water is found at a great depth and was collected in prehistoric times when there were large quantities of water in region (Rogers, 2003; Cohen, 2008). About 70% to 80% of the effective recharge area of the Yarkon-Taninim Aquifer theoretically lies beneath the West Bank; but, the recharged waters flow westward toward the coastal plain. Since the mid-1960s the Israelis have tapped 25% to 45% of their agricultural water from this aquifer, causing a gradual but sustained depletion and increasing salinity (Starr, 1991; Rogers, 2003). Israelis living in the West Bank are prohibited from engaging in extensive farming, and there are strict restrictions on overuse or free drilling by both Palestinians and Israelis (Davis, Maks & Richardson, 1980; Starr, 1991). The Coastal Aquifer is another important source of groundwater, but sea water intrusion has become a growing problem, preventing withdrawals within 40 to 80 meters of the surface (Rogers, 2003).

In 1949 Israel was consuming 17% of its proven renewable water resources; in 1968, 90%; in 1976, 98%; in 1978, 95%; and at the end of the century is was still utilizing more than 90% of its water potential (Davis, Maks & Richardson, 1980; Elke, 1998). Between 1948 and 1998 the country over-drafted its water resources between 15% and 20% beyond the recharge capacity (Cohen, 2008). Although groundwater recharge efforts increased significantly in recent decades, demand and extraction still outpaced supply (Cohen, 2008), and aquifer recharge is also further threatened by urbanization and the proliferation of paved surfaces (Tal, 2002; Tal, 2006). The large increase in cultivated land and harvests in the country's semi-arid regions has also exacerbated the salinity of soils and raised turbidity levels in water that is already naturally high in chloride concentrations and suspended solids (Tal, 2002, 2006). The water level of the Dead Sea, the lowest and saltiest lake on the planet, has been falling at an average annual rate of 1.2

meters per year largely because of the diversion of one billion cubic meters of water per year of the natural flow from Lake Kinneret and the Jordan and Yarmoukh rivers (Tal, 2002; Tal, 2006).

The internationally recognized Falkenmark indicator sets the minimum annual volume of water per capita at 1000 cubic meters per person, and the absolute scarcity level below which countries experience water stress at 500 cubic meters per person (Falkenmark, Lundqvist & Widstrand, 1989). Israel's total volume of renewable water stands at 276 cubic meters per year, which by international standards defines a situation of extreme water shortage (Tal, 2006; Marin et al., 2017). In 2007, average annual per capita household consumption was 61.2 cubic meters, whereas in 2009, it was 52.4 cubic meters (Kislev, 2001).

Israel’s natural deficit has been exacerbated by human intervention. The region’s long history of agriculture and resource exploitation - that consisted of overgrazing, primitive subsistence farming practices, and deforestation - have created a country whose modest precipitation leaves about 80% of its land unsuitable for agriculture without extensive irrigation (Rouyer, 1996; Tal, 2007). Between 1948 and 2007 the Israeli economy grew almost 6-fold per capita in real terms, its resource base grew 38-fold, and its population grew almost 8-fold; it has moved from an agricultural economy to an industrial and service economy, and it had to accommodate successive waves of refugees and immigrants from Europe, the Middle East and the Soviet Union (Starr, 1991; cbs, 2007). The post-independence policy response was initially short-sighted human intervention in favor of expanding water supply which privileged economic development and supported demographic growth over water conservation and environmental protection. The only way that Israel, the West Bank, and Gaza can meet their water requirements is through a combination of the sustainable exploitation of its natural resources combined with an aggressive program to exploit sewage, desalinated water, or imported water, all of which are increasingly costly (Starr, 1991, Tal, 2006). Israel's economic, social, and security future therefore critically depends on either the tapping of new water sources and the preservation of existing resources, and both require the development of new technologies and new institutions (Davis, Maks & Richardson, 1980).

In the 60 years since Independence, Israel gradually implemented a suite of policies that includes the following six major elements: (1) the development of a national bulk water conveyance infrastructure, (2) the use of aquifers as reservoirs, (3) strong demand management, (4) the reuse of treated wastewater for irrigation, (5) the development of large-scale desalination of seawater and brackish water, and (6) institutional reforms that ensure a sustainable financial model for the water-and-wastewater sector and that removes political decision-making from the day-to-day management of water resources (Siegel, 2015; Marin et al., 2017). The last four reforms, which were instituted largely between 1998 and 2006, has allowed Israel to gradually reduce over-exploitation of aquifers through a massive increase in the volume of wastewater reuse and seawater desalination; and the water economy has become more resilient given that the total amount of water production in 2014 has been maintained broadly at the 1985 level, despite a sharp drop in natural water supplies caused by droughts (Siegel, 2015; Marin et al., 2017).

The water economy of Israel has therefore evolved considerably over the past 60 years in response to changing economic, political, social, and environmental factors at various scales. Important innovations in socio-technological niches, regimes and the landscape emerged, coalesced, and diffused to create paradigm shifts in the landscape of the Israeli water economy. At the macro-level, urbanization, economic and demographic expansion, a shift towards a post-industrial economy, and climate change have acted as drivers of innovations within the socio-technical landscape (Tal, 2002, 2006, 2007; Marin et al., 2017). The water economy has been restructured with water being gradually reallocated from agricultural activity towards higher value economic activities; resources have shifted away from building large complex systems to convey water for irrigation towards water and sewerage infrastructure; and water systems now tend to be more decentralized and in the private rather than public sector (Marin et al., 2017). A critical landscape constraint has been the tightening of public finances which helped to shift the dominant governing ideology away from socialism and centralized planning and management, towards neo-liberalism and New Public Management; and power from engineers and agriculturalists to economists, capitalists, and private entrepreneurs (Laster & Livney, 2008; Feitelson, 2013).

At the meso-level, changes in water technologies, environmental and ecological values and attitudes, industry structures, and ideologies related to political-economy have acted as drivers of innovations within socio-technical regimes. The recurring and worsening droughts between 1986 and 1998 changed attitudes about the relative value of water, and its social and economic role, and created a sufficient level of public pressure to overcome political and institutional inertia (Siegel, 2015; Marin et al., 2017). Solving the quantitative and qualitative problems of water supply stimulated a demand-pull for new and more efficient water technologies, and for greater investment in sewerage and recycling infrastructure which provided an economic incentive for private sector entrepreneurship and innovation. The acceptance of market-capitalism and New Public Management has facilitated the rise of public-private partnerships and greater private investment in the water sector (Rouyer, 1996; Laster & Livney, 2008; Feitelson, 2013).

At the micro-level, the development and diffusion of technologies for the construction of large-scale, civil engineering water storage and conveyance systems, like the National Water Carrier, and the drilling of deeper and deeper wells to exploit fossil aquifers, acted as enablers of innovations within technological niches during the 1950s and 60s (Siegel, 2015). This supported the policy of expanding water supply. This was later superseded by the development and diffusion of new technologies in drip irrigation, which was perfected in the 1960s and 1970s, in the reuse of waste-water, which was facilitated by advances in recycling technologies in the 1970s and 1980s, and desalination, which became technologically and economically feasible in the 1990s (Tal, 2002, 2006. 2007; and Siegel, 2015; Marin et al., 2017). With demand still outpacing natural supply, this supported the policy shift towards the efficiency use of water, improvements in water quality, and efforts to find new supplies and unconventional sources. provided the solution.

IV. Governance of the Water Economy

A. Overview

People experience their water-and-wastewater system through the quality of its governance, that is the ways the rules, norms and practices that guide the interaction and decision-making among the actors in the system are structured, sustained, regulated and held to account (Bevir, 2013). Although water has always been a high development and security priority for the pre-and-post independence leaders of Israel (Morag, 2001), the quality of its water governance has not always adequately supported the Israeli water economy nor served the needs of its citizens (Galnoor, 1978; Siegel, 2015; Marin et al., 2017). Much of the success of the Israeli water economy can be attributed to the quality and foresight of its water engineers and planners, and the independence and technical competence of its regulators; however, many of the challenges faced by this sector can be attributed to politicians and policy makers who have used control over the water economy for political gain, turf building, or a highly ideological commitment to economic development and the settlement of outlying regions (Galnoor, 1978; Siegel, 2015).

The water economy of Israel that developed in the decade after Independence was more a reflection of short-term political, ideological, and social realities unique to Israel than a reflection of the country's long-term economic, environmental and ecological realities or imperatives (Laster & Livney, 2009; Feitelson, 2013; Siegel, 2015). Most water engineers, water technocrats, and agrarian interests, for many decades preceding and following independence, were largely affiliated with the ruling Labour Party which gave these stakeholders access to the centers of power and a role in water policy-making (Rouyer, 1996; Menahem, 1998). Although the proportion of Jews who lived and worked on collective farms was always a small percentage of the Israeli population, they exerted a disproportionate influence on politics and culture and were disproportionately represented in among the ranks of politicians, civil servants, and military leaders (Rouyer, 1996; Menahem, 1998; Tal, 2007; Laster & Livney, 2009; Feitelson, 2013).

As a matter of policy, water was an economic resource to be exploited in the interests of national development and self-sufficiency, and as a strategic resource with geopolitical and security consideration (Rouyer, 1996; Menahem, 1998; Tal, 2007). Israel's unique system of land law has also meant that many Israeli's see land and water in a collectivist manner. As a matter of policy most land in Israel ended up as collective property in the hands of either the State or the Jewish National Fund, where it remains to this day. Water and agricultural policy were essentially the same for decades, long after it became a highly questionable, economic paradigm (Menahem, 1998). Elements of this institutional structure remains to this day to influence the water economy even though the structure of the economy and public policy has shifted significantly towards market-capitalism (Rouyer, 1996; Menahem, 1998; Tal, 2007; Laster & Livney, 2009; Feitelson, 2013; Siegel, 2015).

Between 1948 and 1996 water was under the portfolio of the Ministry of Agriculture. This institutional arrangement reflected the initial political priority that had been given to agriculture in early economic development policy; and it also reflected the reality that the agriculture sector, for most of Israel's history, consumed 80% of the country's water. The governance of the water economy in the first several decades after independence largely reflected the power structure in Israel and the central historic role of the agriculture, even though by the 1970s and 1980s that sector had declined in importance relative to the rest of the economy. Agriculture's share of GDP, which was 30% in the 1950s, declined to 1.6% in 2007 (Rogers, 2007); and agricultural products as a percentage of exports, which was 30% in its heydays in the 1960s, declined to a mere 2.4% in 2009 (Felder, 2009). Between 1996 and 2000 responsibility for water briefly became the portfolio responsibility of the Ministry of Infrastructure, which was partially in recognition of the fact that water increasingly had to serve a wider set of social, economic, and environmental needs (Feitelson, 2013).

The water governance regime that emerged between 1948 and 2000 was a complex, inefficient, reactive, and fragmented system where key stakeholders often had competing agendas: the Ministry of Finance set prices for domestic and industrial consumers; the Ministry of Agriculture set prices for farmers; the Ministries of Infrastructure and Environmental Protection were jointly responsible for sewerage, water quality and safety; the Ministry of the Interior controlled distribution; the Ministry of Justice adjudicated water disputes; the Ministry of Defense was responsible for water resources in the Occupied Territories after 1967; and the Ministry of Foreign Affairs was responsible for sharing water with the Kingdom of Jordan (Laster & Livney, 2009; Feitelson, 2013; Siegel, 2015). Although the framework in this period created much friction over authority, the allocation of resources, and the distribution of benefits and burdens, there was some countervailing balance by the role played by the country's three main water technocrats – the Water Commission and the Directors of Tahal and Mekorot – who together through bargaining and compromise implemented Israel's water policy, although in a sub-optimal manner (Galnoor, 1978). The result of this institutional arrangement, and its sub-optimal operation, were water resources that were over-exploited, inefficiently allocated, underpriced, and under-valued which threatened the sustainability and resilience of the water economy (Galnoor, 1978; Marin et al., 2017).

Water governance in the period between 1959 and 2000 was theoretically dominated by the independent Water Commission and the multi-stakeholder Water Board.

Although the Water Commission was managed by a Water Commissioner, and overseen by a Water Board, in practice the Commissioner was effectively an administrator and politicians and agricultural interests played an active role until the reforms of the 2000s (Laster & Livney, 2009). The Water Commission did introduce marginal changes in pricing, and a limited public education campaign to encourage conservation, but nothing sufficient to address the underlying problem of over-exploitation of water and the continued allocation of water to economic activities of lower value (Galnoor, 1978). The Water Board was supposed to create a built-in mechanism of structured public participation and consultation in major decisions affecting the nation's water resources, and its 27 to 39 members government appointed members were drawn from government, the Jewish Agency and civil society, with the latter supposed to make up two-thirds of the Board and representing different groups of water consumers (Raphaeli, 1965). The Board was, however, dominated by agricultural interests and those who favored subsidized prices and expanded supply (Menahem, 1998; Laster & Livney, 2009; Feitelson, 2013). Without a crisis driver to create serious political pressure, politicians and technocrats seemed incapable of establishing new national goals and priorities around water and piecemeal or marginal changes were small in scale and scope (Laster & Livney, 2009; Feitelson, 2013).

The marginal changes in water governance between the 1948 and 2000 could be seen in retrospect as a gradual shift from tendencies of centralization to fragmentation to decentralization as the economic and demographic structure, and the dominant ideological frame of reference of its leaders evolved (Laster & Livney, 2009; Feitelson, 2013). The opening of the National Water Carrier in 1964 represented the reality that

Israel has successfully exploited all its available natural water sources under centralized management. This was followed by a shift to fragmentation where water increasingly became a resource subject to many competing claims from several ministries representing urban and industrial constituencies whose demand for water was also increasing (Galnoor, 1978; Laster & Livney, 2009 Feitelson, 2013). The response during the period of fragmentation was to increase the efficiency of use of existing water resources and later to preserve its quality. The shift from fragmentation to decentralization occurred in the 1990s with the rise of neo-liberalism and New Public Management. This shift in organizational management did not, however, initially result in a fundamental shift in resource management – the realization of a paradigm shift in water policy required the intervention of nature, and the pressure of a series of drought induced crises, for politicians to gain the political will to undertake ambitious water reforms and guide a reluctant populace to a new regime of water governance (Marin et al., 2017). Post-1998 water policy thus shifted from providing access to water to managing water in the face of scarcity, and a new governance framework was developed accordingly (Galnoor, 1978; Marin et al., 2017).

In the early 2000s the new institutional framework for water resource management got politicians out of the day-to-day management of water and a series of far-reaching reforms in water resource management has allowed Israel to achieve water security while at the same time drastically reduce over-exploitation of aquifers (Siegel, 2015; Marin et al., 2017). In 2000 water became the portfolio responsibility of the Ministry of Energy and Water. This important move in policy oversight for water was followed by a series of significant reforms. In 2001 a law was passed requiring ring-fencing of municipal water services (Marin et al., 2017). Ring-fencing is a legal or financial arrangement which separates the activities, assets and liabilities, revenues and costs of municipal water supply operations from the local government to which it supplies its water services. In 2002 a Parliamentary Investigation Committee for the water sector was launched and in 2006 it pushed for changes to the 1959 Water Law which led to the creation of the Israeli Water Authority (IWA) to replace the Water Commission. In the current governance regime, the Water Authority regulates the water-and-wastewater sector; Local Authorities are responsible for water supply and wastewater removal; the Ministry of Environmental protection is responsible for the quality of water resources; the Ministry of Agriculture is responsible for agricultural water, soil conservation and the Drainage Authorities; the Ministry of Health is responsible for water quality; and responsibility for sewerage treatment and reuse is shared by the Ministries of Health and Environmental Protection, the Water Authority, and local authorities (Kislev, 2011; Marin et al., 2017).

The post 2006 reforms have approached Israel's water scarcity on several policy fronts that combines institutional and regulatory reforms with demand management and massive infrastructure investment (Siegel, 2015; Marin et al., 2017). The reforms have at least six main elements: (1) strong demand management to increase the efficiency with which water is used; (2) using aquifers as reservoirs by recharging them with treated wastewater during low-demand months; (3) reuse of treated wastewater for irrigation to replace and release scarce fresh water for domestic and industrial uses and to safeguard the environment; (4) large-scale desalination of seawater and brackish water to supply almost all potable water that municipal and regional utilities distribute in the country; (5)

modernizing the national bulk water conveyance system to optimize the distribution of water across the country from various sources depending on demand; and (6) major legal and institutional reforms, chief among them pricing policies to approach financial sustainability of the water sector as a whole, corporatization of service providers and the establishment of a strong national regulator (Marin et al., 2017).

Some of the reforms have necessitated years of implementation, followed by refinement, to optimize results. This required some difficult political decisions along the way, such as with the sharp rise in domestic water tariff in the aftermath of another major drought in 2008. It also stimulated a series of innovations that succeeded in gradually restoring a sustainable water balance. As of 2017, the availability of quality water in Israel is deemed to be enough to meet the foreseeable needs of the country, even accounting for steady population growth and the foreseeable effects of climate change (Siegel, 2015; Marin et al., 2017). Future growth in domestic and industrial demand is expected to be met through desalination, generating an equivalent increase in the amount of treated wastewater available to farmers for reuse.

B. Legal, Institutional & Regulatory Framework

In the years from 1955-1959 a codex of four laws were enacted to establish the institutional framework upon which the water sector was to be governed (Siegel, 2015; Marin et al., 2017). The principles behind the legislation could be summarized as follows: (1) water resources are exclusively public property with property rights vested in the State of Israel; (2) every person has the right to a water allocation for recognized purposes; (3) water scarcity requires that the uses to which water resources of varying quality are put should be prioritized; (4) the authority for that allocation would be centrally vested in the State of Israel to ensure an optimal use of the limited water resources; (5) water consumers, through their political representatives, have a right to provide their input in the determination of Israel's national water policy and on the rules relating to allocations, priorities and tariffs; and (6) the government had a duty to take action for the prevention the pollution of water resources (Siegel, 2015; Marin et al., 2017). The first piece of the legislation was the Law for Water Measurement of 1955, which required the metering of all water to enable water management, control of water flows and uses, and detailed data collection. The Law stipulated that each consumer, even a self-supplying consumer, was required to have a water measuring device. The 1955 Water Measurement Law was a first step into the creation of an administratively regulated water sector, and it allowed water resource managers to manage both for allocation and conservation purposes (Laster & Livney, 2008; Siegel, 2015; Marin et al., 2017).

The second piece of the legislation was the Law for Supervision of Water Drilling of 1955 which established centralized national control over the production of the water from groundwater sources (Laster & Livney, 2008; Siegel, 2015; Marin et al., 2017). This law was a recognition that even before the establishment of Israel, part of the coastal aquifer had already been depleted, and saline intrusion was occurring, threatening long-term damage to the aquifer. The law regulated the drilling and installation of wells by instituting a permitting scheme, requiring that a measuring device be installed on all wells to measure all water extracted, and establishing that ownership of the land did not create a right to the water resources below its surface. An applicant for a drilling permit had to meet several requirements: (1) specify the drilling location, (2) the depth of the well, (3) the quantity of water to be drawn from the well, (4) the intended life of the well, (5) the results of any trial extractions, and (6) whether the proposed well is a replacement for an existing well or a new well (Laster & Livney, 2008; Siegel, 2015; Marin et al., 2017).

The third piece of the legislation was the Law for Drainage and Flood Prevention of 1957, which was enacted to help reduce and prevent floods due to the rapid urbanization (Laster & Livney, 2009; Siegel, 2015; Marin et al., 2017). This Law regulates flood control and drainage activities for the protection of Israel's land and surface water resources, and stipulates that surface waters, including drainage waters, may not be diverted from or to a waterway without a government permit. The Law also calls for the formation of a National Drainage Board that determines drainage policy, reviews and approves local drainage plans, and, together with regional, basin-based drainage authorities, regulates flood and drainage flows and the construction of drainage systems (Laster & Livney, 2009; Siegel, 2015; Marin et al., 2017). Historically, 12 out of the 20 members of the Board were non-governmental members representing the agricultural sector.

The fourth piece of legislation was the Water Law of 1959 which became the cornerstone of Israel's legal water framework, setting the overall principles for managing the sector and establishing the mechanisms for the allocation of water rights (Laster & Livney, 2009; Siegel, 2015; Marin et al., 2017). It was most recently amended in May 2006. Although earlier laws recognized private rights in water, this law specifies that all water resources, even on or beneath private land, were public property controlled, but not owned, by the state: the state controls, manages and allocates water resources as a trustee for the benefit of the citizens of Israel and to facilitate the development of the land

(Laster & Livney, 2009). Water became common rather than private property in Israel, there are no private or state water rights or resources, and water resource management became highly centralized. The 1957 law also facilitates the collection of data on water consumption patterns for planning of both supply and demand by water technocrats, and the right to use water is limited in time and space and according to a specific purpose. Israel's water sector may include both public and private entities, but both are subject to regulation and oversight. The law also required that the planning for supply infrastructure consider the unique character and needs of each project. After that more than half a century since being enacted, these four fundamental laws are still in place with only minor modifications, indicating their continuing relevance to water resource management in the Israeli context (Laster & Livney, 2009; Siegel, 2015; Marin et al., 2017). Nevertheless, given the neo-liberal and market-orientated turn in Israeli governance, it is highly unlikely that the type of 'paternalistic' legislation Israel passed in the 1950s would be passed today (Laster & Livney, 2009; Feitelson, 2013).

Two other pieces of legislation also require mention. The first is the Streams and Springs Authorities Law of 1965. This law regulates the creation and operation of authorities for the management of streams and springs, but it also introduced an element of decentralization of certain water resources management functions: it allowed the assignment of some functions to local authorities that are granted jurisdiction over the drainage basin of a stream or other water source. This law must be read in conjunction with the Drainage and Flood Control Law since a Drainage Board may be entrusted with the functions of a Stream Authority as well. By combining the two functions, all relevant aspects of river basin management are regulated by a single body. It should be noted that this law did not have ecology or conservation as its focus (Siegel, 2015). No river authority was created until 1988 and no drainage authority received the powers of a river authority until 2001 (Laster & Livney, 2009).

The second piece of legislation is more recent. The Municipal Water and Sewage Incorporation Law of 2001 requires local authorities and municipalities over a 10-year period to establish public ring-fenced corporations to manage local water supply and sewage services (Siegel, 2015; Marin et al., 2017). Prior to the enactment of this law the municipalities were statutorily obliged to supply water and sewerage services within their municipal boundaries. The 2001 law also signaled a first step in the transformation of the administratively managed water sector to a more commercially oriented sector by providing for the gradual transfer of water and sewerage services from the municipalities to corporate entities. The objectives of the Law include improving the operational efficiency and effectiveness of utilities, ensuring a high level of customer service, keeping tariffs affordable, and ensuring their financial sustainability to guarantee sufficient income to finance maintenance and infrastructure investments; the law was also was designed to enable private sector investments in infrastructure and involvement in operations, through public-private partnerships (PPP's) (Siegel, 2015; Marin et al., 2017).

Israel operates a Water Court or Water Tribunal as a court of first instance for matters relating to the water laws with appeals being referred to the Supreme Court (Raphaeli, 1965; Laster & Livney, 2009). It is presided over by a magistrate and two lay members. This court mainly focuses on appeals to decisions made by the respective ministries and agencies that govern water allocation and water quality; while the government seeks redress to its legal issues regarding water through the Magistrate or

District Courts (Dellapenna & Gupta, 2009). Since the increase in environmental awareness which came about in the 1990s, there have been more prosecutions for violations of water and environmental law with the new Ministry of the Environment leading the process, particularly for non-compliant local authorities (Dellapenna & Gupta, 2009).

C. Israel Water Authority (IWA)

The key reform to come out of the 2006 recommendations of the Parliamentary Investigation Committee of the Water Sector was the establishment in 2007 of a new Governmental Authority for Water and Sewerage, to be called the Israel Water Authority (IWA), to replace the previous Office of the Water Commissioner. The IWA was to be a strong, independent government agency responsible for all the elements of the water-and-wastewater value-chain to include potable water and sanitation, irrigation, water resources management. The IWA combines planning of overall water investments - that were formally the responsibility of Tahal - regulatory responsibilities – such as allocating and supervising water rights and regulating tariffs - and supervising the performance of services providers – to ensure they meet service standards for their customers and maintain financial viability (Marin et al., 2017). The IWA was designed to overcome weaknesses of the water sector and address the water crisis by reducing the number of entities involved in the management of the water sector, clarifying the division of responsibilities, and removing the political decision-making from day-to-day management of water resources and the water-and-wastewater sector (Marin et al., 2017). For the first time the entire water economy - urban and non-urban - now falls under one agency (Kislev, 2011). The IWA is headed by a Director who is nominated by the Cabinet for a period of five years.

To ensure oversight of the IWA, to ensure inter-ministerial coordination following the consolidation, and to ensure that the interests of the transferring entities are preserved, the 2006 reforms also included the formation of a Water Authority Council which is comprised of eight members: the Director of the Water Authority, who heads the council; representatives from the ministries of Agriculture and Rural Development, Environmental Protection, Interior, Infrastructure, and Finance; and two independent members who are appointed by the government - one on the recommendation of the Ministry of Infrastructure, and the other on the recommendation of the Ministries of Agriculture and Interior (Kislev, 2011; Marin et al., 2017). The Council is the body authorized to determine tariffs and levies – which were previously the responsibility of Knesset Committees, first Agriculture and later Finance - and many issues under the administration of the Water Authority are to be brought before the Council for consideration. The council is obligated to give the public a fair opportunity to air its concerns before it sets rules on tariffs and other matters, and since its formation has held public hearings on various issues. The formation of the Water Authority Council is considered the main organizational change of the reform and the element specifically designed to overcome the fragmentation in the previous water regime (Kislev, 2011).

D. Mekorot & Tahal

The National Water Authority of Israel, or Mekorot, is Israel's bulk water supplier. It is responsible for managing the country's water resources, developing new sources of water, building, operating and maintaining water facilities, granting of licenses to various sectors for the use of water, and ensuring regular delivery of wholesale water to all urban communities, industries and agricultural users. It also supplies water to Jordan and the Palestinian Authority in accordance with the peace accord. It is a corporate entity owned and controlled by the government, whose main statutory functions are to establish and manage the National Water System, also known as the National Water Carrier. Mekorót is a non-profit, public corporation founded in 1936 by the Jewish Agency and the Histadrut Labour Federation to supply water to Haifa Bay and the Yizre'el Valley. After independence the company expanded its activity to the rest of the country where it built and controls most of Israel's water infrastructure. Since 1967 it also controls all surface and underground water in the occupied territories. The Israeli government has a 33% share, with the remainder divided between the General Federation of Workers, or Histadrut, the Jewish Agency, and the Jewish National Fund - the latter two holding a controlling share (Davis, Maks & Richardson, 1980)

In addition to managing the National Water Carrier, Mekorót operates a seawater desalination plant in Eilat, on the Red Sea, and several smaller desalination plants in other places. It currently supplies 70% of the total quantity of water in Israel, and 80% of the water to urban areas, with the remainder provided through privately-owned facilities. This translates to 1,380 million cubic meters of water, of which 745 million cubic meters were supplied for irrigation, 540 million cubic meters for domestic use, 94 million cubic meters for industry and 27 million cubic meters to replenish over-pumped aquifers. The National Water Carrier system, which conveys water from the water-rich north to the areas deficient in water in the south, alone has a capacity to annually transport 400 million cubic meters of water which is produced from a blend of surface and groundwater. The National Water Carrier supplies a total of 1,000 major consumers, including 18 municipalities and 80 local authorities. Mekorót's current operations contribute about 5 billion new Israeli Shekel (NIS) a year to the Israeli economy, or about 1% of GDP, it has about 2,300 employees, it operates about 10,000 kilometers of water lines, and it owns about 4,000 wells and other installations, and 80 regional water projects across Israel, all of which are incorporated into the National Water Carrier system.

Developing and ensuring the sustainability of an infrastructure of such magnitude and strategic importance has required a financially solid operator. Mekorot has been able to maintain, so far, a healthy financial situation with total revenues of approximately US$1 billion per annum and a AAA national rating (Ma'alot Standard & Poor, 2015). As a regulated public utility owned by the state and operating as a monopoly in a strategic sector, Mekorot has been able to raise as much as NIS 6,661 million (US$1,800 million) of commercial debt through its balance sheet, with a debt gearing ratio of about 67 percent and a rate of return on equity of only 3.2 percent (Ma'alot Standard & Poor, 2015). This has allowed Mekorot to raise on average approximately US$300 million each year for investment over the last decade, at low interest rates through issuance of nonnegotiable bonds to institutional investors (without any explicit government guarantees). Also, corporatized regional utilities as well as Mekorot are now financed through commercial debt with private banks or bonds issuances, without sovereign guarantees.

For many decades Mekorót's accounting and financing operated like the traditional public-sector entity: government financed its investments, the tariff that it charged were set by Knesset committees, and budgetary shortfalls were covered by the

Ministry of Finance (Kislev, 2011). This financing arrangement proved problematic: investment in the water system was dependent on the national budget and not on the needs of the water economy, much energy and resources were expended in lobbying the Ministry of Finance rather than in improving efficiency and productivity, Mekorót had the incentive to accumulate reserves to protect itself rather than support investments, its financial statements did not always reflect all its activities, and its financial practices were not transparent (Kislev, 2011). To address these deficiencies a new regime for financial management, cost recovery and organizational restructuring was developed in 1993 but not signed until 2002. Financial management and cost recovery are now done in accordance with rules laid down by the Council of the Water Authority (Kislev, 2011). Mekorot tariffs are now set annually by the IWA based on five-year business plans, which incorporate performance targets to foster incentives for efficient operations, tariffs reflect the price of the actual costs of production and bulk transportation of water, and tariffs must fully reflect capital expenditures and private financing costs (Marin et al., 2017). Mekorot was therefore strongly impacted by the reforms of 2006: it went from being a government-owned monopoly operating in a cost-plus environment to becoming a regulated public-sector monopoly, still owned by the government but operating completely as a commercial entity.

Seventy years of addressing significant engineering, environmental and security challenges, and the employment of continual research and experimentation, have made Mekorot one of the most innovative and technologically advanced water companies in the world, and a leader in water project engineering, desalination, water reclamation, water safety and water quality (Kislev, 2011; Marin et al., 2017). Mekorot's mandate as an integrated national water utility provides it a unique combination of experience and know-how with innovative technologies and processes for the management, operation and treatment of all types of water resources, whether its source is derived from surface, underground, brackish, seawater or effluents (Kislev, 2011; Siegel, 2015; Marin et al., 2017). Mekorot has increasingly leveraged this experience and know-how in the global water economy, its international business has generated several hundred million dollars of water technology export business, and it has built and is operating plants in Cyprus and Argentina (Rabinovitch, 2012). Beyond the economic benefit to Israel of Mekorot's growing global presence are the diplomatic benefits from economic and technological engagement with other countries, including its Arab neighbors in the region (Rabinovitch, 2012; Siegel, 2015)

The Water-Planning for Israel Company, or Tahal, was founded in 1952 a non-profit government corporation with ownership divided between the Israeli government at 52%, and the Jewish Agency and the Jewish National Fund at 24% each. Tahal was Israel's water planning authority charged with providing the government with research and consumption forecasting, planning services for the Water Commission, and engineering advisory services for water projects being constructed by Mekorot. At its height in the 1970s it employed 1,000 persons (Kislev, 2011). Upon completion of the large projects in the National Carrier system in the 1960s, Tahal began working abroad and became a large international firm. Also, as the number of independent hydro-engineers increased, the Water Commission increasingly gave work to experts outside Tahal. At the end of the 1980s the Water Commission opened its own planning division, which has since leaned heavily on these outside experts. Tahal lost its monopoly and in

1996 it was privatized when the state sold its shares in Tahal. Tahal remains the largest and more experienced water planning company in Israel and it currently employs about 500 professionals and is engaged in dozens of projects in Israel and abroad, many of them as a partner (Menahem, 1998; Kislev, 2011).

E. Municipal Water Corporations

The municipal water and sewerage departments of Israel's local governments were historically responsible for providing water-and-wastewater services to urban communities. Although Israeli's generally received a reliable and affordable supply of potable water, the performance of these municipal utilities was considered disappointing: politically motivated financial management led to poor operational and investment decisions, and tariffs were sometimes used to pay general expenses (Kislev, 2002, 2011; Laster & Livney, 2009; Marin et al., 2017). Despite years of pressure from the Ministry of Finance these utilities did not improve performance and infrastructure began to decay (Kislev, 2011). The performance of water-and-wastewater utilities depend heavily on the level and timing of expenditure on maintenance and upgrading of infrastructure, and municipalities often failed to make these expenditures (Kislev, 2002).

Beginning with the enactment of the Municipal Water and Sewage Incorporation Law of 2001, the government began a decade long process to implement an ambitious program of reform of municipal water and sanitation services (Kislev, 2011; Marin et al., 2017). The 2001 law, approved under the auspices of the Ministry of Interior, directs local governments to establish public ring-fenced municipal water corporations to manage local water supply and sewerage services. Municipal water and sanitation utilities can be owned and operated by local municipalities, private companies, or public-private partnerships, but Mekorot is excluded from entering this market (Kislev, 2002). These utilities are regulated under licenses granted by the IWA, and they have been gradually transformed into utilities run along corporate lines. A 2004 amendment to the law made the formation of these corporations obligatory.

Today about 56 Municipal Water Corporations provide services to 187 of Israel's 210 municipalities and local councils serving a combined population of over five million (Kislev, 2002, 2011; Marin et al., 2017). The process of reform has been slow, there have been teething problems as the agents in this new institutional regime move along an inevitable learning curve, and the Superintendent of the Corporations is trying to reduce the number of utilities to produce a less fragmented and more efficient system (Kislev, 2002, 2011; Marin et al., 2017)

The existence of municipal water and sewerage departments, and now municipal water corporations, meant that Israel actually had two interdependent yet separately administered water economies: one was the national system containing the water sources and their reservoirs, the National Water Carrier and the national water supply system, the desalination plants, and the effluent recycling systems; the other was the urban water sector containing intra-urban water supply, sewage removal, and the treatment facilities (Kislev, 2011). The two water economies have separate issues as problems they deal with differ: the national water economy deals with questions of sustainable resource management, the development of water supply utilities for distribution and recycling, and desalination; the urban water economy deals narrowly with water distribution and sewage collection in each urban center or cluster; and in terms of administrative scale, the two water economies are fundamentally separate (Kislev, 2011). The creation of the IWA should help to overcome this history of fragmentation and improve coordination.

The independent Municipal Water Corporations have so far performed better than their politically run predecessors (Laster & Livney, 2009; Siegel, 2015). The new incentive structure created by the IWA has led to increased investment in facilities, greater willingness to employ cutting edge technologies, and evidence of an increase in entrepreneurship and innovation - unlike the traditional governance structure for utilities which encourage risk-averse behavior (Siegel, 2015; Marin et al., 2017). Between 2006 and 2015 these newly constituted utilities have been able to reduce unaccounted-for-water from an average of 16% to less than 5% of water produced. The utilities now work more closely with water technology companies to employ the latest technologies to save energy, reduce leaks, and maintain water quality, a practice reinforced by the 70% subsidy they receive for the employment of new water technologies; and cash flows have improved because municipalities, who rarely paid for the water under the old regime when politicians controlled the utilities, now pay like all other customers (Siegel, 2015). To oversee these new utilities, two regulatory agencies were formed that were later assimilated into the IWA: the Public Utilities Authority (PUA) for Water and Sewage, which would be responsible for the quality of the services and the tariffs; and the Superintendent of the Corporations, whose job it was to license these companies, to monitor the agreements between them and the local governments they served, and to approve their development plans (Kislev, 2011).

F. Municipal Utilities Association

Regulatory supervision of the provision of potable water and sanitation services by municipalities is the responsibility of the Municipal Utilities Association (MUA).

After passage of the Municipal Water and Sewage Incorporation Law of 2001, initial progress in establishing the newly constituted utilities was slow, but the pace of reform improved in 2009 when the MUA was transferred from the Ministry of Interior to the IWA. Since it was transferred to the IWA, the MUA has taken a proactive role in helping these utilities improve their governance and overall operational performance and to encourage them to become incubators for technological innovation. The MUA has created a framework of actions which combines financial incentives and technical guidance with strong supervision of utilities including performance targets and sanctions enforcement.

A major reform relates to tariffs and financing and the MUA uses the tariff-setting process as a regulatory tool by establishing the portion of the national water tariff that each utility can keep (Marin et al., 2017). Tariff revenues have become the sole source of financing for each utility which allowed the MUA to introduce financial incentives for operational performance. Any efficiency gains achieved by the utility's management are automatically translated into the utility's bottom line, which the regulator allows to be transferred from the utility to the municipal budget—providing obvious financial incentives for local governments and mayors to support the performance improvement of their respective utilities (Marin et al., 2017). The MUA also approved a steep rise in tariff levels in 2009 because of the application of the principle of full-cost recovery. In conjunction with this move towards financial independence, almost all investment is now funded through commercial debt financing (Marin et al., 2017). In theory this should ensure that investments are financially viable. Significant improvements have been achieved in bill collections, in network maintenance, and in reducing non-revenue water levels; and many water utilities are now generating a small operating profit (Kislev, 2011; Marin et al., 2017).

Another important strategy of the MUA is to reduce political interference in staffing, make the hiring of staff more demanding than those of local authorities, and to ensure that salaries are competitive to attract competent people (Marin et al., 2017). Historically many local utilities, especially small utilities, lacked technical capacity. Managerial positions must now meet specific requirements set at the national level with respect to professional credentials and undergo periodic reviews by a dedicated appointment committee at the national level. The MUA has also been regularly issuing technical guidance and detailed standards on operational issues as well as employing bench-marking, which are key to improving the efficiency of these utilities (Marin et al., 2017). The MUA has developed a long list of key performance indicators relating to a wide range of operational efficiency and customer relations matters. The MUA regularly audits each water utility and has started to make public the results, grading individual utilities along a scale (excellent, very good, good, requires significant improvement, fail). Finally, the MUA has not shied away from its supervisory role, which includes imposing sanctions and enforcing them, whenever necessary. Some of the technical guidelines and key performance indicator targets are mandatory, and not achieving them can lead to sanctions.

G. Public-private Partnerships

The private sector in Israel has long played a role in the water economy. In terms of the public utility sub-sector these relationships have come to play an increasingly important role in recent years, especially since the neo-liberal turn in Israeli policy and governance in the 1980s and the push to expand desalination and reform municipal water-and-wastewater services in the 2000s. Partnerships contracts with Israel's private sector is an important feature of the Israel’s corporate-style reforms of water utilities and are seen as a tool to improve operational performance, reduce costs, raise private funding for infrastructure investment, ensure the financial sustainability of major infrastructure, and increase access to expertise in an increasingly complex water economy which employs increasingly complex technologies (Marin et al., 2017). Subcontracting arrangements are in place for a wide variety of operational tasks.

Although Merkorot has long been involved in desalination projects, and has long operated several smaller plants, the seawater desalination program of the 2000s has been largely implemented through Build-Own-Transfer (BOT) or Build-Own-Operate (BOO) schemes in which private concessionaires entirely finance the investments and are responsible for operation and maintenance for these facilities for 25 years (Marin et al., 2017). The amount of private investment raised under the first four desalination BOT-BOO projects with private concessionaires (Ashkelon, Palmachim, Hadera and Sorek) totaled of about US$1,300 million (Marin et al., 2017). One example of an innovative PPP is the 2016 independent power production (IPP) contract put in place for biogas production at the wastewater treatment plant of Kfar Saba- Hod Hasharon, a town of 160,0000 in the center of Israel. The biogas produced by the anaerobic digestion process provides about 80 percent of the electricity needed by the plant, saving about 20 percent of the overall energy costs of that facility (Marin et al., 2017).

H. Pricing & Cost-recovery

Under the direction of the IWA a new financial and governance framework has been gradually instituted to place the Israeli water economy on a course toward financial viability, and to improve the efficiency with which water-and-wastewater services are provided (Kislev, 2002, 2011; Marin et al., 2017). All the utilities providing water-and-wastewater services will be corporatized: Mekorot has been transformed into a regulated public company, and municipal water and sanitation services have been gradually transformed into corporate-style regional utilities. Two key principles of the reforms are full-cost recovery through tariffs, which is the price assigned to water supplied by a public utility, for the entire water value chain; and performance managements backs by both incentives and penalties. Water tariffs have been gradually increased for all users to approach full-cost recovery and direct budget subsidies to the sector have gradually been phased out - although there remains significant cross-subsidies between water uses and the central government has invested heavily in recent years in sewage systems (Kislev, 2002, 2011; Marin et al., 2017). A uniform tariff level and structure has been instituted for the country, with all potable water and sanitation customers paying the same price. The uniform tariff is the basis for cross-subsidies between consumers as those who live farther away require additional pumping which raises costs (Marin et al., 2017). The reforms indicate the shift in power to those who advocated market-orientated practices as well as the strong political will to implement the reform (Laster & Livney, 2009; Feitelson, 2013 Marin et al., 2017). The reforms led to improvements in efficiency by the regional utilities in the period between 2009 and 2013 and this allowed the IWA to start reducing the tariff levels in 2014, gradually passing back part of the savings to consumers (Marin et al., 2017).

In 2017 the uniform average tariff for potable water and sanitation for the urban sector was NIS8.92 (US$2.4) per cubic meter. The national tariff for potable water and sanitation services is based on a two-tier increasing- block structure designed to support demand management through conservation, while still ensuring that people have access to a minimum consumption volume at an affordable price (Marin et al., 2017). The tariff for the first block, corresponding to consumption up to 3.5 cubic meter per capita per month, or 115 liters per capita per day, is NIS6.56 (US$1.8) per cubic meter; while the tariff for the second consumption block is NIS10.56 (US$2.85) per cubic meter. Approximately 75 percent of residential consumption is billed at the lower tariff. The tariff is allocated among services providers with 44% going to the water utilities for water distribution and sewage collection, 22% going to Mekorot for bulk water transport and freshwater production, 18% percent going to cover sewage treatment costs, 16% going to cover desalination costs, and 4.5% going to subsidies.

The tariff structure for irrigation is different from water and sanitation services but it is also moving toward full-cost recovery (Marin et al., 2017). The price for irrigation water in Israel is among the highest in the world, but this supports more efficient water practices and promotes the production of higher value crops. Tariffs for irrigation water vary widely depending on the source of the water, the region, and the time of the year; while extraction levies vary with the site and season during which the water is withdrawn (Marin et al., 2017). Freshwater prices range between NIS0.8 (US$0.22) and NIS2.6 (US$0.70) per cubic meter; brackish water prices range between NIS0.9 (US$0.24) to NIS1.6 (US$0.43) per cubic meter; and treated waste-water prices range between NIS0.8 (US$0.22) to NIS1.25 (US$0.34) per cubic meter, which is highly subsidized to encourage farmers to use it.

As of 2017 the Israeli water sector has achieved almost full financial autonomy - except for wastewater reuse and desalination - almost all the costs of investing and operating water infrastructure are now covered by users through tariffs; and Israel is theoretically able to meet all future demand from multiple users (Marin et al., 2017). The ability of the water sector to move toward self-financing is a remarkable achievement given the fact that Israel's water scarcity and its topography makes water particularly expensive to produce and deliver to users (Rapheli, 1965; Marin et al., 2017). The establishment of a single, independent regulator for all water-and-wastewater services capable of overseeing the water economy in an integrated and holistic manners has been important in achieving what for decades the previous governance regime failed to achieve.

Although tariffs designed to ensure full-cost recovery have been effective in moving water utilities towards financial sustainability, the effectiveness in practice of price as a tool of demand management is less certain (Kislev, 2002, 2011). In the urban sector the historical record shows a large overall increase in water use by urban consumers, of about 0.6% per year, but the increase in water consumption was far less than the increase in disposable income (Kisvel, 2011). In the agricultural sector the historical record in Israel shows a large overall decline in water use (Kisvel, 2011). In the industrial sector the per capita increase in water use in industry remained flat because of greater efficiency in water use (Kisvel, 2011). The increases in urban water use are far more closely correlated with increases in industrial output and population, with per capita water consumption remaining relatively flat, despite an almost three-fold increase in the consumption of goods and services by Israeli consumers (Kislev, 2011). Most economic analyses suggest that urban demand for water is highly inelastic, and thus not responsive to price regulation. The evidence challenges the use of price as the sole means to achieve sustainability and suggests the need to also consider public education and the availability of water efficiency technologies (Tal, 2006; Kislev, 2011; Siegel, 2015). Pricing seems to be a more powerful and relevant tool when it is employed to ensure the financial sustainability of water-and-wastewater utilities through full-cost recovery.

H. Reflections on the Governance of Israel's Water Economy

Marin et al (2017) have identified several lessons that can be drawn from Israel's experiences in the process of developing a sustainable water economy that may be relevant to other water-scarce countries.

1. It is important that there is public awareness about the scarcity of water, and a national consensus around its social and economic value which should be aligned with the need for sustainable water resource management (Rouyer, 1996; Menahem, 1998; Marin et al, 2017). The national consensus around sustainable water management should be reinforced by pricing water at its actual cost (Marin et al, 2017), but any subsidies should be explicit, transparent, and economically justifiable (Kisvel, 2002 & 2011; Laster & Livney, 2009; Feitelson, 2013).
2. The governance of water-and-wastewater utilities and infrastructure should also achieve financial sustainability as efficient and effective utilities require regular maintenance, upgrades, and expansions; and this should be achieved through tariffs that achieve full-cost recover (Kislev, 2002; Marin et al., 2017).

3. All water-and-wastewater projects should go through rigorous project appraisals; and only projects that show a positive net present value and positive internal rate of return should be able to access project financing, preferably from private investors and without a sovereign guarantee.
4. In the event of extreme water scarcity, strong control and enforcement of water allocations may be necessary to complement pricing incentives (Marin et al., 2017); however, the governance framework must be structured to prevent its control by narrow sectoral interests as occurred in Israel through its agricultural lobby (Menahem, 1998; Laster & Livney, 2009; Feitelson, 2013).
5. Sustainable and integrated management of the entire water cycle requires the comprehensive and timely collection of data, and the technical capacity to use that data to create models, forecasts, and performance targets (Marin et al., 2017). This level of sophistication in data management requires the creation of an appropriate legal, institutional, and technical framework (Laster & Livney, 2008; Siegel, 2015).
6. In the context of extreme water scarcity, especially in a geographically small country, a centralized and integrated water carrier may be more efficient and effective in managing the entire water cycle than a decentralized water carrier (Siegel, 2015; Marin et al., 2017). The governance framework of centralized institutions must, however, be structured to prevent its control by narrow sectoral interests (Menahem, 1998; Laster & Livney, 2009; Feitelson, 2013).

7. The private sector should be brought in to carry out specific functions outside the sphere of competence of the public sector, to help contain costs, increase access to financing, and spread or reduce project risk (Siegel, 2015; Marin et al., 2017). Israel’s water sector has had considerable success with PPPs that have helped to stimulate a globally competitive water technology industry (Rabinovitch, 2012; Siegel, 2015).
8. There should be a clear division of labor and responsibility between the political, policy, regulatory, and operational management functions that serve the water economy; and there must be mechanisms for transparency and accountability (Menahem, 1998; Laster & Livney, 2009; Feitelson, 2013; Siegel, 2015; Marin et al., 2017). In the specific case of Israel this seems to have been achieved through the recent establishment of the IWA (Marin et al., 2017).
9. Finally, reforms in the water economy are a long, difficult, and continuous process which requires careful planning and implementation, strong and sustained political will, a mix of incentives and penalties, and a minimum degree of consensus among key stakeholders (Menahem, 1998; Laster & Livney, 2009; Kislev, 2011; Feitelson, 2013; Marin et al., 2017).

V. National Water Strategy

A. Overview

Israel's national water strategy has gone through several iterations between 1948 and 2010 where each iteration has seen a dominant focus: the expansion of supply from natural sources, the management of existing resources, management of water quality, the expansion of supply from unconventional sources, and demand management to achieve sustainability. Prior to 1964 the water strategy was to primarily source supply locally; after 1964 the primary strategy became to source water nationally. The national water strategy has included several innovative principal national investments designed to either increase water supply or increase the efficiency in use of existing supplies. The first was the integrated management of the Sea of Galilee and the groundwater aquifers, which feed into an integrated national water grid increasing water supply; the second was wastewater treatment and reuse for irrigation; and the third was desalination of seawater and brackish groundwater; while a parallel strategy of water harvesting and waste-water storage via a network of reservoirs represents a more recent local level strategy (Tal, 2006).

The discussion of strategy might seem to suggest that Israel had a coherent water strategy which policy makers and planners rolled out over time – this was not the case as many of the water plans produced by technocrats were largely ignored until crisis forced political action (Menahem, 1998; Kislev, 2011). Over the years hundreds of plans for water projects of all scales were drafted; four Water Master Plans were prepared in the three decades up to 2010; and although the effort invested in these plans enriched the knowledge and understanding of the water professional, they generated little interest from their intended political audience (Kislev, 2011). The 1988 Water Master Plan recommended a reduction in water to the agriculture sector, but this was successfully challenged by agricultural interests both inside and outside government; while the 1997 Water Master Plan recommended the reopening of consideration for desalination, but this was dismissed by the incoming Water Commissioner in favor of the continued exploitation of natural sources (Kislev, 2011). In 2002, in the wake of the water crises, the Director of the Water Authority presented a Water Master Plan which represented a return to long-term water planning. The 2002 strategy recommended developing a water supply that was independent of rainfall, climate resilient, and environmentally responsible; that significantly reduced the allocation of water to agriculture by encouraging greater water efficiency in that sector; and that eventually requires the agriculture sector is to pay the same rates for water as domestic and industrial users (Laster & Livney, 2009; Kislev, 2011; Marin et al., 2017). The latest Water Master Plan, published in 2012 by the Water Authority, outlines a strategy to ensure water availability until 2050; which assumes a rise in annual water demand from 2,131 million cubic meters in 2010 to 3,571 million cubic meters in 2050; a drop in natural water availability of 10-15% due to climate change; and a compensatory increase in the production of alternative water sources such as desalination and treated wastewater (Water Commission, 2012). The latest plan calls for major investments and adjustments in policy and practice, and concerns have been raised of the political will to implement these recommendations (Kislev, 2011).

B. National Water Carrier.

Israel has three main natural water sources: the Sea of Galilee (Lake Kinneret), the Mountain Aquifer and the Coastal Aquifer. Although their relative importance has declined in the last two decades with the rise of reclaimed water and desalination they remain an important part of Israel's water economy with a legacy that will last for generations (Tal, 2006; Cohen 2008; Kislev, 2011; Marin et al., 2017). These sources were incorporated into Israel's water economy through an integrated water conveyance system - the National Water Carrier - which opened in 1964; and the water is allocated primarily through an administrative process to various sectors by the Water Authority (Kislev, 2011). This complex system of aqueducts, tunnels, reservoirs and large pumping stations transports large amounts of water from one region to another – initially from the relatively wet northern Galilee to depleted central aquifers and to the arid south; but recently from the South to the North as the addition of desalination has realigned Israel's water portfolio (Tal, 2006; Dreizin, Tenne & Hoffman, 2008; Cohen 2008; Marin et al., 2017). It is the main water project of Israel, and to date its largest civil engineering project, and its construction involved considerable technical challenges as it traversed a wide variety of topographical and geologic conditions (Cohen, 2008; Siegel, 2015). The system and it consists of giant pipes, open canals, tunnels, and reservoirs, and large-scale pumping stations. The original goal of the National Water Carrier was to provide irrigation water to Negev. Although the Carrier provided 80% of Israel's water, 80% of that water was utilized for irrigation and the remainder for domestic consumption; however, today this ratio is reversed as the use of reclaimed water and more efficient irrigation technologies have changed the country's pattern of water demand (Tal, 2002, 2006, 2007; Kislev, 2002, 2011).

Most of the water infrastructure in Israel is integrated into the National Water Carrier and the main components of this network extend for about 130 km from the Sea of Galilee to the edge of the Negev desert. The Sea of Galilee system feeds into a 168 square km lake which contains 4 billion cubic meters of water from which is annually pumped approximately 500 million cubic meters out of Israel's annual demand of 2 billion cubic meters (Tal, 2006; Cohen 2008). The Sea of Galilee lies below sea level, and the point from which the water is pumped lies approximately 209 meters below the sea. From this depth the water is pumped to a point 44 meters above sea level where it flows by force of gravity through a canal carved into the rock (Cohen, 2008). Sea of Galilee is Israel's largest source of potable water; however, to satisfy the increasing demand water from the neighboring aquifers was added to this reservoir (Tal, 2006; Cohen 2008). The integrated nature of the National Water Carrier means that about 95% of the country's proven reserves are controlled by one water network (Davis, Maks & Richardson, 1980). While this centralized and integrated organizational arrangement might increase operational efficiency from economies of scale, it also presents several risks to Israel's water system.

The National Water Carrier has come under criticism from several directions, including for its negative environmental consequences (Davis, Maks & Richardson, 1980; Tal, 2006). Water from the Sea of Galilee is relatively salty, transporting an estimated 170,000 metric tons of chlorides to the soils and groundwater in the center of the country; it also has high levels of turbidity which raises the suspended solid levels in the water supply leading to aesthetic and health concerns; and the diversion of water to the National Carrier has reduced the amount of water which flows through the lower Jordan and into the Dead Sea which is drying up (Tal, 2006; Cohen 2008). To address the sediment and pH issues a long delayed new system of sand filtration and treatment for the reservoirs of the National Water Carrier finally began operation in 2006: this is supposed to reduce the corrosive characteristics of the water and minimizing chemical reactions with other water sources (Tal, 2006). There are also plans for an expensive project to bring water from the Red Sea to recharge the Dead Sea while generating hydro-electric for Israel, Jordan and the Palestine Authority.

One of the most remarkable innovations of Israel water resource management is the use of aquifers as storage reservoirs for the national water system (Marin et al., 2017). Through the National Water Carrier, Mekorot uses the storage capacity of the Sea of Galilee and the Coastal and Western Mountain aquifers to provide the base load to meet the country's water needs. These three sources, however, became over-exploited and were no longer being naturally replenished by rainfall (Tal, 2006). With the advent of desalination and the reclaiming of most urban waste-water, these aquifers can now be recharged and used as storage reservoirs. Where the integrated nature of the National Water Carrier facilitated over-exploitation of the aquifers, this integrated capacity now allows Mekorot to integrate and optimize the various sources of natural and unconventional water to ensure that water is stored underground to provide a buffer in the event of any future shortfall. Aquifers are more secure than surface reservoirs and less water is lost to evaporation, and they can be used to provide natural filtration for water of marginal quality (Siegel, 2015; Marin et al., 2017).

C. Wastewater & Irrigation.

In regions of the world with abundant water resources, where long retention times enable the degradation of some pollutants, moderate amounts of pollution can be absorbed by nature and naturally treated as it moves through the water cycle. In an arid country like Israel, which suffers from a shortage of water, where water resources are exploited to their maximum capacity, where retention times are short, and where there are few large bodies to dilute pollutants, waste-water treatment becomes very important for protecting environmental health and water quality (Friedler, 2000). These negatives of waste-water in arid regions must be balanced against some potential positives: waste-water is a reliable source of potentially usable water as it tends to be produced at a relatively constant rate throughout the year, and it is almost constant between years with the tendency to increase with an expansion in population and economic output, which has been the case in Israel (Friedler, 2000). Wastewater recycling and reuse practice therefore becomes critical for maintaining or enhancing the quality of conventional water resources; and the challenge for water resource managers is to ensure that treated waste-water meets quality and safety requirements for use in agriculture and for environmental and ecological purposes (Tal, 2006; Friedler, 2000).

Although many Israeli communities build waste-water treatment facilities in the 1950s and 1960s they were not well supervised, and sometimes poorly managed, they rarely went beyond primary treatment, there was no universal coverage, and many communities dumped waste-water into streams and gullies (Kislev, 2011; Marin et al., 2017). This state of waste-water mismanagement led to a series of publicly embarrassing events. In the 1970s and 1980s bathing beaches along the Mediterranean, used by both locals and tourists, had to be closed because sewerage pumped out to sea washed up back on shore (Kislev, 2011). In 1970 there was an outbreak of cholera, and in 1988 an outbreak of polio, and both were attributed to contaminated water (Kislev, 2011). In 1997 several athletes attending the international Macabiah Games died from exposure to toxic pollutants after falling into the Yarkon River when the bridge they were crossing collapsed (Siegel, 2015). The first water crisis that occurred in 1985 also became a major driver for an expansion in recycling and reuse of waste-water (Kislev, 2011; Marin et al., 2017).

Israel is today one of the few countries in the world that has managed to almost entirely close the urban water cycle. In the 1960s, Israel recycled less than 10% of its waste-water, or about 130 million cubic meters, and most of the water supplied to the agriculture sector was of drinking water quality, compared to 2015 when 500 million cubic meters were recycled (Kislev, 2011; Marin et al., 2017). Israel presently recycles about 90%, and reuses almost 87%, of the total domestic sewage production of the country: which is far ahead of most other countries, such as Spain which recycles about 12%, and the United States which recycles only about 2.5% of its total domestic sewage production (Tal, 2006; Marin et al., 2017). Israel is served by about 67 large, modern waste-water treatment facilities and the use of reclaimed water now constitutes about one-fifth of the country's total water supply (Tal, 2006; Kislev, 2011; Marin et al., 2017). Reclaiming urban water is an important strategy for expanding supply in regions with limited water resources and where increasing urban water demand is usually met by reducing water supply for irrigation, which causes social and economic hardship in the rural sector (Friedler, 2000). Reclaimed water is capable of being used as a substitute for conventional potable water which is sometimes used for irrigation, or for other purposes that do not require water of drinking quality, while releasing some of the pressure on the conventional water resources (Friedler, 2000). Reclaimed waste-water helps Israel close a negative water balance in a country where all the conventional water resources are exploited to their maximum capacity (Friedler, 2000).

Agriculture has been important to Israel's economic development, but it has historically made heavy demands on Israel's limited water resources. This has changed with the increased use of reclaimed and other marginal water which accelerated in the mid-1980s. In the 1960s agriculture used about 80% of Israel's available water production, while agriculture today uses about 50% of Israel’s available water. Agriculture's demands on freshwater is smaller now because of the increased use of reclaimed wastewater which supplies more than 40% of the country’s irrigation needs (Kislev, 2011; Marin et al., 2017). In the early 1960s waste-water diverted to agriculture constituted only 4% of the quantity of water used in the urban sector; today the proportion of waste-water diverted is about 55%. What this means is that over the past 40 years the volume of water demanded by the agricultural sector has not grown significantly, although agricultural output has grown several-folds due to more efficient or intensive use of water, pesticides, and fertilizers (Kislev, 2011). This level of agricultural productivity in an arid or semi-arid country like Israel with a growing population and expanding non-agricultural economy would not be possible without the increasing use of reclaimed water.

Desalination. Israel considered adding desalinated seawater to their water resource portfolio as early as the 1960s, but major investments in this source were not pursued at that time because it was not technically and economically feasible (Kislev, 2011; Siegel, 2015; Marin et al., 2017). Mekorot, however, established the first seawater desalination facility in 1965 to address the chronic water shortages facing the city of Eilat, a resort town located at the extreme southern tip of Israel on the Red Sea (Spiritos & Lipchin, 2013). The technology Mekorot employed at Eilat was vaporization technology which is a highly energy-intensive process, and Mekorot began the search for an alternative, energy-saving process which it eventually found in reverse osmosis. In the early 1970s Mekorot began installing small-scale brackish water reverse osmosis-desalination plants, for small isolated southern agricultural communities not served by the National Carrier (Kislev, 2002, 2011; Garb, 2010; Spiritos & Lipchin, 2013). About 39 of these brackish water desalination plants are in operation.

It was not until the water crises of the 1980s and 1990s when desalination technology had advanced to the point of being technically and economically feasible, and a consensus was reached that Israel that faced structural water scarcity, that the government found the political will to add significant seawater desalination capacity to the country's water portfolio (Kislev, 2011; Siegel, 2015; Marin et al., 2017). A Master Plan was prepared in 1997 to chart the integration of large-scale seawater desalination plants within the existing national water supply system at minimal additional cost (Tenne, Hoffman & Levi, 2013). The aim was to add enough capacity in next two decades to ensure that most of the water supply for municipal consumption would come from desalinated water, to ensure the country’s water security and to allow the natural water reserves in the aquifers to be restored (Kislev, 2011; Marin et al., 2017). This decision to make the substantial investment in new infrastructure became politically and economically feasible because of the simultaneous discovery offshore of large reserves of natural gas which for the first time provided Israel with a domestic energy supply (Siegel, 2015; Marin et al., 2017). Since 2005 Israel has built five large desalination plants along the Mediterranean Coast based on seawater reverse osmosis with a total capacity of 585 million cubic meter per year, or about 85% of domestic urban water consumption and 40% of the country’s total water consumption (Kislev, 2011; Siegel, 2015; Marin et al., 2017). The long-term goal for seawater desalination is to increase total annual production to 1.75 billion cubic meters (BCM/year) by 2040 (Tenne, 2010).

Four of the five seawater desalination facilities were developed through PPPs with private concessionaires under build-operate-transfer (BOT) and build-operate-own (BOO) contracts; while the fifth was built by Mekorot. In 2000 a tender was issued for building the first desalination plant in Ashkelon, south of Tel Aviv. In 2001 the VID Desalination Company consortium received rights to build and operate for 25 years a 100 million cubic meters per year facility (Kislev, 2011; Siegel, 2015; Marin et al., 2017). Construction began in 2002 on the $250 million plant which became operational in August 2005, providing approximately 15% of the Israel's needs. At the time of its opening, the Ashkelon facility was the largest reverse-osmosis seawater desalination plant in the world. The Palmachim facility was opened in 2007, it is operated by Derech HaYam, and it has capacity of 90 million cubic meters; the Hadera facility was opened in 2010 it is operated by IDE and Shikun U'Binui, and it has capacity of 127 million cubic meters; the Sorek facility was opened in 2013, it is operated by 25 years IDE and Veolia, and it has capacity of 127 million cubic meters; and the Ashdod facility was opened in 2016, it is owned and operated by Mekorot, and it has a capacity of 100 million cubic meters per year (Marin et al., 2017). Mekorot's Ashod facility has, however, been plagued by delays, technical problems and cost overruns (Kislev, 2011; Marin et al., 2017).

Ashkelon, the first facility, has the highest cost of production at US$0.78 per cublic meter, while Sorek, the fourth and largest facility, has the lowest cost of production at US$0.54 per cublic meter (Marin et al., 2017). The relatively low cost of Israel's desalinated water has been key to ensuring the financial viability of the whole system so that desalinated water remains affordable for customers despite applying full cost recovery through tariffs (Garb, 2010; Spiritos & Lipchin, 2013; Marin et al., 2017). The low cost structure has been achieved through a combination of factors: financial risk was kept low by the scale and operational mode of the new desalination plants, and by the PPP contracts, which allowed the private sector operators to secure large amounts of private financing on the best possible terms; Israeli desalination plants operate on a 24/7 basis which makes it possible to achieve significant economies of scale and absorb large fixed costs, compared to most other countries which use desalination for peak-load demand only; the presence of an integrated National Water Carrier allows the number, size and location of the facilities to be tailored to achieve economies of scale in production and a lower costs for distribution; and the use of Israeli natural gas means that the plants have a relatively clean, reliable, locally available supply of relatively low-cost energy (Garb, 2010; Spiritos & Lipchin, 2013; Marin et al., 2017). Energy costs, typically represents about half to two-thirds of the price of desalinated seawater (Tenne, 2010). Brackish water desalination is typically about half the cost of seawater desalination and this is produced at roughly $0.30 per cublic meter (Tal, 2006); and plans are to increase annual production of water from brackish water from roughly 30 million cubic meters to 90 million cubic meters by 2020 (Tenne, 2010).

The addition of seawater desalination to Israel's water portfolio brings many wider costs and benefits. There are social, environmental and health considerations: there are concerns about seawater desalination facilities creating a loss of public coastal open spaces; there are concerns about the long-term cumulative impact of concentrated brine discharges into a limited area of the sea; there are concerns about the additional greenhouse gases from the higher energy requirements of desalination; and there are concerns that desalination is too effective at removing minerals from water, some of which are needed and have to later be added back (Tal, 2006; Tenne, 2010; Garb, 2010). On the other hand there are benefits to the national economy as a whole, to domestic and industrial consumers of water, and to the environment: water produced from desalination is softer than most other water sources, and this reduces wear and tear on any equipment that uses water; and the low lower concentrations of chloride and sodium in water from desalination will have a lower environmental impact when it is used for agriculture and recharging aquifers (Tenne, 2010; Garb, 2010; Tenne, Hoffman & Levi, 2013).

The Israeli experience with desalination is being closely watched around the world for its technological attributes that have achieved high levels of energy efficiency and low operating costs; as well as for its sophisticated fiscal and institutional arrangements of private sector involvement (Garb, 2010; Marin et al., 2017). The addition of desalination to Israel's water portfolio was an exercise in managing complexity and required the ordination of numerous policy-based, technological, engineering, architectural, economic, social, and managerial factors before Israel could claim to have some of the world's most energy-efficient and cost-efficient in the world large-scale desalination facilities (Tenne, 2010; Marin et al., 2017).

D. Stabilization Reservoirs.

Israel has aggressively developed an extensive network of more than 200 small-scale reservoirs that annually collects about 260 million cubic meters of surface runoff and partially treated sewerage water which today provides about half of the water consumed by Israeli agriculture (Shelef, Juanico & Vikinsky, 1987; Friedler, 2001; Tal, 2006). At first the reservoirs were constructed to dam and impound floodwaters, with the primary objective of replenishing groundwater, but this source varies considerably between years. Most of the more recently constructed reservoirs are stabilization reservoirs constructed to hold the increasing volume of treated waste-water which is collected year-round for agricultural use during the summer and autumn dry seasons (Tal, 2006; Marin et al., 2017). Stabilization ponds have been used in Israel for decades, but it was not until the 1970s that their construction began on a large scale (Shelef, Juanico & Vikinsky, 1987). Reforestation is also an important part of capturing floodwaters and Israel has increased tree cover from 2% in 1948 to 8% of its land area in 2014 (Marin et al., 2017). The major force behind this water and reforestation initiative is the Jewish National Fund (JNF) which is responsible for the construction of most of these reservoirs since the 1980s, and they considerable expand the water resources of some of Israel's most arid regions (Tal, 2006).

When stabilization ponds were initially introduced they were conceived exclusively as storage reservoirs; however, with concerns about water quality growing in the 1970s and 1980s, their capacity to treat wastewater soon became evident (Shelef, Juanico & Vikinsky, 1987; Tal, 2006). Stabilization ponds use solar energy, which is abundant in Israel, and they cost far less to operate than mechanical or chemical waste-water treatment systems but are effective and safe enough to produce irrigation water for many types of crops while reducing the need for fertilizer (Shelef, Juanico & Vikinsky, 1987). With a design life-span of more than 40 years the annual repayment for capital recovery should be low; and when combined with the low production cost of water from this source, reservoirs are a cost-effective option for those farming communities that can afford the investment (Friedler, 2001).

Although stabilization reservoirs might seem low-tech when compared to drip irrigation and desalination, the construction and maintenance of these facilities adds to the capability of the water technology industry. To guarantee that the water they store is not a threat to the environment and to public health, reservoir technology has become more sophisticated and effective over the years because of the accompanying research and development, and decades of actual experience in building and operating these facilities reservoirs in past decades (kkk-jnf.org., undated). Stabilization reservoirs require sophisticated engineering technology to prevent embankments from collapsing, sealing technology using plastic sheets, water pipes, filters, pumps, irrigation systems, control systems and fences (kkk-jnf.org., n.d.).

VI. Innovation, Entrepreneurship & Technology in Israel's Water Economy

Technology has long been an important enabler of Israel's water economy, providing the country's engineers and technocrats with tools and techniques to exploit scarce water resources, to use that water with increasing degrees of efficiency and effectiveness, and to protect the quality of that water and the environment from which it comes (Tal, 2007; Kislev, 2011; Siegel, 2015). Enabling water technologies increases the economic value-creation potential of water resources which in turn helps to increase output in agriculture and industry, protects public and environmental health, saves the economy money, and makes the economy more productive and competitive (Tenne, Hoffman, Levi, 2013). To address its water scarcity Israel has employed several technological solutions, not all of which were successful. At various times the country attempted to drill deep into the earth to find fossil water, to seed clouds and modify weather, to develop water saving technologies and reclaim sewage, and the desalinization of sea water.

Some of the areas of expertise in which Israel has developed world-class capability include water infrastructure for conveyance and storage, recycling and reclamation of waste-water, bio-filters for purifying runoff, efficient irrigation and fertigation, rehabilitation of polluted streams, soil conservation, dry climate agriculture, desert reforestation, seawater and brackish water desalination, deep well drilling, water data analytic software, geology and hydrology (Tal, 2007; Megersa & Abdulahi, 2015; Siegler, 2015). The creation of a flourishing and globally competitive water technology sub-sector is a result of a combination of both public and private sector entrepreneurship and innovation, public policy and public investment, and government incentives. The heavy public investments by Israel's water-and-wastewater utilities provides a market and testing ground for local technology which often gains a local foothold before being offered on the world market. This world leadership in water technology is both a source of export income from equipment and services, and a tool of international diplomacy and goodwill (Siegel, 2015; Marin et al., 2017).

Israel tops the world for R&D intensity and the bulk of Israel's economic growth is linked to R&D investment, innovation and entrepreneurship in key high technology sectors (UNESCO, 2015). Israel spends one of the highest proportions of GDP on civilian R&D at about 3.5%, is ranked as one of the most innovative countries in the world, has one of the highest per capita publication rates for scientific articles and for patent filing, outspends most countries on education, has one of the highest ratios of scientists and engineers to the general population, has the world's highest concentration of R&D centers, has several of the world's top ranked research universities, has the world's highest ratio of Nobel Laureates with eight in the sciences, and leads the world in access to venture capital for start-ups with almost US$2,400 million in 2013 alone; and it is far ahead of the United States on all of these measures of innovation and entrepreneurship (UNESCO, 2015). The basis for the global scientific leadership has to do with Israel's unique circumstances – its unique challenges, a highly educated population, and a government willing to invest in key areas of national importance (DeHaan, 2008). Many of the sectors for which Israel has industrial, scientific, and technological leadership are directly build on public investments, such as the defense industry and water resource management (UNESCO, 2015).

Israel's public and private sector have made a concerted effort in recent years to promote innovations and entrepreneurship in the water sector and have established a 'triangle of innovation' that bring together private industry, water utilities and university research centers into an ecosystem to support the development and commercialization of innovative water technologies (Siegel, 2015; Israel New Tech, 2017). Each element of the triangle brings a different contribution to the ecosystem. The private sector provides most of the entrepreneurs, new ideas and technologies, and the majority of the capital to finance the R&D to commercialization process; public and private utilities provide a large domestic market for water technologies, and facilities for real-world testing; the government provides considerable funds to support R&D, and several government agencies manage programs to support the development of innovative water technologies; and the universities collaborate with all the other actors in the ecosystem by training world-class scientists and engineers and assisting with R&D (DeHaan, 2008; UNESCO, 2015). The public-sector support for innovators and entrepreneurs is considerable: Office of Chief Scientist under the Ministry of Economy provided NIS254 million between 2007 and 2015; the IWA provided NIS 94 million since 2008; the Chief Scientist of the Ministry of Energy and Water provides NIS20 million per year for the R&D and pilot stages of innovation and commercialization (Marin et al., 2017).

B. Water Technology Companies

There are currently about 600 companies in Israel involved in some aspect of water technology that together annually earn about US$2 billion and provide thousands of jobs (Ben-Zoor & Priampolsky, 2016; Israel New Tech, 2017). Many of these companies were able to establish themselves initially through the Israeli domestic market but now do most of their business globally. The government of Israel invests heavily in R&D and supports innovators and entrepreneurs in many areas of clean technology and water technology because these sectors are important engines of economic growth (Lemarchand, Leck & Tash, 2016). The following are examples of water technology companies that have benefited from public assistance through funding for R&D and other supportive policy measures:

1. Netafim. This firm is considered by some to be Israel's most successful water technology business. Netafim was founded in 1965 and became a pioneer in drip irrigation, a technology that increases the efficiency of water use in irrigation. Israel is now a global leader in drip irrigation, with 30% of the global market, and Netafim is its largest participant in that market with a global workforce of 2,800 people and annual sales of about US$800 million, of which 80% is exported (Siegel, 2015; Ben-Zoor & Priampolsky, 2015). Israel's drip irrigation industry alone is a US$2.5 billion industry.

2. Chromagen. This company was founded in1962 and became a pioneer in solar

thermal water heaters, a technology which saves energy, and for which Israel is a global leader (Siegel, 2015).

3. IDE Technologies. This company was founded in 1965 and became a global leader in water treatment solutions. IDE specializes in the design, construction and operation of desalination facilities and industrial water treatment plants and has built 400 desalination plants around the world (Siegel, 2015).

The following are some more examples of globally competitive water technology companies are at the forefront of bringing Israeli technology to the global marketplace:

1. TaKaDu. This company was founded in 2009 and is a pioneer in water network management systems which offer water utilities Internet-based solutions to improve network efficiency and planning decisions through the real-time, 24/7 analysis of water data. TaKAdu's technology helps save water by monitoring the state of water infrastructure and the early detection of leaks in pipes (Ben-Zoor & Priampolsky, 2015).

2. Arad Technologies. This company was founded in 2000 and is a pioneer in the development, manufacture, and marketing wireless automatic meter reading systems worldwide. The Arad Group was founded in 1941 and since then has sold millions of water meters around the world and the company manufactures over 500,000 units a year, which had made Arad into one of the leading companies in the global water measuring industry (Ben-Zoor & Priampolsky, 2015).

3. Amiad Water Systems. This company was founded in 1962 and is a pioneer in water filtration solutions for industrial, municipal, and agricultural use. Amiad's water filtration technologies environmentally-friendly and self-cleaning and use a

process that employs no chemicals nor polymers with a level of efficiency that wastes less than 1% of the water that goes through the process (Ben-Zoor & Priampolsky, 2015).

4. Aqwise. This company was founded in 2000 and is a pioneer in wastewater treatment for the industrial and municipal markets. Aqwise's solutions have been successfully installed in over three hundred municipal and industrial plants in more than 35 countries, serving a variety of industries including food & beverage, pulp & paper, pharmaceuticals, and oil & gas (Ben-Zoor & Priampolsky, 2015).

Israel's domestic success and its global experience prompted the World Bank and the Israeli Ministry of Economy in 2015 to sign an agreement to assist developing countries facing complex water challenges. The Ministry of Economy committed $500,000 to the World Bank Group's Water Global Practice to support this initiative, which will also encourage the export of Israeli water technologies to these countries (Ben-Zoor & Priampolsky, 2016; Israel New Tech, 2017).

D. Israeli Incubator Program.

In 1991 the Ministry of Industry and Trade, now Ministry of Economy, through the Office of the Chief Scientist (OCS), established an incubator program which eventually spawned 28 technological incubators across Israel (Frenkel, Shefer & Miller, 2008; Siegel, 2015; Israel New Tech, 2017b). The launch of the program coincided with the flood of technically and scientifically competent Russian Jewish immigrants who needed to be settled in Israel (DeHaan, 2008; Berry & Wasserteil, 2014). These incubators have successfully supported more than 200 projects in electronics and communication, software, medical devices, new materials, biotechnology, renewable energy, and, of course, water. The OCS is responsible for implementing the government's policy of encouraging and supporting industrial research and development in Israel, its annual budget of about US $300 million supports about 1,000 projects undertaken by 500 companies, and its support of innovators and entrepreneurs have helped make Israel a major center for high-technology businesses. The OCS supports R&D projects of Israeli companies by offering conditional grants to partially fund the approved R&D expenditure for a period of 2 to 3 years after which the start-up or project must be financially self-sustaining. Start-ups that have commercially successful projects will be under an obligation to repay the grant by royalty payments of 3% to 5% of its future revenues (Israel New Tech, 2017b).

In 1992, the government began providing venture capital to support high technology start-ups given the absence of a private venture capital market at that time (DeHaan, 2008). The fund was called Yozma and it was provided $100 million in government money. Since then Israel has become the country with the most venture capital available per citizen with most of this money coming from the private sector and Yozma has been privatized (DeHaan, 2008). The government also offers tax breaks and numerous other incentives to support foreign and local investment and R&D (Berry & Wasserteil, 2014). One of the strengths of Israel's public incubator and venture capital policies has been the practice of the government refraining from picking winners and allowing the selection of projects to be primarily merit-based (DeHaan, 2008; Siegel, 2015). The program has also been successful in its rate of graduation – about 85% - and its rate of survival after graduation – about 75% - which suggests that the selection process is rigorous; and incubators have become more financially self-sustaining over time (Frenkel, Shefer & Miller, 2008; Siegel, 2015).

Starting in 2000 the incubators were 'privatized' because venture capital funds became more willing to invest in technology start-ups - although the government continues to provide financial support for start-up R&D in key economic sectors and maintains shares in many of the incubators, so they are essentially public-private partnerships (Frenkel, Shefer & Miller, 2008; Berry & Wasserteil, 2014; Siegel, 2015; Israel New Tech, 2017b). Government support for the remaining 24 incubators, and the start-ups they support, is still considered necessary because private capital still prefers to invest in technologies with lower risks and shorter commercialization periods (Frenkel, Shefer & Miller, 2008); and because evidence suggests that businesses which are nurtured in incubators have a higher survival rate (Berry & Wasserteil, 2014). Around the same time the government started to privatize their incubators, several private incubators began operation. These incubators can also access funds from the OCS but most of their resources come from the private sector. They differ, however, from the public incubators in the amount of money they invest in projects, the type of projects in which they invest, the background of the entrepreneurs and innovators, and their focus on private rather than national goals (Frenkel, Shefer & Miller, 2008). In Israel the amount of private sector direct investment and venture capital channeled to water and other clean technologies is smaller than all other high technology sectors (Berry & Wasserteil, 2014). A publicly supported incubator for water and clean technologies fills a gap in the private investment market which probably exists because of the long commercialization period for these technologies and their narrow markets.

The Kinrot Ventures incubator was founded in 1993 is the only Israeli start-up incubator to focus solely on water technologies. It is also the largest investment body in the world in the water sector, in terms of the number of technology companies supported is a rarity in the group of Israeli incubators, since it is the only incubator focused exclusively on the water sector, and essentially it is Israel’s water incubator. Kinrot Ventures was privatized in 2006 but is was later acquired by Hutchinson Water's Israeli subsidiary in 2012 and renamed Hutchison Kinrot and has now expanded into the broader field of Clean Technology. Hutchison Water Israel E.P.C Ltd operates the incubator under a franchise from the Israeli Innovation Authority and has agreed to invest at least $25 million in the incubator and in its portfolio companies over eight years (Israel New Tech, 2013) The Israel Innovation Authority is an independent public entity that implements Israel's innovation policy and supports Israel's innovation infrastructure and knowledge economy, and it was established in 2016 to replace the OCS that was under the Ministry of Economy (Israel Innovation Authority, 2017). Kinrot Venture's competitive selection process looks for companies that ideally have experienced managers, a clear or unique business model, a solution that meets a significant market need, a technology that has universal or very wide applicability, and capable of being protected by robust intellectual property rights. In addition, unlike some incubators in Europe and the United States, Kinrot Ventures in heavily involved in the management of the start-ups to ensure that experienced guidance is provided to the young business (Israel New Tech, 2017b).

E. The Entrepreneurship & Partnership Center for Water Technologies (WaTech).

In 2004, Mekorot established the WaTech to leverage the company's decades of experience in operating complex water systems by supporting innovators and entrepreneurs from both start-ups and mature companies locate, develop, test, and commercialize new technologies for both the Israeli and the international markets. By establishing a center with this type of focus Mekorot also hopes to develop its own human capital, find new business and research partners, identify and meet its own emerging technological needs, identify new sources of income, and expand its own commercial presence across the globe. Mekorot is itself deeply involved in R&D which is carried out in the operational systems of the company and four R & D centers at its disposal: Eshkol Central Laboratory, which is the center for surface water purification and monitoring technologies; Shafdan, which is the center for advanced wastewater and effluent technologies; Ashdod, which is the center for seawater desalination technologies; Sabcha (Eilat), which is the center for desalinated brackish and seawater desalination technologies. WaTech has research relationships with four major Israeli universities: Ben-Gurion University, Hebrew University, Technion, and Tel Aviv University. WaTech is designed to bring together various actors in the Israeli water economy – water companies, research institutes and universities, technology incubators, investors and venture capital funds – who work together to collaboratively find solutions to existing and emerging water problems (Merkorot.co, 2017). WaTech further supports this work by establishing a system for information and knowledge management, and by helping to get the resulting technologies patented to protect intellectually property rights so that its commercial value can be properly captured (Merkorot.co, 2017).

Some of the specific support WaTech offers innovators and entrepreneurs includes access to experimental sites at Merkorot facilities where they can conduct studies in the alpha and beta phases of testing and commercialization; access to Merkorot's experienced project planning staff who help innovators and entrepreneurs build a systematic experimenting program to test innovative technology, develop products, and choose the right applications to support their R&D; access to experienced engineering and technical staff who assist in integrating the experiments into Merkorot's facilities during the alpha and beta phases of testing; access to the business development center where contact can be made to potential investors, partners, and clients from Merkorot's wide international network; support in validating technologies at the end of the testing process; and access to financing to support commercialization of the technology (Merkorot.co, 2017). WaTech's innovators and entrepreneurs have access to Merkorot's international partners which include major global water companies such as Veoila, Suez, Thames Water Utilities, and DOW. To date WaTech has tested more than 1,000 proposals for water technology projects and projects, has contracted with several dozen start-up companies, and conducts about 40 studies a year locate, develop, and commercialize new water technologies (Merkorot.co, 2017).

F. Water Technology and Environmental Control Exhibition & Conference (WATEC).

In 2009 Israel hosted the first Water Technology and Environmental Control Exhibition & Conference to allow water stakeholders from around the globe to share their experiences regarding the current and future trends of the water economy. WATEC Israel attracts water professionals, entrepreneurs, and innovators, manufacturers, researchers, investors, academics, purchasers and policy makers from around the world; and the companies which are represented are both Israeli and International. WATEC Israel is a biennial exhibition taking place over three days at the Israel Tel Aviv Convention Center; but WATEC conferences have also been held in Peru in 2014 and Italy in 2016 and 2017. The format of WATEC includes an exhibition and a professional conference, it provides an opportunity for those who attend to advance cooperative activities and arrange new business endeavors, and it serves to boost Israel's presence in the global water technology market. The theme of WATEC 2017, which was held in September, was water in the digital age, where information and communication technologies, which increases speed and agility, 'big data,' cyber security, transparency and optimization are reshaping the industry and opening new opportunities for Israeli companies to drawn on other areas of Israeli high-technology excellence (WATEC, 2017). Many of the emerging water technology firms are being started by entrepreneurs and innovators from the computer industry, proving the value of networking across disciplines and multi-disciplinary collaboration for solving complex water problems (The Economist, 2011).

C. Distant Meter Reading Technology.

This is one example of the employment of multiple technologies to water resource management. This allows water usage to be tracked in real time, analyzed by sophisticated software, and unusual patterns of water use immediately identified and addressed. A water profile can be created for each customer and unusual patterns of usage identified. The result is an immediate response to leaks which traditionally go undetected for long periods of time, a reduction is water use, and smaller bills for customers (Siegel, 2015). This is the same type of technology used to detect credit-card fraud. It is gradually being implemented by Israeli utilities and Israeli water technology companies are betting that this technology will become a global standard within one to two decades (Siegel,

2015).

Other Israeli water technologies include robots that patrol water and sewerage mains to monitor their condition and identify places within the network where proactive maintenance is required (Siegel, 2015). This type of technology reduces unaccounted-for-water and maintains water quality by reducing leaks from sewerage mains.

G. Drip Irrigation & Seeds.

The most significant increase in water use efficiency has occurred in the agricultural sector. Given that agriculture is still the biggest user of water in Israel, and irrigation the single biggest use, it is understandable that it is to this sector, and this specific activity, that most attention must be directed in the effort to have a significant impact on the Israeli water economy (Davis, Maks & Richardson, 1980, Tal, 2006, 2007; Siegel, 2015). The ability and willingness of Israel's agricultural sector to maximize its use of water saving technologies depends both on the availability of these technologies and the economic and financial incentive which government offers Israeli agriculture to affect such a conversion (Davis, Maks & Richardson, 1980, Tal, 2006, 2007).

During the last 60 years while Israel's population grew by a factor of 7, and agricultural production expanded by a factor of 16, the proportion of high-quality fresh water allocated to farmers steadily declined, largely due to the introduction of during the 1960s which increased agriculture's output per unit of water (Tal, 2006; Isenberg, 2010). Drip irrigation solves several vexing problems for farmers: by decreasing overall water delivery, it reduces residual salts and minimizes water usage; by delivering nutrients to the root zones at optimal intervals for their use by growing plants, it reduces soil pollution and helps maintain a dry soil surface; and it allows crops to be grown in marginal soil because water and nutrients are delivered to the roots (Tal, 2006; Isenberg, 2010).

The dominant method of irrigation around the world is flood irrigation, and this has been the case since the agricultural revolution thousands of years ago, follows by sprinklers – both highly inefficient and ineffective methods of irrigation which are dependent on a cheap and reliable supply of water (Solomon, 2010; Megersa & Abdulahi, 2015). Flood irrigation loses more than one-half of the water through evaporation or runoff, and great amounts of energy are required to deliver great amounts of water through large and complex water networks; while sprinklers lose at least one-third of the water (Siegel, 2015). Up until at least the 1950s flood irrigation and sprinklers were still the dominant means of irrigation in Israel and agriculture used 70% of the country's water supply, just as does most of the rest of the world; today 75% of Israeli fields employ drip irrigation and the remaining 25% use sprinklers (Siegel, 2015). Globally only about 5% of the world's fields benefit from drip irrigation, another 15% use other methods of irrigation, and 80% of the world's crops still rely on rainfall (Siegel, 2015). This small percentage of irrigated fields still outperform rain-fed fields by supplying about 40% of the world's crops (Megersa & Abdulahi, 2015). Drip technology may ultimately have the greatest global impact in a world where growing water scarcity and a growing global population threaten to result in a food crisis in the coming decades if innovative solutions are not found (Siegel, 2015; Megersa & Abdulahi, 2015).

Drip irrigation is the most energy and water efficient of all the irrigation systems (Megersa & Abdulahi, 2015). Drip irrigation can deliver savings of water for irrigation of between 40% to 70% of water since soil evaporation, surface runoff, and deep percolation are greatly reduced or eliminated; it can reduce the amount of fertilizer and energy needed to produce crops, which saves money and reduces pollution; it improves the quality of the output; it increases yields between 100% to 500% per unit of land for a given among of water and fertilizer; and it allows marginal land to be brought into agricultural production (Siegel, 2015; Megersa & Abdulahi, 2015). Drip irrigation is both commercially and environmentally advantageous; however, the reluctance of many farmers to adopt this method of irrigation is primarily the result of institutional inertia or a failure to achieve technology translation. An example of institutional inertia is the continuing practice of providing farmers with market-distorting subsidized water, which Israeli farmers were able to secure since 1948 (Kislev, 2012; Siegel, 2015); while an example of failed technology translation is the failure to create an enabling environment through the transfer of requisite knowledge or the absence of technical support, which is what Blass faced in the 1960s on the road to commercialization of this technology from entrenched academic and bureaucratic interests at Hebrew University and in the Ministry of Agriculture, and risk adverse manufacturers of agricultural technologies (Garb & Friedlander, 2014; Siegel, 2015). This institutional inertia almost succeeded in defeating Blass; however, Blass found partners among the Negev farmers, whom he had helped several decades earlier, who needed this technology for their own farms as well as for additional source of revenue through their manufacture (Siegel, 2015). The socialist collective farms of Israel became incubators for a major industry, and socialist farmers became entrepreneurs and innovators from a revolutionary water technology, building on the pioneering and risk-taking spirit that they had as pioneer farmers and settlers decades earlier.

To complement its global leadership in water efficiency technology, Israel is also a leader in seed production with Hazera, Israel's largest seed producer, having annual sales of about US$200 million (Reisman, 2005; Amit, 2015). Israel's innovative strains of seeds are designed to produce plants that can grow using less water as well as plants that are designed to thrive in brackish water (Siegel, 2015). This way water and energy savings can be realized from multiple sources.

VII. Application of Porter's Diamond

A. Factor Conditions.

The competitive basis of Israel's economy is significantly shaped by the country's ability to overcome its scarcity in fresh water. The traditional base sector of the Israeli economy, agriculture, and the current base sectors of the economy, such as high-technology and tourism, are all heavily dependent on the availability of a reliable supply of fresh water. Despite the critical role of water in the economy, Israel is one of the most water scarce countries in the world. Israel in general is deficient in basic factors except for sunlight, which is not yet competitive as a general source of energy, and now offshore natural gas, which is being used to provide energy for the desalination of seawater. More important than basic factors, with which a country is naturally endowed, are specialized and advanced factors which a country must create for itself such a critical mass of high-quality human capital that is innovative, entrepreneurial, and technological capable, high quality infrastructure, and a sufficient pool of financial capital.

The Israeli economy is built primarily on advanced and specialized factors, many of which are an outgrowth of its water scarcity and the agricultural and defense sectors. Water scarcity helped to develop expertise in civil engineering, geology, and hydrology as Israel's water technocrats had to find water in deep and difficult places under the ground and move water over difficult terrain from water surplus to water deficient regions (Cohen, 2008; Siegel, 2015). Water scarcity forced the agricultural sector to eventually adopt drip irrigation, climatically controlled greenhouses; and used water to decrease the demand for fresh water, and fergitation to minimize contamination of soil and groundwater (Kartin, 2001; Tal, 2006, 2007; Siegel, 2015). The defense sector developed capacity in specialized and advanced factors such as software and robotics that were relevant to agriculture, the water-and-wastewater, and water technology sectors (Siegel, 2015). Israel is one of the most scientifically and technologically advanced countries and its specialized and advanced sectors are always being upgraded to remain competitive (Breznitz, 2007; Berry & Wasserteil, 2014; UNESCO, 2015)

To develop and sustain its specialized and advanced factors Israel's economy is well supported by public and private funding for venture capital and R&D; its universities produce a large number of competent scientists and engineers; many of its national servicemen leave the armed forces with technological and management skills; and its researchers are highly productive in publishing peer reviewed journal articles and in securing patents; and its entrepreneurs and innovators have an outstanding track-record in commercializing technologies (Peled, 2001; Frenkel, Shefer & Miller, 2008; DeHaan, 2008; Isenberg, 2010; UNESCO, 2015; Ben-Zoor & Priampolsky, 2016). Israel's scientific, technological and economic achievements since the reforms of the 1980s and 1990s is impressive: almost half of Israel's exports come from high-technology sectors such as information and communication technology, life sciences, chemicals, pharmaceuticals, robotics, defense, and water technology; it has been the most research intensive country in the world for many years with the private sector committing almost 4% of GDP to R&D, about twice the level of the Unites States, the Netherlands, and Singapore; its foreign direct investment inflow is over 4% of GDP; the country had over 77,000 full-time researchers; more than one-third of bachelor degrees and more than half of doctoral degrees were in science, technology, engineering and math; three Israeli research universities rank among the global top 75 in mathematics and four among the top 200 in physics and chemistry; its rate of journal article publication is about 1,400 per million inhabitants, which is higher than the United States but somewhat lower than Singapore and the Netherlands, and the vast majority of these are in science, technology, and engineering; the country attracts more venture capital per capital than any other country and it has 70 active venture capital funds, of which 14 are international (Aharoni, 2014; UNESCO, 2015). The government, both directly and indirectly, played a significant role in the upgrading of factors to the benefit of the water sector and the wider economy.

B. Related & Supporting Industries

Israel water technology sector has worked hard to create a water technology ecosystem comprised of businesses, universities, research centers, financiers, business incubators, and governments ministries and agencies (DeHaan, 2008; Isenberg, 2010; Ben-Zoor & Priampolsky, 2016). The presence of a business environment comprising related suppliers, competitors and complementary firms is regarded as highly supportive for an industry to build competitive advantages. Such a geographical concentration of companies, suppliers and supporting firms is a classic example of an industrial cluster. These players in the water technology ecosystem are examples of the related and supporting industries along the water value chain that facilitate innovation through exchanging ideas, co-creating of knowledge, supporting R&D and field testing, and facilitating commercialization of technologies. The higher the quality of the water sector's related and supporting industries, such as through their global competitiveness, the more innovative and entrepreneurial will be the players in the water sector. Israel's relatively small size, and relatively large number of water technology firms, allows its water technology players and their related and supporting industries to easily network and collaborate. This was the case with drip irrigation and the collaboration between several Kibbutz to develop and manufacture this product. As such Israel's water sector can be considered a mature water technology cluster with an industry that has adopted a financially sustainable business model, and water technology firms that are no longer dependent on the local market for the bulk of their revenue.

The highly developed agriculture sector would require a high degree of technological sophistication to grow crops on marginal land that were competitive based on both price and quality (Tal, 2007). The water technology industry and various trade associations also promote the sector.

C. Demand Conditions

All Israeli water technology firms gained an initial market foothold in the domestic market. Demand conditions relate to the size and nature of the market such as its growth rate, the complexity of customer requirements, and the mechanisms that transmit domestic preferences to foreign markets. This is a significant driver of innovation and product improvement, especially when the local market is particularly demanding as this prepares firms to globally competitive. The scarcity of water, its uneven geographical distribution, its inconsistent temporal availability, and the geological challenges that had to be surmounted to access water and transport it to where it was needed, forced water engineers to be innovative. The willingness of the government to invest heavily in water infrastructure, such as the National Water Carrier, provided a guaranteed initial market; and when local market demand was satisfied, or as more players entered the market, water firms were able to offer their expertise and technologies overseas (Isenberg, 2010; Siegel, 2015; Ben-Zoor & Priampolsky, 2016).

Israeli water technology firms are located along almost the entire water value chain, and this is the result of Israel's water economy history. The water economy was initially interested in expanding supply, so the initial demand was for civil and hydraulic engineering; later the water economy became interested in efficient water use and improved water quality, so this drove demand for drip irrigation and recycling; and when the water economy again needed to expand supply, this drove demand for desalination technologies. Israel is a world leader in each of these areas (Cohen, 2008; Siegel, 2015). As the market in Israel became saturated, these firms would all eventually look beyond the country's relatively small domestic market.

D. Firm Strategy, Structure and Rivalry

The performance of Israel's water technology firms in terms of innovation and competitiveness is strongly linked to the degree of rivalry, the strategies, and the structure of the firms in that sector. This element of the diamond relates to the firm-based theories of internationalization that focus on the actions of individual firms. Israel's water technology industry with up to 600 firms is the largest of the six clusters examined – the Netherlands may nationally have more firms in the water sector, but these are spread across several clusters in a larger geographic space, and there is distinct regional expertise or competencies in the Dutch case. Competition or inter-firm rivalry plays a big role in driving innovation and the subsequent upgrading of competitive advantage and most technologies have several firms competing in the Israeli market. Israel Science & Technology Directory (2017) lists 14 firms currently in the irrigation business. Consequently, many water technology firms in Israel generate most of their sales, in many cases as much as 75%, outside Israel.

E. Role of Government and Chance

Governments can play a role in developing and supporting clusters through procurement of advanced technologies, setting high product standards, supporting specialized factor creation, and encouraging competition, the government of Israel has supported and nurtured the water technology industry in several ways and both directly and indirectly. Public utilities were initially, and still remain, both a major producer and purchaser of Israeli water technology (Cohen 2008; Siegel, 2015). Probably the most important role the government played was in the support for the creation of specialized factors. The government initially supported the water technology sector with venture capital and business incubators when the private sector did not offer these in Israel - although in the last two decades the private sector has taken over the lead with both types of facilitation (Frenkel, Shefer & Miller, 2008). The government, through the Office of Chief Scientist (OCS), has been careful to only support those startups and projects with the best chance of success, as demonstrated by the quality of their proposals and their proposed business models. The OCS also provided funds to support research and development and many of the firms receiving this support were able to commercialize their technologies. The government was also the main enabler in the development of human capital through the public universities which trained generations of competent scientists, technologists and engineers (UNESCO, 2015); but Israel’s high-technology capabilities and impressive economic achievements can also be traced to the important role played by defense and military sector (Peled, 2001). The military served as a training ground for many of Israel's innovators, entrepreneurs and technologists; and defense-related R&D had important spillover effects as electronics, software, and robotics all played a role in today's more complex water technology environment (Peled, 2001).

Various ministries of government also promote the water technology industry, through information placed on their websites or through more active promotion. Some of these public initiatives are done in conjunction with the private sector. An example is the Israel Export and International Cooperation Institute (IEICI). The IEICI is a public-private partnership established and funded by the government and the private sector whose task is to promote Israel's high-technology and consumer goods industries around the world and which bills itself as the “premier gateway for doing business with Israeli companies” (IEICI, 2017). IEICI has more than 50 years expertise in penetrating foreign markets to promote Israeli technology, in product scouting, in providing professional information, in drafting business plans, in organizing incoming and outgoing delegations, in participation in exhibitions and international conferences around the world, and in establishing joint ventures and strategic alliances between foreign clients and Israeli companies (IEICI, 2017). The IEICI has a dedicated Water Sector as well departments dedicated to closely related industries such as agro-technology and clean technology. IEICI engages in extensive marketing activities around the world with the support of the commercial attaches in Israeli embassies and contracted professional consultants.

The Government of Israel was initially slow to strengthen environmental regulations and demand greater water efficiency; however, more stringent regulations for pollution and waste-water, higher water prices, and regulations requiring the introduction of water saving devices and technologies have stimulated innovation and made it easier to commercialize. The early requirement that all water customers must be connected to a meter to receive water stimulated the local manufacture of water meters: for a number of years there was a guaranteed market. Once the Israeli market was satisfied these firms had to look overseas and Israel is now one of the world's leading manufacturers of water meters.

The early socialist governments of Israel were initially poor in using regulations to encourage competition; and the lack of competition was exacerbated by government ownership of large segments of the economy, the close relationship between government and the trade unions, and the small domestic market (Aharoni, 2014). Although Israeli utilities were initially all owned by government, the water technology sector was not, however, owned by the state. Entrepreneurship and innovation in the water technology sector, as in many other technology sectors, was driven by competition for a share of the international market, while domestic stimulants of innovation were related to Israel's severe water scarcity.

Chance also played an important role in stimulating Israel's water technology sector and providing entrepreneurs and innovators with both opportunities and incentives.

VIII. Conclusion

Israel possesses a sophisticated and globally competitive water technology cluster which is characterized by a high degree of entrepreneurship and innovation from both public and private players. The public sector at first played a leading role in developing Israel's water sector through major public infrastructure works which tapped natural water sources and redistributed this water across regions. The private sector now dominates the water technology sector; and public-private partnerships now dominate the supply of water, through desalination, and recycling, through the water-and-wastewater utility sector.

Civil and hydraulic engineering at first dominated the water technology sector, and in the early decades the Israeli water economy was an investment-driven sector when the National Carrier was being constructed. Later the Israeli water economy shifted to an efficiency-driven sector as finite water resources, a growing population, and growing economy required a greater quantity of water from finite stocks. Efficiency became a driver for recycling, reuse, and conservation through drip irrigation. More recently the need to desalinate seawater to meet growing demand and overcome stressed natural supplies became a driver for a shift to an innovation-driven water economy. Today the industry is dominated by devices and instruments increasingly related to water and energy efficiency, water quality, purification, and desalination. Scarcity was the main driver stimulating entrepreneurship and innovation in the water sector over the entire period; however, pollution, environmental protection, and climate change have now become important drivers as well.

Given Israel's geographic and demographic characteristics the water technology cluster should be considered a national scale cluster; and given the continued growth of the sector – domestically through recycling and desalination, and internationally through the full range of technologies – the cluster should be considered as transitioning from a growing to a mature cluster. As an emerging cluster, Israel's water technology industry is still experiencing growth, especially from international sales. As a mature cluster Israel's water technology firms have been able to withstand downturns through exports, and the continuing demands to expand Israel's domestic water supply through non-conventional sources. Israel’s water economy and its water technology sector offers important lessons: there is an important role for the public sector as innovator, entrepreneur, regulator, investor, and venture capitalist; water utilities must adopt financially sustainable business models, and this provides the financial resources for upgrading the sector and supporting technological innovation; and because the domestic water economy is subject to various market failures, is dominated by monopsony utilities, and is structurally fragmented it requires a carefully constructed institutional framework that coordinates and aligns the work of public, private, and academic actors that make up the sector.

CHAPTER 11

DISCUSSION & ANALYSIS

I. Introduction

Whether or not a water technology cluster becomes an integrated part of an economic system, develops into a competitive network of interdependent firms and supporting organizations, and is able to develop and diffuse innovative technologies, depends in part on the economic and institutional context in which the cluster emerges. This statement leads back to the study's six research questions: (1) Do governments intervene to promote the development of industrial clusters for water technology firms? (2) What public policies and strategies do governments employ to support the development or expansion of water technology innovation clusters? (3) What are examples of successful clusters in which specific strategies of government intervention can be used as good practices? (4) What are the roles and responsibilities – or the division of labor – between public and private partners in developing or expanding water technology innovation clusters? (5) Do individual or organizational champions facilitate the development and diffusion of water-related technologies and enhance the competitiveness of water technology innovation clusters? (6) Does the institutional setting of a jurisdiction affect the development and diffusion of innovative water-related technologies?

One dominant position on the role of government is that the rise and functioning of clusters and the diffusion of innovations are processes driven primarily by market forces. Governments should not interfere with market forces outside a limited range of interventions designed to facilitate the smooth and dynamic functioning of markets, namely policy instruments that create favorable framework conditions and reduce market imperfections (Porter, 1998; OECD, 2009). This position constrains public policy and shifts strategy from direct intervention – such as being an institution builder - to indirect inducement – such as being a facilitator of networking, a provider of incentives, a corrector of market failures, and a remover of systemic and market inefficiencies and imperfections.

The processes driving institutional and technological change and the characteristics of both institutions and technology, act as either constraints or enablers on the emergence of competitive water technology innovation clusters, and the development and diffusion of water technologies. Clusters are organizational units of interrelated firms within a geographic region that emerge from a particular social, economic and environmental context; clusters operate under a governing institutional framework that constrains or enables its functioning; and clusters evolves a structure and approach to strategy which supports diffusion of innovations and determines its competitiveness (Porter, 1998; Markusen, 1996). Technological and institutional innovations – meaning the development, application, diffusion, and utilization of new knowledge, technology, social and political practices - play a major role in reinventing water and wastewater regimes. Technological and institutional innovations include changes to a broad range of physical infrastructure for water delivery and treatment that drives greater efficiency and improved environmental outcomes; but political, cultural, social, and economic factors that serve as the contextual backdrop also hinders or enables such changes. If innovators, entrepreneurs and the water technology clusters in which they operate are to solve challenges in the water economy, the intertwined nature of the technologies, institutions and the social and political systems that control change, must be understood if policy makers are to influence them (Kiparsky et al., 2013)

To stimulate the development and diffusion of water-related technologies the EPA has put forward nine strategies for the development of water clusters. The strategies involve bringing together a wide cross-section of stakeholders – including businesses, academia, researchers, and public utilities - to develop a portfolio of policies, regulations, and financial instruments that, when taken together, will institutionalize and promote water technology innovation along the entire continuum from development, to testing and validation, to deployment (EPA, 2012). These strategies will be validated by being critically examined in a robust conceptual framework grounded in well-established theories from economics and the social sciences. The conceptual framework is built primarily around theories related to clusters and competitiveness (Porter, 1998), institutional change and economic performance (North, 1990), and diffusion of institutional innovations (Rogers, 2003). The conceptual framework uses inductive reasoning which allows for generalization or extrapolation from the six chosen cases studies to reach general conclusions about the efficacy of the EPA’s nine cluster development strategies. Institutions and institutional performance are considered important to cluster development: institutions can vary widely in their impact on economic performance from those that produce growth and development to those that produce stagnation; they provide a structure to guide human behavior and reduce uncertainty involved in human interaction; they help to create the incentive structure in a cluster and economy; they determine transaction, production and agency costs which impact competitiveness; and they influence the diffusion of knowledge, skills, and practices that shape the direction and rate of social, political and economic change, which in turn gradually alters the original institutional framework.

The nine strategies for cluster development are built on several premises that clusters have several beneficial characteristics that justify public policy intervention and the employment of specific strategies to support their development. These premises are: (1) that industry clusters within an economically connected region promote positive spillovers, labor market specialization, and the sharing of industry-specific inputs; (2) that thriving regional innovation ecosystems create institutions that build social capital and networks which improve communication and knowledge sharing; and (3) that the cumulative effect of these synergistic relationships are productivity growth, cost or technological advantages, and increased competitiveness (Porter, 1990, 1998, 2000; Porter & Kramer, 2011; Wessner, 2012). The cluster development strategies identified by the EPA for inclusion in economic development policy at all scales of government are as follows: (1) the design and implementation of appropriate policies, regulations, and procedures by federal, state and local governments to encourage innovation and entrepreneurship and facilitate the commercialization and adoption of technologies; (2) the encouragement and leveraging of R&D by federal laboratories, universities or other research institutions; (3) the facilitation of technology transfers from the public to the private sector; (4) the creation of networks for facilitating communication and knowledge diffusion and cross-agency cooperation; (5) the encouragement of champions and cluster leaders; (6) the encouragement of more public-private partnerships; (7) the development of new relationships with the investment community and the leveraging of private capital from private capital markets; (8) the nurturing of technology start-ups; and (9) the partnering with established water-technology, water-intensive, and water-enabled businesses (EPA, 2012; Fieldsteel, 2013)

II. Analytical Framework

A. Policies, Regulations, and Procedures.

Governments at all scales can play significant facilitative and simulative roles that support the development of clusters, encourage innovation and entrepreneurship in water technology, and influence the processes that lead to the development, commercialization, diffusion, and adoption of water technologies. In all six case studies governments have been an active, and sometimes even the leading, stakeholder in setting the governance and operational practices of the water technology clusters through the design of policies, regulations, standards, and systems of permitting. Governments have four major means of leverage to support R&D and innovation, namely regulation, public procurement, fiscal instruments and information provision (Grotenbreg and van Buuren, 2017; De Vries et al., 2016; Selviaridis, 2016; Edler and Georghiou, 2007). The four types of public support do not have to be employed by one single public actor; rather, different public authorities can complement each other as long as there is alignment.

This strategy supports the assertion by Porter (1998) in the Diamond Model that governments play an important role in encouraging and stimulating the development of competitive industry clusters. This strategy also supports the assertion by Douglass North (1990) that formal rules guide economic and social interactions, when rules are well designed they promote order and certainty in a socio-economic system, and by extension give rise to institutional arrangements that create efficient markets with low monitoring and transaction costs.

In the United States formal rules at both the federal and state levels are meant to facilitate and simulate innovation and entrepreneurship in water-related technologies. The federal government, primarily through the Environmental Protection Agency (EPA) and Small Business Administration (SBA), has been actively supporting the creation of a rule-based institutional framework that stimulates the development of water technology clusters. There are numerous pieces of legislation designed to promote innovation and entrepreneurship, encourage R&D collaborations between the federal government, universities and the private sector, and improve the process for the commercialization of water technologies. The federal government also plays a critical role in encouraging innovation and entrepreneurship by setting environmental standards and controlling water pollution. The Clean Water Act (CWA), for example, established the basic structure for regulating pollutant discharges into U.S. waters, setting wastewater standards for industry, setting water quality standards for all contaminants in surface waters, and funding the construction of sewage treatment plants under the construction grants program. These federal and state policies and regulations attempt to support water technology clusters because clusters with competitive firms will promote local economic development, directly by building water technology firms and indirectly by supporting water-enabled or water-intensive industries that are dependent on a reliable supply of water.

The facilitative and simulative roles of government have been even more pronounced in the three other countries studied. The Dutch water economy is governed and managed at multiple scales and good water governance is the cornerstone of a strong water economy and a sustainable and resilient environment. The institutional framework for the Dutch water economy is characterized by diverse players at national, regional and local scales operating in a decentralized management structure, but with robust policy guidance and legislative and regulatory support from the national government. The national government draws up policy and takes some responsibility for national or regional water issues that cross provincial boundaries, while the provincial government is responsible for implementing these policies in specific measures and plans. Each player in the Dutch water economy has its own areas of responsibility but the complex nature of Dutch water resource management requires considerable cooperation, coordination and collaboration among the parties. The study highlighted at least two strengths of the institutional framework of the Dutch water economy. One strength, especially as exemplified by the Rijkswaterstaat, has been its ability to undergo numerous changes in role, organization, and practice over the last 200 years in response to social, political, economic, environmental, demographic, and technological changes in The Netherlands (Lintsen, 2002; Van Den Brink, 2009; Lonnquest et al., 2014). Another strength has been a successful record of financial solvency which helps to ensure operations are efficient and infrastructure is maintained at a high standard. The success of the Dutch water resource model is due to several factors: the application of private sector management practices in select areas of operations; the commitment to transparency, public accountability, and self-regulation; the practice of bench-marking to continuously improve the quality of service and lower costs; the application of science and technology; the commitment to full-cost recovery; and the culture of continuous learning and adaptation (Schwartz & Blokland, 2002; Lintsen, 2002; Van Der Brugge, Rotmans & Loorbach, 2005; Marques, 2010; Metz & van den Heuvel, 2012; Lonnquest et al., 2014). Public procurement and the domestic utility industry are an important source of domestic demand.

The facilitative and simulative roles of Singapore's government led to the transformation of the Singaporean water economy and the development of a viable water technology cluster built on a framework of good governance established by a politically strong-willed, innovative and entrepreneurial government. The government championed an integrated strategy of long-term comprehensive planning, promulgated effective laws and regulations, established efficient institutional arrangements, and pursued practical and effective approaches to water problems. The policies to protect Singapore's water resources and her environment were carefully implemented, and the regulations rigorously monitored and enforced, by a collection of technically competent public agencies. The government of Singapore regularly updates and amends this comprehensive framework of policies, legislation, regulations, codes of practice, and best-practices; it carefully allocates roles and responsibilities between public and private partners; and it provide an enabling institutional environment for sustainable economic development. Some of the most important policies implemented by the government in Singapore have related to pricing which has variously been employed as a tool for cost recovery - to ensure the financial resources for expanding supply and operating the water-and-wastewater system at the highest levels of efficiency and reliability – and as a tool for demand management – to encourage conservation to reduce the need to expand supply indefinitely (Tortajada, 2006a & 2006b; Marques, 2010; Tortajada, Joshi &

Biswas, 2013). Another significant policy has been to encourage private sector investment in the water economy and public-private partnerships which has been critical to the strategies of expanding water supply through reclaimed water and desalination.

The Israeli water governance regime that emerged between 1948 and 2000 was initially innovative but as the water economy evolved it proved complex, inefficient, reactive, and fragmented system where key stakeholders often had competing agendas, and water allocation was by politically motivated state fiat rather than market price or highest value use. The result of this institutional arrangement, and its sub-optimal operation, were water resources that were over-exploited, inefficiently allocated, under-priced, and under-valued which threatened the sustainability and resilience of the water economy (Galnoor, 1978; Marin et al., 2017). The reforms in the 2000s led to the creation of the more politically independent Israeli Water Authority (IWA) to replace the Water Commission, required ring-fencing of municipal to water services, introduced greater economic and financial discipline into the water economy, made both utilities and all consumers face the true environmental and economic costs of supplying fresh water and treating waste water, encourage greater private sector investment and management into the water economy, and stimulated a series of innovations that succeeded in gradually restoring a sustainable water balance (Siegel, 2015; Marin et al., 2017).

The strategy of government designing and implementing appropriate policies, regulations, and procedures to encourage innovation and entrepreneurship in clusters and facilitate the commercialization, diffusion, and adoption of water-related technologies answers research questions one and two: (1) governments do intervene to promote the development of industrial clusters, and (2) they employ a suite of public policies and strategies to support the development or expansion of water technology innovation clusters. Table 11.1 below provides a sample of policies, regulations & procedures which governments in the six clusters employed and this validates the first of the EPA's nine strategies for cluster development.

Table 11.1. Sample of Policies, Regulations & Procedures to Support Water Technology Clusters

Country	Innovation Legislation	Environmental Legislation	Policy/Plan	Agency
USA (Federal)	US Federal Technology Transfer Act (1986) Small Business Technology Control Act (1948) Technology Transfer Act (1992) Small Business Research & Act (2013) Water Development Enhancement Act (1992) Water Resources Development Act (2016)	Federal Water Pollution Control Act (1948) Clean Water Act (1972) Water Resources & Development Act	Strategy for American Innovation	EPA SBA
Cincinnati			RUN Agreement	
Milwaukee			Milwaukee 7 Framework	MMSD
Tacoma	Innovation Partnership Zone	Growth Management Act (1990)	Puget Sound Water Quality Plan	Puget Sound Water Quality Authority Tacoma Environmental Services
Netherlands		Groundwater Act (1981) Surface Water Pollution Act (1969) Soil Protection Act (1986) Water Management Act (1989) Water Supply Acts (1957) 1975& 2000 Water Ownership Act (2004). Water Services Act (1992)	Top Sector Alliance for Innovation and Knowledge	
Singapore	Government Procurement Act (1997)			PUB
Israel	Water and Sewerage Corporations Law of 2001	Water Law (1959)		Water Authority Water Board

B. Research and Development.

The sustainability and competitiveness of the emerging water economy is heavily dependent on the development and commercialization of water technologies that increase the efficiency of water use, reduce the amount of energy that are required to treat and move water, and reduce the levels of pollution that enter the water cycle from human activities. A critical role of water technology clusters is the development and commercialization and diffusion of new water technologies and adoption of existing technologies developed elsewhere. All six clusters governments have established formal policies, systems, and processes to encourage and leverage R&D undertaken by a network of government laboratories, universities or other research institutions to facilitate the development, commercialization and diffusion of water-related technologies.

This strategy supports the assertion by Porter (1998) in the Diamond Model that upgraded and advanced factors play an important role in encouraging and stimulating the development of competitive industry clusters and that governments can facilitate upgrading factors by supporting R&D. It also supports the assertion by North (1990) that the kinds of skills and knowledge which are developed will shape the direction of change and gradually alter the institutional framework of a socio-economic system. Government support for R&D can influence the speed, direction, and magnitude of institutional change. This strategy also supports the assertion by Rodgers (2003) that an innovation-diffusion process should reduce uncertainty about an innovation and speed up its rate of adoption. Public support for R&D can increase knowledge of an innovation’s existence and its observability to potential adopters, thus reducing uncertainty and speeding up its rate of adoption.

In the United States both the federal government and private universities lead the engagement into water technology research. The EPA provides funds for R&D to help attract technology firms to water technology clusters, while the SBA provides other technical support that encourages the diffusion of the innovations that result for these collaborations. Most US clusters water technology have emerged in cities with universities engaged in water-related research, large pools of engineers and scientists, water intensive and water enabled industries, and challenges related to fresh, waste, and storm water. At the cluster level both the Global Water Center and the Center for Urban Waters have facilities to support a limited R&D capability. The R&D framework in each US cluster has also garnered considerable experience addressing local problems especially in the areas of urban stormwater, pollution of freshwater and estuary systems. The local environment provides a unique real-life laboratory for addressing many water quality issues affecting urban centers and the natural environment. The R&D, innovation, and entrepreneurship landscape in the United States has implications for the US securing global technological leadership in the water technology industry, which justified public intervention: the US water technology landscape already suffers from a low rate of entry of young people into science, engineering and technology fields, especially environmental disciplines; water technology does not attract significant amounts of funding, both public and private, for R&D; and too much of the research into the water economy is closer to social science than the basic or applied science and technology which is required to build a viable technology sector (Miller, 2017).

The globally competitive position of Dutch water technology industry would not be possible without public, private, and academic investments in water-related innovation, entrepreneurship, and R&D. Dutch universities produce many competent water scientists and hydraulic engineers; its researchers are highly productive in publishing peer reviewed journal articles and in securing patents; and its entrepreneurs and innovators have an outstanding track-record in commercializing water technologies. Despite the technological standing of the Dutch water technology and environment sectors, the level of funds available for R&D falls far behind other 'Top Sectors' which are more commercially attractive.

In Singapore the government views R&D in its high-technology sectors as a key driver for economic growth and a strategic investment in the city state's long-term competitiveness. The government supports water technology with sustained public R&D investment and the institutional framework to allocate this support in a targeted and strategic manner. The institutional framework for R&D is underpinned and led by several key public agencies which ensures that the country builds and maintains local knowledge and expertise. Singapore's public universities are producing a cadre of competent water scientists and technologists and they have ample opportunity to practice their craft in both the public and private sectors. The challenge for the sector is that it remains highly dependent on R&D support from government and purchases from public utilities; and much of the private sector investment in R&D is a result of the presence of multi-national firms which Singapore has actively attracted to strengthen the local technology sector (UNESCO, 2015; Singapore Department of Statistics, 2017; Sagar, 2017).

Israel is the world's most research-intensive country, and this is linked to its investments in R&D and to innovation and entrepreneurship in its water technologies. Both the public and private sectors have considerable experience in an increasingly complex water economy which employs increasingly complex technologies to address a growing water deficit. Both public and private R&D play a key role in upgrading factors in the water sector whether through drip irrigation, recycling and reuse of used water, or desalination. Israel’s researchers are highly productive in publishing peer reviewed journal articles and in securing patents and its entrepreneurs and innovators have an outstanding track-record in commercializing water technologies. To develop and sustain its specialized and advanced factors Israel's water economy is well supported by public and private funding for R&D; and its universities produce a large number of competent scientists and engineers (Peled, 2001; Frenkel, Shefer & Miller, 2008; DeHaan, 2008; Isenberg, 2010; UNESCO, 2015; Ben-Zoor & Priampolsky, 2016).

The strategy of government establishing an institutional framework of formal policies, systems, and processes to encourage and leverage R&D undertaken by government laboratories, universities or other research institutions to facilitate the development, commercialization and diffusion of water-related technologies answers research questions one, two, and six: (1) governments do intervene to promote the development of industrial clusters, (2) they employ a suite of public policies and strategies to support the development or expansion of water technology innovation clusters, and (3) the institutional setting of a jurisdiction does affect the development and diffusion of innovative water-related technologies. Table 11.2 below provides a sample the network of R&D partners which governments in the six clusters helped build; and this validates the second of the EPA’s nine strategies for cluster development.

Table 11.2. Research & Development Partners in Water Technology Clusters

Country	Research Centre	Universities	Industry Partners
USA (Federal)	Andrew W. Breidenbach Environmental Research Center		
Cincinnati		Universitiy of Cincinnati Universitiy of Dayton Universitiy of Northern Kentucky	Northern Kentucky Sanitation District Duke Energy
Milwaukee	Global Water Center	School of Freshwater Sciences, UWM	Veolia
Tacoma	Center for Urban Waters Institute for Environmental Research and Education	UW, Tacoma Washington State University	Parametrix GeoEngineers and CH2M HILL
Netherlands	TTIW Wetsus UNESCO – IHE Water Application Center	Wageningen University University of Twente University of Groningen TU Delft VHL University	Wetsalt Vitens Innovation Sentec
Singapore	Public Utilities Board	Nanyang Technology University Singapore National University	PWN Technologies Hyflux
Israel	Grand Water Research Institute Center for Water Sensitive Cities	Technion Ben-Gurion University Tel Aviv University Birziet University Hebrew University	TAHAL Merkorot- WaTech

C. Supporting Technology Transfers and Commercialization.

The public sector is both a major developer and consumer of water technologies through its historic responsibility for water infrastructure. The public sector is also a regulator of the water sector through its historic responsibility for the protection of public and environmental health. This requires that the public sector have policies and an institutional framework to facilitate the transfer of technology between key stakeholders, especially from the public to the private sector given that the scale and scope of the role of the latter is increasing in the emerging water economy. All six clusters have established formal policies, systems, and processes to facilitate the transfer of technology between key stakeholders, and in most cases this institutional framework was created initially by the public sector.

This strategy supports the assertion by Porter (1998) in the Diamond Model that related and supporting industries can stimulate other companies in the water value-chain to upgrade their factors and innovate, and that government can influence each of the five other forces in the Diamond model to encourage and stimulate the development of competitive firms and industry clusters. North (1990) points out that well-established socio-economic systems are hard to change and display tendencies towards path dependence. Change requires entrepreneurs who change the incentive regime as well as promote new skills and knowledge. This strategy also supports the assertion by Rodgers (2003) that the innovation-diffusion process goes through five distinct stages from 'knowledge' to 'confirmation' with each stage having an uncertainty bottleneck to clear before adoption can be considered complete.

In the United States the federal government is taking a lead role in supporting the transfer, commercialization, and diffusion of water technologies. The EPA in Cincinnati, for example, carries out research projects and develops methods, models, and tools that help states and communities assess environmental risks and make decisions to safeguard the environment, public water systems, and public health. This research is of technical and commercial value to innovators and entrepreneurs and can positively impact local economies. The EPA also partners with local utilities to facilitate the commercialization of technologies by making it easier for companies to try out their innovations in controlled, government-approved settings. In addition, the three US industry associations studied all formally support water innovators, entrepreneurs, and universities in the transfer and commercialization water technologies for industrial, utility, and environmental markets.

Confluence, through its multistate memorandum of understanding between regulators from Ohio, Kentucky and Indiana, has facilitated a process designed to simplify and expedite the commercialization process of water technologies by allowing startups and firms to get water innovations approved by all three states at once. The Water Council, through its Innovation Commercialization Exchange (ICE) Institute, identifies and evaluates promising and emerging water technologies from across the full spectrum of the water R&D community and connects these technologies to water related industries - including utilities, agriculture, and manufacturers. The Center for Urban Waters is building on the nationally and globally recognized expertise of the City of Tacoma in environmental remediation and storm-water management, much of which comes from experience built up from the clean-up and restoration of the former Superfund site at Commencement Bay. The Center provides a repository for this scientific knowledge and technical expertise, a world-class research center, and a collaborative intellectual environment where a diverse mix of environmental scientists, analysts, engineers and policymakers develop policy and design and implement creative and sustainable solutions to restore and protect the Puget Sound.

In The Netherlands there exists institutional mechanisms for the transfer of technology between stakeholders and the commercialization of water technology at both national and local levels. At the national level the Rijkswaterstaat, through its historic role of knowledge management and information dissemination, and as a demanding and sophisticated purchaser of engineering services, contributes significantly to innovation and entrepreneurship in the Dutch water economy (Lintsen, 2002; Lonnquest et al., 2014). Current Dutch national economic policy employs the concept of the quadruple helix which ensures that government, research institutes, and businesses combine and transform their knowledge and expertise into innovative products, services, and skills that deliver smart, cost-effective, and commercially viable solutions for the management of water resources.

At the cluster level, the Water Campus in Leeuwarden employs a model called the Water Technology Innovation Chain to support water technology firms accelerate the time to commercialization and increase the rate with which technologies are successfully commercialized. This is achieved by bringing together in a single, central location all the supportive institutional elements which entrepreneurs and innovators would require throughout the whole commercialization process, from idea to business. The Water Campus provides a single focal point for education, scientific and technological knowledge, business support, and match-making related to water-and-wastewater.

At the firm level, Dutch water technology firms benefit from a combination of a very strong scientific and technological position, strong and technically stringent demand, and decades of international experience; however, the scientific and technical capacity for Dutch firms to develop technologies is not well supported by the entrepreneurial and innovative capacity to commercialize these technologies due to a paucity of home entrepreneurs, a weak entrepreneurial spirit, a cultural reluctance to take risks, and a regulatory regime which generally does not reward risk taking. These are issues which are generic to innovation in The Netherlands, weakens the national and sectoral innovation systems, and makes it difficult to translate knowledge and experience to commercially successful business ventures (van der Veen, 2010).

In Singapore the public, private and academic stakeholders in water technology cooperate closely under a robust institutional framework established by the government to attract foreign water companies to Singapore, provide R&D funding, and help Singapore-based companies and research institutes develop and commercialize water technologies for the global marketplace.

Israel’s flourishing and globally competitive water technology sub-sector is a model of the successful transfer and commercialization of water technologies. This was not always the case. In the decades prior to 1990, the transfer and commercialization of water technologies in Israel suffered from a weak institutional framework to support innovation and entrepreneurship, and the transfer and commercialization of water technology was shaped by public policies that focused the industry on expanding supply to the politically powerful agricultural stakeholders through exploration, well drilling, and water transportation from water endowed regions to water deficient region of the country. Organizations which were early in recognizing the unsustainable nature of Israel's existing water policy were initially ignored until water shortages in the 1990s, but this unreceptive environment encouraged water innovators and entrepreneurs to look overseas to develop markets for their technologies. When the water innovation environment changed from the 1990s onwards, in response to both politico-ideological shifts and severe droughts, the water technology industry was sufficiently mature to overcome its early fragmentation and build networks that better integrated public sector, private sector, and academic stakeholders and dramatically improve the institutional arrangements for the transfer and commercialization of water technologies. Within the Israeli water economy, innovation, entrepreneurship, technology transfer, and technology commercialization occurs through a 'triangle of innovation' that integrates all stakeholders into a water technology ecosystem. Each element of the triangle – the private sector, government, public and private utilities, and universities - brings a different contribution to the ecosystem.

The strategy of government establishing an institutional framework of formal policies, systems, and processes to facilitate the transfer of water-related technologies between key stakeholders answers research questions one, two, and six: (1) governments do intervene to promote the development of industrial clusters, (2) they employ a suite of public policies and strategies to support the development or expansion of water technology innovation clusters, and (3) the institutional setting of a jurisdiction does affect the development and diffusion of innovative water-related technologies. Table 11.3 below provides a sample of the channels for supporting the transfer, commercialization, and diffusion of water technologies which governments in the six clusters helped build; and this validates the third of the EPA’s nine strategies. The channels include networks of public sector research institutions, regulatory agencies, public-private partnerships of various kinds, private incubators and accelerators, industry associations, and public and private utilities.

Table 11.3. Sample of Channels for Supporting the Transfer, Commercialization, and Diffusion of Water Technologies

Country	Public	Public-Private	Private	Industry Associations	Utilities
USA	Andrew W. Breidenbach Environmental Research Center				
Cincinnati				Confluence	
Milwaukee				Water Council	MMSD
Tacoma	City of Tacoma Economic Development Board	Center for Urban Waters Institute for Environmental Research and Education			City of Tacoma Environmental Services
Netherlands	Rijkswaterstaat	Water Technology Innovation Chain, Leeuwarden			
Singapore	Public Utilities Board Economic Development Board International Enterprise Singapore SPRING Environment and Water Industry Programme Office	HydroHub Water Center of Excellence Center for Advanced Water Technology		IWA SWA	
Israel	Water Authority Water Board	Israel Export and International Cooperation Institute Tahal Israel Tech Transfer Organization Israel Science Foundation	Kinrot - Incubator	IWA	Merkorot-WaTech

D. Facilitating Communication and Diffusing Knowledge.

Communication, through networks, personal relationships and community ties, is vital for the success of organizations and institutions (North, 1990; Porter, 1998; Rodgers, 2003). The highly fragmented water economy and water technology industry requires the creation of robust networks for facilitating communication and knowledge diffusion. The diffusion of knowledge is a fundamental function of a socio-economic system. Water stakeholders need a wider range of detailed information about regulatory requirements and technology performance, and the characteristics of stakeholders, such as who is connected to whom. The type, quantity, and speed with which information flows all impact the performance of the industry. Water technology networks are complex social systems made up of heterogeneous stakeholders who must cooperate and coordinate their activities and learn from each other. This suggests the need for distributed or organic networks rather than traditional hierarchies. All six clusters have established formal policies, structures, and processes to facilitate communication and knowledge diffusion, and in most cases this institutional framework was created initially by the public sector.

This strategy supports the assertion by Porter (1998) in the Diamond Model that industry structure, related and supporting industries, and government can influence communication and knowledge diffusion and stimulate the development of competitive industry clusters. This strategy would align with North's (1990) suggestion that robust institutional arrangements for collaboration, coordination, and information sharing are important in the water technology industry because stakeholders need more information to make decisions and reduce information asymmetries to minimize transaction and agency costs. This strategy would also align with Rodgers (2003) five-stage model for innovation-diffusion in that the structure for communication and diffusion of knowledge and innovations are central to the efficiency of the water technology industry and thus its competitiveness.

In the United States the creation of networks and communication channels that better integrate the water technology value-chain and facilitate water technology commercialization and diffusion have been key to building water technology clusters. At the national level one of the key goals of the EPA's cluster program has been to build networks and facilitate communication. The EPA does this through active support for the creation of industry associations to connect key stakeholders across organizational and disciplinary boundaries within the water industry. More robust connections between water stakeholders create synergies that increases the economic potential of the entire water industry. The EPA has also supported the publication of market analysis and technology reports on the companies and market trends shaping innovation the U.S. drinking water sector. These strategies are repeated at the local level in all three US water technology clusters through multiple strategies: establishing of regional networks, hosting of conferences, building bridges with other water clusters around the world, developing green infrastructure to promote sustainability, and conducting public education, facility tours and presentations on water quality issues and the impact of climate change.

In The Netherlands the institutional arrangements for facilitating communication and diffusing knowledge occurs at multiple levels. At the national level the Rijkswaterstaat's role of 'knowledge creator and diffuser' and 'knowledge absorber' has been well institutionalized. The Rijkswaterstaat is a knowledge intensive agency that creates and supplies innovations to its sub-contractors and to water resource partners at lower political scales; and it also absorbs innovations from its suppliers, sub-contractors, and research partners. The Rijkswaterstaat is staffed by highly trained and experienced technical and policy personnel in possession of a 'hydraulic imagination' and with a willingness to experiment, which are key preconditions for communication and knowledge diffusion. The Netherlands is also a top performer in the production of scientific publications, far ahead of the EU and the United States. The Dutch government also works to raise the profile of the water sector: water technology firms may receive national honors and awards for excellence in science, technology, and innovation. Public efforts at communication and knowledge diffusion are complemented by the work of other organizations such as the Netherlands Water Partnership (NWP) which is an independent body which represents the Dutch water sector on the global stage. The NWP is committed to solving global water related challenges through the exchange of information on Dutch water expertise, by supporting water policy developments, and by expanding market opportunities for its members through trade missions, exhibitions and conferences. At the local level the city of Leeuwarden, through The Water Campus, is hoping to act as a 'hub' for a worldwide network of water technology businesses and research organizations and to serve as a central point where knowledge about water is collected, where innovation takes place, and where water technology is commercialized (Ebbekink & Lagendijk, 2017).

In Singapore inter-agency coordination and public outreach have long been strengths of the institutional framework for water resource management, and this has facilitated communication and knowledge diffusion among key stakeholders involved in environmental protection, public health, and water-and-wastewater management. The network of public agencies and private associations help water companies in marketing their products and services, in building networks with potential partners, and in facilitating local water companies and related organizations to work closely with government agencies on water technology development, skills acquisition and industry missions. The Water Network, for example, employs a networking strategy that provides a platform for the people, private and public sectors (3Ps) to meet, share information and give views to the PUB on policies and programs concerning all aspects of the city state's water. Singapore's institutional arrangements for facilitating communication and diffusing knowledge about water, sanitation and environmental considerations goes beyond that of any other cluster studied and includes companies developing water technologies, other players in the water economy, and the general public.

In Israel the water technology sector initially lacked robust formal mechanisms for effective and efficient communication and knowledge diffusion of its water technologies, especially for technologies and expertise developed in the public sector. For many years detailed water studies and water plans were produced but largely ignored due to the development priorities and political influence of a narrow segment of the water economy, namely agricultural interests and their allies in government. After economic liberalization in the 1980s and the water crisis of the 1990s, better institutional arrangements for communication and knowledge diffusion in both the public and private sectors emerged. In 2004, Mekorot established WaTech to carry out R&D, support innovators and entrepreneurs from both start-ups and mature companies and find solutions via cooperation and collaboration with different water stakeholders both nationally and internationally. WaTech is responsible for developing and registering patents as Mekorot's intellectual property, and in applying information and database management to enrich the professional knowledge at the disposal of the Mekorot group and its industry and academic partners. Israel's water and wastewater industry has also hosted in Israel several three-day biennial Water Technology and Environmental Control Exhibition & Conferences, as well as in Peru and Italy. Israel's researchers are also highly productive in publishing peer reviewed journal articles and in securing patents.

The strategy of government establishing an institutional framework of formal policies, systems, and processes to facilitate communication between key stakeholders and knowledge diffusion answers research questions one, two, and six: (1) governments do intervene to promote the development of industrial clusters, (2) they employ a suite of public policies and strategies to support the development or expansion of water technology innovation clusters, and (3) the institutional setting of a jurisdiction does affect the development and diffusion of innovative water-related technologies.

Table 11.4 below provides a sample of the channels for facilitating diffusion of knowledge and increasing communication among water stakeholders which governments in the six clusters helped build; and this validates the fourth of the EPA's nine strategies. The key channels identified were industry, professional, and technical publications, capacity building mechanisms, conferences and workshops for dissemination of knowledge, and the creation of industry associations for networking and advocacy.

Table 11.4. Sample of Channels for Facilitating Diffusion of Knowledge & Increasing Communication among Water Stakeholders

Country	Publications	Capacity Building	Conferences	Associations/Partnerships
USA (Federal)	U.S. Drinking Water Innovation Vendor Outlook Report Mapping Report on Proposed Water Cluster in Cincinnati Region		EPA Annual Drinking Water Conference EPA Annual WTIC Leaders Meeting WH Water Summit	
Cincinnati		Confluence Water Research Consortium	Groundwater Conference	Confluence Regional Utility Network
Milwaukee		Coaching/Mentoring of Innovators/Entrepreneurs MMSD-Public Education/Tours	Global Water Conference	Leeuwarden/Monpelier Tianjin
Tacoma	Encyclopedia of the Puget Sound Puget Sound Institute	Collaborative Research, Policy Making & Environmental Projects	Wellspring Conference	Center for Urban Waters
Netherlands Partnership	Dutch Water Sector	Rijkswaterstaat	WEFTECH	Netherlands Water
Singapore	Innovation in Water - PUB Environment and Water Industry Programme	Public Utilities Board Water Week (SIWW)	Singapore International Singapore Water Association	HydroHub
Israel	Water Technology in Israel- Bank Leumi	KLL-Jewish National Fund IsraAid/MASHAV Merkorot-WaTech	Water Technology& Environmental Control Exhibition & Conference	Merkorot-WaTech Israel Tech Transfer Organization

E. Cluster Champions

Champions are critical to the facilitation of the cross-agency cooperation that is necessary to build and sustain a business cluster. The formation of individual business, industries and clusters are often formed because of the vision, persistence, and magnetism of individuals or small groups who invest significant time and personal capital in building the social capital which will ultimately sustain the firm or industry. Champions can come from the private or public sectors and volunteer or are selected to facilitate change and communication. All six clusters have had champions but not all were individuals nor industry leaders: where the public sector played a leading role the cluster champion was often a politician or a public entity.

This strategy recognizes that the pressure to strive for competitive advantage often arises from leadership which recognizes the need for change, embraces change, and promotes innovation and the upgrading of factors; and leaders help harness and amplify systemic forces of the diamond (Porter, 1990). This strategy aligns with North (1990) who asserts that the need for change creates opportunities for entrepreneurs who recognize the benefits that could flow from institutional changes, but he cautions that there exists a tension between those who seek to promote change and those who seek to maintain the status quo which results in path dependence for a socio-economic system. The strategy also supports Rodgers (2003) assertion that innovativeness and the innovation-diffusion process are both socially-constructed and different groups have different rates at which they are willing to adopt innovations. Champions are themselves often innovators and entrepreneurs who act as gatekeepers and facilitate innovations being brought into a socio-economic system.

In the United States champions have been important in pulling together a coalition of stakeholders that is required to build and sustain water technology clusters. These champions have included politicians, policy makers, planners, business leaders, researchers, and academics. At the federal level the EPA's Sally Gutierrez has emerged as the national champion for the water technology industry and the focal point for federal support for emerging water technology clusters. At the cluster level the membership of the board of directors for Cincinnati's Confluence is drawn from across the tri-state region and is composed of a variety of leaders and experts from industry, government and academia. Allan Vicory, the first Chairman of Confluence, is a national and international leader on water quality and water resource management issues with 40 years' experience in river basin management. For 24 years, Vicory served as the Executive Director and Chief Engineer of ORSANCO, an eight-state agency established to control and abate water pollution in the Ohio Basin. Vicory currently works with Stantec, where he manages regulatory interface, watershed planning, and water quality initiatives. The champions behind the formation of The Water Council were the chief executive officers of two Milwaukee water technology companies, Rick Meeusen of Badger Meter and Paul Jones of A.O. Smith, who took up a latent idea and made it a reality. In 2006 Meeusen and Jones convened a meeting of local business, civic, and academic leaders to formulate a vision, work out a strategy, identify resources, and prepare a plan to make Milwaukee into a regional and global center for freshwater expertise and technologies.

On the other hand, Tacoma's water technology cluster lacks the type of champions found in Cincinnati and Milwaukee, especially from the private sector. The water technology industry in Washington State is much more fragmented and geographically dispersed than Milwaukee or Cincinnati and it lacks an industry association to match Confluence or the Water Council. Public sector agencies and academic institutions provide most of the staffing and operational support for the Tacoma IPZ at the Center for Urban Waters. The main figures to champion Tacoma's water technology cluster are therefore from the public sector and academia which reflects the nature of the work which dominates the agenda of the cluster, the restoration and protection of the Puget Sound. Tacoma's cluster has also suffered from a high rate of turn-over of key leaders in several of its member agencies. Nevertheless, the leadership at the Center for Urban Waters have been engaged in building on the Tacoma's assets, crafting a strategy for growing the cluster, and achieving the center's vision and mission of creating a world-class research facility dedicated to finding solutions to the problems of urban living and its impact on the environment. The leading role of private sector champions is most U.S. clusters is reflective of the preeminent role of the private sector in economic life and the country's strong culture of entrepreneurship.

In The Netherlands the champions of the water industry also come from both the public and private sectors, however the public sector has historically played a particularly central role at both the national and local levels. At the national level the Rijkswaterstaat has for 200 years provided leadership, technical support, coordination, and knowledge for the Dutch water sector primarily through major public infrastructure works. The Netherlands is a water-centered society and the Rijkswaterstaat, the single most powerful Dutch public institution, is at the cultural and technological heart of the country. In the city of Leeuwarden, the city's planners and policy makers are active champions for the water technology cluster centered at the Water Campus.

The Dutch water industry has recently seen the emergence of several strong associations that work closely with the public sector to support the water sector. The Netherlands Water Partnership (NWP), located at the International Water House in The Hague, is a partnership of public and private, profit and non-profit organizations, and knowledge institutions that support the water sector, primarily in export and international cooperation. The NWP was founded in 1998 by Jeroen van der Sommen who, after a long career in managing water supply projects on behalf of organizations such as the World Bank and the European Union, built the association into a partnership of 200 organizations. The goal of the NWP is to offers its members networking, knowledge sharing, visibility and influence. The Water Alliance, founded in 2010 in the Northern Netherlands, is another partnership of Dutch public and private companies, government agencies and knowledge institutes involved in water technology. The goals of the Water Alliance are to supports the progress of the Dutch water technology sector through networking, and to reinforce the development of the Leeuwarden Water Campus as the physical core of the Dutch water technology industry. Its Supervisory Board is made up of leading figures from the regional governments, knowledge institutions, and water industry and it is located at the Water Campus in Leeuwarden. ENVAQUA is a Dutch trade association for 125 suppliers and producers of environmental and water technologies with a combined worldwide turnover of EUR 4.2 billion and 20,000 employees. ENVAQUA’s goal is to connect Dutch technology companies with customers around the world, increase export opportunities of its members, and support collaborations with its partners to promote innovation and knowledge development. It was formed in 2015 from the merger of two industry associations that were themselves formed in the 1980s.

In Singapore the main champions of the water sector were historically from the public sector beginning with its first prime minister, Lee Kwan Yee, who recognized that water was a strategic resource that was key to economic development, public and environmental health, and national security. During his tenure he closely supervised the water sector. Singapore's case suggests that a combination of strong political will, sustained public support, and a sense of urgency are required to marshal the resources and maintain the focus over the decades that are often required to solve water challenges. The vision of Lee helped to create a sustainable and comprehensive institutional framework which is underpinned by several important public agencies. The Ministry of the Environment and Water Resources (MEWR) manages water as a strategic national resource; the Public Utilities Board (PUB) holistically manages the country's water supply, water catchments, and used water; the National Environment Agency implements the environmental policies established by the MEWR; the Environment and Water Industry Development Council (EWI) turned the environment & water industry into a strategic growth area; local public universities develop human capital to carry out basic and applied research; the Agency for Science, Technology and Research (A*STAR) raises the level of science and technology competency in Singapore; the Economic Development Board (EDB) turns local companies into internationally competitive high-technology enterprises; and the Singapore Water Association (SWA) for promotes Singapore as a point of reference for all water technologies and services.

In Israel two key figures, Levi Eskhol and Simcha Blaas, were critical to the early development of the country's water economy; but individual personalities have become less important as champions of the water economy as water institutions and institutional arrangements have become more established. Levi Eskhol and Simcha Blaas began laying the foundations for Israel's water institutions and water economy in the 1930s and developed a comprehensive philosophy and strategy to address the problem of water supply. This approach led to institutions and institutional arrangements dominated by the public sector and political priorities. These men helped to create and lead organizations such as Mekorot Water Company and Tahal, and Levi Eshkol served as head of Mekorot, Minister of Agriculture and Development, and Prime Minister, and he was also active in the promotion of industries that were necessary to support and sustain the development of water projects. Shima Blass, a hydraulic engineer, was a key figure in designing the Israeli National Water Carrier, an innovator and entrepreneur in drip irrigation, and founder of Netafim Irrigation Company in 1965 which now employs 3,000 people and operates in 150 countries through 37 subsidiaries, with 13 factories. Blass had struggled for years to both perfect drip irrigation and overcome institutional resistance and intellectual skepticism to this technology.

The changing political, economic, demographic and environmental landscape from the 1980s has seen the Israel's water economy evolve and restructure, the private sector increase the scope and scale of its involvement, reforms in the legal framework, and the rise of new water institutions and institutional arrangements. The current context lacks individual champions such as Eshkol and Blass, but the industry is now represented by an increasingly robust public-private institutional framework reflective of its increasing maturity. The Israeli water industry is represented by the Israeli Water Association (IWA) which was founded in 2001 as an interdisciplinary professional body representing institutions and organizations involved in water and the water industry. The goals of the IWA include the dissemination of information that helps solve water problems, influencing decision-makers in government and institutions to use evidence-based policy that supports the continuous optimization and improvement of Israel's water economy, and maintaining Israel’s links to leading international organizations such as the International Water Association (IWA) and the American Water Environment Federation (WEF).

The strategy of government encouraging or supporting champions who facilitation of the cross-agency cooperation necessary to build and sustain water technology clusters answers research questions one and five: (1) governments do intervene to promote the development of industrial clusters, and (2) individual or organizational champions do facilitate the development and diffusion of water-related technologies and enhance the competitiveness of water technology innovation clusters. Table 11.5 below provides a sample of the champions for water technology clusters; and this validates the fifth of the EPA’s nine strategies. All six clusters had champions and they played instrumental roles in every case: some were individuals while others were organizations; and some came from the public sector while others were from the private sector.

Table 11.5. Examples of Water Technology Cluster Champions

Country	Political	Public Sector	Private Sector	Industry Association
USA		Sally Guiterrez		
Cincinnati			Allen Vickory	Melinda Keuyer
Milwaukee	Mayor		Rick Meeusen Paul Jones	Dean Amhaus
Tacoma		Tacoma IPZ		
Netherlands		Rijkswaterstaat Water Campus		Jeroen van der Sommen/ Netherlands Water Partnership Water Alliance ENVAQUA
Singapore	Lee Kwan Yee	Ministry of the Environment and Water Resources Public Utilities Board Environment and Water Industry Development Council A*STAR Economic Development Board		Singapore Water Association
Israel	Levi Eskhol	Simcha Blaas Merkorot		Israeli Water Association

F. Public-private partnerships

Water and sanitation services are universally accepted as a public good whose universal provision supports public and environmental health, local economic development, and an internationally competitive economy. Water and sanitation providers must provide high quality, reliable services at affordable prices while facing complex challenges and ensuring the alignment with diverse stakeholder's objectives, often with conflicting expectations. The universal provision of this public good requires a good governance framework, significant financial capital for infrastructure provision and upgrading, a sustainable revenue stream to ensure financial viability, increasingly sophisticated technologies to minimize water losses and energy use, and sound management to ensure efficient service delivery to both domestic and commercial customers. Public sectors increasingly lack the resources and expertise to equally address all these challenges in an optimal manner and are increasingly turning to public-private partnerships (PPPs) as a desirable model to develop, improve and sustain water and sanitation services. PPPs allow governments who are ultimately responsible for the provision of water and sanitation services to allocate or delegate responsibilities for planning, designing, financing, constructing, and operating to the party optimally positioned to manage specific components of a water or sanitation project. PPPs also enable the public sector to access types of knowledge and skills it does not possess and to introduce innovation and entrepreneurship into project implementation and management that a purely public undertaking would find difficult. All six case studies demonstrate the increasing importance of PPPs, as well as both public and private sector innovation and entrepreneurship, to the delivery of water and sanitation services.

This strategy supports the assertion by Porter (1998) in the Diamond Model about the important role of government in setting the institutional framework for cooperation and competition, and also the role of industry structure and strategy, or how firms set goals and objectives, and are organized and managed, are all critical to competitiveness. This strategy of optimally allocating roles and responsibilities through PPPs addresses the concern of North (1990) for institutional and governance arrangements that increase cooperation and coordination and reduce transaction and agency costs. This strategy also reflects the concern of Rodgers (2003) for complexity and its negative impact on the innovation-diffusion process. An innovation will not be adopted unless stakeholders understand ‘how’ and ‘why’ an innovation works and this requires a thorough understanding of ‘how-to-knowledge’ and ‘principles-knowledge’ related to the innovation. Excessive complexity is negatively correlated with the rate and speed of adoption of innovations, and well-structured PPPs can introduce governance arrangements that reduce complexity, and technical and management arrangements to ensure that it is used correctly.

In the United States governments at all levels are becoming increasingly entrepreneurial as a strategy to encourage local economic development and provide traditional public services in the most efficient and effective manner. Public-private partnerships are increasingly a key component of this entrepreneurial strategy. In Cincinnati the city government, local public utilities, local businesses, local universities, non-profits in economic development, venture capitalists, and universities involved in education and research enter partnerships to implement projects such as the MetroWest Commerce Park, to attract high-volume, high-water-quality users to Cincinnati, and Pipeline H2O, a business incubator which specializes in advanced manufacturing and clean technologies. In Milwaukee The Water Council actively brings together research entities, existing businesses, start-ups, and government agencies to commercialize technology, promote water entrepreneurship, and increase access to capital; while the Milwaukee Metropolitan Sewer District maintains a PPP with Veolia Water to operate and maintain the city's two sewage treatment plants and other facilities while the MMSD retains ownership. Tacoma's Center for Urban Waters is a collaboration of the City of Tacoma, Port of Tacoma, Economic Development Board for Tacoma-Pierce County, Washington Economic Development Commission, University of Washington Tacoma, and Washington State University, it was financed with tax-exempt 63-20 bonds, and its board it made up of members from the public and private sectors and academia. The

Center houses offices, laboratory space, and water research and testing facilities, and researchers from the University of Washington and Puget Sound Partnership, and the City of Tacoma' Environmental Services Division labs and offices staff.

In The Netherlands the public and private sectors have always collaborated in the water economy. Traditionally the public sector served as contractor and developer of infrastructure which the private sector built; however, the allocation of roles and responsibilities has evolved as the water economy has become more complex and water technology has become more sophisticated. Public-private partnerships (PPPs) as an organizational structure and contractual arrangement are becoming increasingly important as evidenced by the increase in the scale and scope of industry associations, business and technology incubators, and research facilities. In the province of Friesland, the municipality of Leeuwarden has brought together the Water Alliance, and research institutes Wetsus and CEW, under The Water Campus. The various Dutch water industry associations such as the NWP, the Dutch WA and ENVAQUA are all PPPs. Public-private partnerships in the form of contractual arrangements such as Design-Build-Own-Operate (DBOO) are used in the Netherlands for water-and-wastewater infrastructure and services because this structure has demonstrated the ability to build a consortium, carry the risk of large, long-term investments, and apply appropriate technological solutions to urban water problems. The Delfland Water Board, responsible for wastewater treatment for The Hague, was the first city to opt for a PPP in the Dutch water sector. The Delfluent PPP is considered a model for encouraging good governance and public accountability in water services because the contractual arrangement allows for independent verifications and audits, performance monitoring, parliamentary oversight, and independence from conflicting commercial interests.

In Singapore, water and sanitation was historically the preserve of the government. In 2003 the government officially introduced PPP schemes and private sector participation in service provision and it has become increasingly important in the water economy. The institutional framework for the water economy now includes various public-private and private-private relationships to complement traditional public-public arrangements. For PPPs, delegated public management is the preferred arrangement for new water-and-wastewater facilitates, usually taking the form of 15-30-year Build-Design-Own-Operate (BDOO) contracts. The scope of PPPs in water and wastewater in Singapore is not, however, as great as in other sectors because the severe scarcity of water makes it a strategic resource over which the government must maintain considerable direct control. Delegation to the private sector and the use of PPPs have thus been confined to NEWater and desalination plants.

In Israel the public sector at both national and local scales traditionally dominated the water economy and the provision of water and sanitation services. The private sector has long played a role in the water economy, particularly in the water technology sub-sector. In recent years the private sector has also become increasingly involved in service provision in the utility sub-sector in response to an increasingly complex water economy which employs increasingly complex technologies. This shift in policy has largely been driven by a neo-liberal turn in Israeli policy and governance which has been underway since the 1980s and which has accelerated since the 2000s with the expansion of desalination and reforms to municipal water-and-wastewater services. PPP contracts are an important feature of the corporatization of water utilities and are designed to improve operational performance, reduce costs, raise private funding for infrastructure investment, ensure the financial sustainability of major infrastructure, and increase access to technology and expertise.

The strategy of government increasingly encouraging or supporting PPPs to optimally allocate roles and responsibilities within an increasingly complex water economy answers research questions one, two, four, and six: (1) governments do intervene to promote the development of industrial clusters, (2) they employ a suite of public policies and strategies to support the development or expansion of water technology innovation clusters, (3) they are increasingly strategic about the allocation of roles and responsibilities – or the division of labor – between public and private partners in developing or expanding water technology innovation clusters, and (4) the institutional setting of a jurisdiction does affect the development and diffusion of innovative water-related technologies.

Table 11.6 below provides a sample of the PPPs employed in each water technology clusters; and this validates the sixth of the EPA’s nine strategies. All six clusters employ PPPs and they play instrumental roles in every case; however, the way in which PPPs are employed does vary across jurisdictions. The United States and The Netherlands use PPPs much more broadly than Singapore and Israel, which partially reflects the traditionally stronger role of a well-established private sector. Israel and Singapore are newly independent states which emerged in the post-World War II era when state-led development was the dominant development model; and both countries faced water shortages which were strategic and immediate security risks which necessitated greater government control. The Israeli institutional framework is increasingly evolving to resemble what exists in the US and The Netherlands as the private sector becomes more established. In all the clusters, however, PPPs are an increasingly favored organizational structure and contractual arrangement for water and waste water utilities.

Table 11.6. Sample of Public-Private Partnerships in Water and Wastewater

Country	Research	Economic Development	Business Facilitation	Incubators	Utilities
USA	Andrew W. Breidenbach Environmental Research				
Center					
Cincinnati Park project		MetroWest Commerce	Confluence	Pipeline H2O	RUN
Milwaukee	School of Freshwater Sciences		The Water Council	The Water Council	MMSD-Veolia
Tacoma	Center for Urban Waters	Center for Urban Waters	Center for Urban Waters		
Netherlands	Water Campus Wetsus CEW-Leeuwarden	Water Campus	Water Campus Water Alliance NWP ENVAQUA	Water Campus	Delfluent
Singapore		HydroHub			Sembcorp NEWater Keppel NEWater Hyflux
Israel					Ashkelon Palmahim Hadera Sorek Ashdod

G. The Investing Community and Private Capital Markets.

The global market for water technologies offers huge economic opportunities; however, exploiting these opportunities requires access to appropriate sources and forms of finance. The ability of innovators and entrepreneurs to access appropriate sources and forms of finance depends on the governance frameworks and culture, the legal and regulatory environment, the nature and types of risk in the water economy, and the reward structures that are present. The water economy faces a number of challenges and bottlenecks: (a) financial flows from the private investment community into the water economy tend to be insufficient, (b) public spending on water is usually a small share of the budget, (c) profitability of utilities is often weak due to traditionally inadequate systems for cost recovery linked to pricing methodologies and practices, (d) utilities are capital intensive industries with long payback periods and a desire to recover sunk costs before investing in new technologies, (e) innovators and entrepreneurs find it difficult to field test and scale up technologies, (f) utilities are risk averse due to public health concerns and thus slow to adopt new technologies; (g) and startups and small firms do not have the resources to respond to market opportunities, nor the capacities to access already available sources of funding. This means that water technologies go through long cycles from R&D to commercialization, and that financing is dominated by government grants, loans, or public subsidies, or reliant on foreign aid in the case of developing countries. An innovative and entrepreneurial water economy, and water technology subsector, requires knowledge about access to finance and the development of new relationships between private funders, industry, technology firms, and research organizations to foster innovation. It also requires government, regulators and utilities committed to sustainable financial models based on full-cost recovery for water and wastewater services and which factor in a cost to reflect the scarcity value of water.

This strategy supports the assertion by Porter (1998) in the Diamond Model about the important role of government in setting the institutional framework, and also the importance of creating advanced factors such as efficient financial systems to support and sustain competitiveness. One reason why innovators and entrepreneurs struggle to raise adequate financial capital is incomplete or asymmetric information in the water economy. According to North (1990) institutional arrangements that improve the observability of human behavior and facilitate credible, third-party enforcement of contracts can help to improve the quality and quantity of information and the timeliness of its flow, which should in turn help increase the quantity of financial capital available and lower transaction and agency costs.

In the United States financing of utility investments, R&D, and technology commercialization usually come from quite different sources such as debt, grants, and venture capital with different payback periods and risk profiles. Capital improvements in municipal water systems, which can often require substantial investments, are usually financed with low-cost, long-term debt; the development and commercialization of water technologies, which are designed to save water, reduce energy consumption or prevent pollution, are more often financed out of retained earnings and grants from larger technology companies; and smaller technology companies usually seek grants, angel investors, and venture capital. Utility investments carry low risk despite long investment payback periods because water tariffs provide a steady revenue stream; while technology investments carry greater risk because of a long and uncertain commercialization process.

Many of the technology investments, such as smart metering, leak detection, storm water capture, and water recycling are smaller capital investments for which traditional bond issues may not be financially feasible. Access to venture capital varies considerable across the United States and this form of investment tends to flow to industries which offer a quick and potentially large return. Ohio, Wisconsin, and Washington State all have small venture capital markets. Partnerships between water technology companies and local water and wastewater authorities, which help with R&D, field testing and commercialization, and which are mediated and facilitated by industry associations, can be particularly productive in accelerating the pace of commercialization and diffusion.

The Netherlands has one of the strongest financial markets in Europe, to include venture capital; and the national government offers incentives to the startups through matching capital injections and tax breaks. Despite this favorable overall environment small firms, which are the largest component of employment growth and are more innovative, have difficulty accessing venture capital; most of the venture capital is concentrated in central and southern regions around Amsterdam, Rotterdam and Eindhoven; and only a small fraction of venture capital goes to water, wastewater or the environment because these have long commercialization periods and investors prefer more general purpose technologies that serve a wider market and have shorter commercialization periods. The long-term health of the Dutch water technology industry remains significantly tied to the investment cycles of the water and wastewater utilities.

In Singapore the government is the single largest provider of funds for R&D and other investments in the water economy, through agencies like A*STAR which is both a major research funder and a major research performer, and a builder of networks through the consortium of 18 institutes which it overseas. Singapore's government has invested heavily in the upgrading its startup ecosystem by strengthening the institutional framework, by providing incentives to attract entrepreneurs and venture capitalists, by cutting regulatory red tape, by helping to protect intellectual property, and by allocating public money for early investments. Private capital markets in Singapore, to include venture capital, have grown exponentially over the past half-century into a multibillion industry. Singapore's venture capital industry is different from much of the rest of Asia in its willingness to fund high technology startups; however, there is a need for more growth-stage capital as funds are not properly spread across the startup lifecycle, and venture capital is a small fraction of the overall amount invested in R&D, though its effective over other forms of capital in helping to get technologies patented and commercialized make it an important complement to other forms of capital.

The strategy of government creating for water technology innovators and entrepreneurs the institutional framework to improve access to appropriate sources and forms of finance answers research questions one, two and six: (1) governments do intervene to promote the development of industrial clusters, (2) they employ a suite of public policies and strategies to support the development or expansion of water technology innovation clusters, and (3) the institutional setting of a jurisdiction does affect the development and diffusion of innovative water-related technologies.

Table 11.7 below provides a sample of the level and sources of funds which water technology innovators and entrepreneurs can access; and this validates the seventh of the EPA's nine strategies. In all six clusters governments attempt to create or improve the institutional framework to improve access to appropriate sources and forms of finance;

however, without governments grants or strong investments in water and waste water utilities to drive demand for water technologies, technology firms struggle to access funds from private sources including venture capital.

Table 11.7. Level of Contribution of Funds by Source for Water Technology

Country	Public Grants	Private Grants	Venture Capital	Crowdfunding
Cincinnati	Low	Low	Low	Negligible
Milwaukee	Low	Low	Low	Negligible
Tacoma	Low	Low	Low	Low
Netherlands	Medium	Low	Low	Negligible
Singapore	High	Medium	Low	Negligible
Israel	High	Medium	Medium	Negligible

H. Nurturing Technology Startups.

Water technology innovators and entrepreneurs require a sustained enabling institutional framework if they are to successfully complete the cycle from R&D to commercialization. The water economy is a traditionally fragmented and conservative sector and the best institutional framework brings together academia, industry, finance, regulators, and utilities to mentor and coach startups, increase the probability of the successful commercialization of their innovations, and increase the probability of survival when the direct support is discontinued. This institutional framework is normally provided by accelerators and incubators which often begin life as public-private partnerships or are sustained under the umbrella of an industry association. The existence of accelerators and incubators provide recognition that startups need more than a great idea and financial capital: they need management advice to develop a resilient and sustainable business model; marketing and sales advice to identify problems and needs that have been validated in the market; legal advice to protect intellectual property;

access to a network of industry experts and prospective partners who can help them to test, deploy, scale-up and commercialize their innovations; and, above all, customers who see them as credible suppliers of solutions to their problems over the life-cycle of those problems rather than purveyors of one-time transactions. This complex but robust institutional framework must guide innovators and entrepreneurs to understand where they should focus their most scarce resources - time and energy – in the right activities and towards the correct outputs and outcomes. In addition to general competencies, accelerators and startups must have specific competiences: different water technology clusters have specific areas of expertise. Accelerators and incubators must be capable of supporting startups based on their areas of technological focus to best leverage the expertise of the cluster and increase the survival rate of the startup. Each of the six clusters considered in the study have somewhat different areas of focus or expertise based on their unique water challenges and the public policy priorities which have shaped their respective water economies.

The strategy of nurturing technology startups supports the assertion by Porter (1998) in the Diamond Model about the importance of upgrading basic to advanced factors, and of the role of related and supporting industries in stimulating innovation and upgrading because of close working relationships with suppliers and customers for testing, perfecting and scaling up technologies, the quick and constant flow of market information, and an ongoing exchange of ideas that can accelerate the pace of innovation. North (1990) recognized that stimulating economic growth, in this case facilitating the entry of new firms into the market, requires institutional arrangements that reduce barriers to entry such as transaction and agency costs, and incomplete and asymmetric information. This strategy also supports the assertion by Rodgers (2003) that there are several attributes that need to be fostered that reduce the uncertainty around the innovation process, namely triability and observability. Incubators and accelerators increase the visibility of an innovation (observability) and offer more opportunities for experimentation with an innovation (triability), which increase the speed and likelihood of adoption.

In the United States the nurturing of startups is considered critical to the development and deployment of technologies to support and address water challenges. At the federal level the nurturing of startups in clusters is a key pillar of regional economic development in general and the clean technology program in particular. The EPA Office of Water, for example, supports early stage companies through grants, particularly its own Small Business Innovation Research program. The support for startups is also evident at the local level. Confluence also has access to 4 networked business incubators and accelerators, including The Hamilton Mill, and beta-site testing facilities to include the EPA's facilities in Cincinnati, local universities, and local public utilities. Pipeline H2O is a business incubator in Hamilton, Ohio which is managed by and based at The Hamilton Mill. Pipeline H2O a public-partnership initiative specializing in advanced manufacturing and clean technologies whose mission is to identify the world’s leading water-based startups and commercialize their technologies. The Water Council supports startups at the World Water Hub through an initiative called The BREW Accelerator (Business, Research, Entrepreneurship in Wisconsin). This accelerator is designed to support water innovators and entrepreneurs with wide ranging business and technical support, to integrate them into a collaborative network of technologists, innovators, and entrepreneurs, and to fund those with commercialization potential through various public and private resources which are channeled through the The Water Council. In Tacoma neither the Center for Urban Waters and the Tacoma Urban Clean Water IPZ explicitly focus on supporting startups: the former is focused on research while the latter is focused on local economic development by building a water technology cluster. In 2017, the Pure Blue non-profit water accelerator, Aqualyst, was launched in Tacoma with six startups.

In The Netherlands the overarching national framework for innovation places a high priority on supporting startups with both local and foreign entrepreneurs. Dutch immigration law was liberalized in 2015 to make the country more attractive to foreign startup entrepreneurs. To support entrepreneurship, innovation, R&D, and the commercialization of technology, many Dutch cities are becoming actively involved in cluster programs and provide incubators for startups. WaterCampus Leeuwarden offers starting and existing companies a comprehensive set of business support and networking services to develop and market innovative ideas in the field of water technology. These services include coaching, access to facilities, such as laboratories, as well as an international network and funding, and the selection process is competitive and tends to focus on themes. The Water Campus also hosts a networking event called Water Tech Fest for startups, investors, professionals and decision makers working in the water technology sector.

In Israel innovation and entrepreneurship are key drivers of the country's high technology sectors and of its economic growth. The government, beginning in 1992, began to play an active role in supporting high technology start-ups where previously it had primarily focused it resources on public sector projects. In the 1990s there was an absence of a private venture capital market and the government filled the void with capital, through a fund called Yozma, and through the establishment of incubators, both of which have now been transferred to the private sector. Starting in 2000 the incubators and Yozma were 'privatized' because venture capital funds became more willing to invest in technology start-ups - although the government continues to provide financial support for start-up R&D in key economic sectors and maintains shares in many of the incubators, so they are essentially public-private partnerships.

The strategy of government creating the institutional framework for accelerators and incubators to assist water technology innovators and entrepreneurs develop, commercialize and diffuse innovations answers research questions four and six: (1) governments are increasingly strategic about the allocation of roles and responsibilities – or the division of labor – between public and private partners in developing or expanding water technology innovation clusters, and (2) the institutional setting of a jurisdiction does affect the development and diffusion of innovative water-related technologies. Table 11.8 below provides a sample of the sources of sponsorship for accelerators and incubators in water technology clusters; and this validates the eighth of the EPA's nine strategies. Incubators and accelerators were present in all six clusters; however, there was a strong division of labor as to who sponsors them. They were more likely to be sponsored by the public sector and public-private partnerships than by the private sector and universities. In some jurisdictions, like Israel, they evolved from public sponsorship to eventually be privatized as the industry matured and became more commercially viable.

Table 11.8. Source and Level of Sponsorship of Incubators & Accelerators in Water Technology Clusters

Country	Public	Private	University	Public-Private
Cincinnati	Negligable	Low	Low	Medium
Milwaukee	Negligable	Low	Low	Medium
Tacoma	Medium	Low	Low	Low
Netherlands	High	Low	Low	Medium
Singapore	High	Low	Low	Low
Israel	High	High	Medium	High

I. Partnerships with Established Businesses & Universities.

Clusters foster collaboration between many different groups to include interconnected firms, supporting institutions, local governments, business chambers, universities, investors and many others to promote economic growth and technological innovation. The synergies from a wide cross section of interconnected stakeholders in a cluster also produce important public goods and positive externalities for its members. The various stakeholders in a cluster have common interests and concerns that affect competitiveness and productivity that make them have an interest in cooperation, coordination and mutual improvement without conflicting with their competitive needs. While large firms often have the financial resources to support the commercialization or deployment of new technologies, they often face various sorts of constraints or impediments to R&D, innovation, diffusion, or serving specific niche markets which can be overcome by building partnerships with smaller firms, startups and universities. Larger firms often acquire smaller firms with specialized skills and technologies, or spin these off if their skills and technologies to not fit well with their business portfolio or business model. Small firms on the other hand benefit considerably from the opportunity to participate in robust networks where they learn about the industry and acquire the business and management skills to become more productive and competitive; and small firms benefit from university R&D and graduate programs which multiply the reach of their own limited research capabilities. Learning-through-interacting is increasingly vital in the emerging knowledge economy. Positive social capital among cluster members facilitates access to important resources and information while minimizing the risk to intellectual property that could arise with predatory firms. Private industry associations within clusters serve a number of important functions: they institutionalize cluster linkages; provide a neutral forum for identifying common needs, constraints, and opportunities and provide a focal point for efforts to address them; and they help ensure that cluster development is led by the private sector rather than controlled by government. Water technology clusters are ecosystems and they cannot function competitively if important elements, like financial intermediaries or trade associations, are absent (Moore, 1993, 1996).

The strategy of partnering with universities and established companies supports the assertion by Porter (1998) of the importance to innovation of related and supporting industries in the Diamond Model. Close working relationships between innovators and entrepreneurs and partners in industry and academia will strengthen R&D systems and support an ongoing exchange of ideas, skills, and practices that can accelerate the pace of innovation. North (1990) see economies engaged in the process of dynamic evolution that is fostered by the human learning, the acquisition of skills, and development of tacit knowledge, an adaptive process that improves decision-making and maximizes efficiency and is facilitated by cooperative interaction between stakeholders. Partenrships between established universities and business and small firms and startups helps to overcome the information asymmetries and information deficits that increase transaction and agency costs. This final strategy also supports the assertion by Rodgers (2003) that the innovation-adoption process can be improved in increasing the observability and triability of an innovation, especially by connecting entrepreneurs with the adopter categories of innovators and early adopters. Building relationships with universities and established firms is likely to increase the speed and likelihood of adoption of new innovations.

In the United States all the clusters in the case study consist of partnerships between the private sector, local, state and federal governments, public utilities, non-profits, economic development agencies, universities, and public and private research facilities. Confluence already has relationships with several regional universities and has set a membership target of around 250 companies and about 90 utilities to participate in the program. Examples of these kinds of relationships include Stantec, one of the largest water consultancies in the world, which provides Confluence critical resources of technological knowledge and industry connections; and Procter and Gamble which put up the seed money to get Confluence an office and is providing international connections. Wisconsin is still home to more than 200 companies that depend on water as a key input and a similar number that produce technologies to support water-intensive and water-enabled industries. Many of these are members of The Water Council. Public and private universities in the state have been willing to align their training and research to support the council and the state has helped with the resources to make this a reality, most notably the $53 million investment in the University of Wisconsin-Milwaukee's School of Freshwater Sciences. The Tacoma Urban Clean Water Technology IPZ is a partnership that involves two universities, research laboratories, public economic development organizations, local governments, workforce training organizations, and the Center for Urban Waters. Relationships between small water firms and startups and established firms and universities will be even more important in the future if government grant money declines or public R&D priorities shift.

In The Netherlands the water economy has had a long history of cooperation between the public sector, private actors, and universities and considerable attention is given to the appropriate roles and spheres of responsibilities of each. This pattern of cooperation with the private sector continues through outsourcing and public-private partnerships which are encouraged along many parts of the water chain to keep prices for water services affordable and to best leverage the strengths of both sectors.

Singapore's two major public universities, Nanyang Technology University and Singapore National University, have a strong global reputation in relations to water R&D and for graduating competent water scientists, technologists, and engineers. University faculty have begun to use their research to spin-off water technology startups and graduates are employed throughout the water economy. Singapore has managed to build several local water technology companies, like Hyflux, but its success at attracting international companies to its HydroHub means that about 200 private companies and 26 private research centers across the value chain of the water industry are based out of Singapore. These private companies and research centers, when combined with public utilities and universities, have boosted Singapore's internal water management capabilities and positioned Singapore as a competitive exporter of water technologies to countries in Asia, the Middle East, Latin America, and Africa.

Israel has a well-developed water technology ecosystem with about 600 water technology firms in several fields, to include about 100 startups, and a large number of universities and research centers that make the capabilities of the country's water cluster both deep and broad. The partnering of universities and water technology firms is an embedded practice in Israel with the water research center at Sde Boker in the Negev being an excellent example. Sde-Boker acts to promote R&D projects in collaboration with universities, research institutes and industry partners as well as offering services as a development and test site for industrial companies.

The strategy of government creating the institutional framework for partnering with established businesses, universities and other organizations to support cluster development and promote the development and diffusion of water-related technologies answers research questions one, two, four and six: (1) governments do intervene to promote the development of industrial clusters for water technology firms, (2) they employ a suite of public policies and strategies to support the development or expansion of water technology innovation clusters, (3) governments are increasingly strategic about the allocation of roles and responsibilities – or the division of labor – between public and private partners in developing or expanding water technology innovation clusters, and (4) the institutional setting of a jurisdiction does affect the development and diffusion of innovative water-related technologies.

Table 11.9 below shows the degree of success by clusters in partnering with established firms and universities in supporting cluster development and the development and diffusion of water-related technologies; and this validates the EPA's ninth and final strategy. Partnerships existed in all six clusters but was particularly strong and universal for universities, and for innovative utilities seeking greater efficiencies.

Table 11.9. Degree of Success by Clusters in Partnering with Universities and Established Firms

Country	University	Water-intensive	Water-enabled	Utilities
Cincinnati	High	Low	Low	High
Milwaukee	High	Medium	Medium	High
Tacoma	High	Low	Low	High
Netherlands	High	Medium	Medium	High
Singapore	High	Medium	Medium	High
Israel	High	High	High	High

CHAPTER 12

CONCLUSION

The six regions examined in this study all contained a collection of interrelated organizations focused on applying technology to solving water-related issues. In all cases these organizations emerged to address local social, economic, and environmental issues connected to water quality and quantity. The degree to which these clusters were hindered or facilitated in their move from being nascent clusters to either emerging, growing or mature clusters is a reflection of public policy priorities and strategies. For Singapore and Israel, the driver was a primarily a severe local deficit which the respective governments had to address as a matter of national security and to support rapid economic development. Over time Singapore and Israel developed technical capabilities which led to the emergence of water technology innovation clusters: for Singapore the decision to upgrade their technologically sophisticated emerging water sector into a 'Hydrohub' was a conscious matter of public policy; while for Israel the emergence of a mature traded cluster has been more organic given the critical mass of technology firms and supporting organizations. For Israel, the policy and strategy focus now needs to be on enabling international competitiveness to sustain a mature industry. Both countries, having largely solved their local problems and possessing significant technical and managerial capacity in water, can now be reallocate some of these resources and move from being primarily local clusters to being primarily traded clusters.

For The Netherlands, the Leeuwarden cluster in the north is the newest Dutch water technology cluster, with mature clusters specializing in maritime and delta technology already well-established in the south of the country. The primary driver for delta technology was the historic threats of flooding from both rivers and the sea and this is a mature traded cluster; the contemporary driver for emerging Leeuwarden cluster is water-use efficiency and water quality especially from the intrusion of salt, brackish or polluted water into fresh water reserves. The eventual goal is to make this a traded cluster. Delta technologies emerged to solve issues that were an ongoing threat to human life; while issues of the quantity and quality of freshwater address risks to the agricultural and industrial base of the Dutch economy and the Dutch natural enviornment. For Cincinnati and Tacoma, the primary driver was pollution: point pollution from industry, non-point pollution from agriculture, and stormwater pollution from urbanization which threatened human and environmental health. For Milwaukee, the divers were pollution, flood control, and supporting many local water-intensive and water-enabled firms with a traditional demand for water technologies. Milwaukee's local cluster predates the clean technology cluster initiatives of the EPA and the SBA; however, Leeuwarden, Milwaukee, Cincinnati and Tacoma are all now the target of focused and proactive public policies and strategies to upgrade these clusters until they too become internationally competitive traded clusters.

In all six clusters public intervention was necessary to upgrade them from nascent and emerging stages to growing and mature because the water economy in general, and the water technology sector in particular, suffer from both government and market failure. In addition, the public good nature of water and sanitation inhibited the process for the development, commercialization and diffusion of water-related technologies needed to address increasingly complex challenges in the water economy. Unlike some other technology sectors where market demand drives innovation and entrepreneurship, the water technology sector has a different industry structure which affects the product development and diffusion cycle and lowers the appetite for risk among investors and financiers. Overcoming these complex problems requires policies and strategies that create the correct institutional framework to improve the rate at which new water technologies are developed and commercialized. The best institutional framework is a water technology innovation cluster or ecosystem and to nuture them where they arise.

Table 12.1 below shows the relationship between the nine cluster development strategies identified by the EPA and the key theories in the conceptual framework. The table offers two key insights: (1) that the strategy framework for cluster development developed by the US EPA to support the development of water technology innovation clusters can be shown to be strongly grounded in well-developed and widely used theories related to clustering and competitiveness (Porter), institutions and economic performance (North), and the diffusion of institutional and technological innovations (Rogers); and (2) that in each of the nine strategies government was empirically found to play a key role in the development of water technology clusters. The discussion in the previous chapter showed how the nine strategy steps were present in all six case studies.

Table 12.1. Linking Cluster Development Strategy to the Conceptual Framework

Strategy	Porter's Diamond Model	North's Institutional Change	Roger's Innovation-Diffusion Model
1	Government	Formal economic & social rules Institutions & Governance	How-to-knowledge Principles-Knowledge
2	Government Upgraded & Advanced Factors	Institutions & Governance Formal skills & knowledge	Awareness-Knowledge How-to-Knowledge Principles-Knowledge Trialability/Observability
3	Government Upgraded & Advanced Factors Related & Supporting Industries	Entrepreneurs Formal skills & knowledge	Awareness-Knowledge How-to-Knowledge Principles-Knowledge Relative advantage Compatibility Complexity Trialability/Observability.
4	Government Industry Structure & Strategy Related & Supporting Industries	Institutions & Governance Cooperation/Coordination Information sharing	Awareness-Knowledge How-to-Knowledge Principles-Knowledge Trialability/Observability
5	Government Leadership (public & private)	Entrepreneurs Change Agents	Entrepreneurs Gatekeepers
6	Government Industry Structure & Strategy	Institutions & Governance Cooperation/Coordination	How-to-Knowledge Principles-Knowledge
7	Government Upgraded & Advanced Factors	Incomplete/Asymmetric Info Institutions & Governance 3rd party contractual enforcement	
8	Government Upgraded & Advanced Factors Related & Supporting Industries	Incomplete/Asymmetric Info Institutions & Governance Formal skills & knowledge Developing tacit knowledge Cooperation/Coordination	Trialability/Observability
9	Government Related & Supporting Industries	Institutions & Governance Formal skills & knowledge Developing tacit knowledge Cooperation/Coordination	Observability Trialability Innovators Early adopters

In the case of Singapore and Israel, the identification of the nine strategy steps was primarily retrospective. The nine strategies were not employed as part of a proactive, overarching, formal water technology cluster strategy; but the were still to be found among the successful policies and strategies that these two countries employed.

Singapore's government comprehensively developed a highly integrated water sector but only recently began to organize it as a cluster or ecosystem as it desires to move from an adaptor of foreign technologies to an exporter of water technologies that leverages the city-state's unique knowledge and experiences in stormwater management, water treatment, desalination, and closed-loop water cycle management. The other four newer clusters have adopted a formal, proactive approach to cluster development: The Netherlands by naming water one of its 'Top Sectors' and a priority for economic development; and the United States which identified 14 nascent clusters and developed the Clean Technology Cluster Initiative. Although the US is the global leader in water technology because of its overall industrial and research leadership, its water technology industry was, and remains, highly fragmented. The nascent and emerging US water technology clusters are therefore ideally positioned to benefit from the proactive deployment of the nine strategies for cluster development developed by the US EPA, which represents a well-articulated approach to public intervention in the water economy to support cluster development and drive the development and diffusion of innovative water-related technologies.

This dissertation sought to answer six research questions. The case studies suggest that all the research questions can be answered in the affirmative:

1. Governments do intervene to promote the development of industrial clusters for water technology firms.
2. Governments do employ a suite of public policies and strategies to support the development or expansion of water technology innovation clusters?

3. The six case studies provide examples of successful clusters in which specific strategies of government intervention can be used as good practices.
4. Successful development or expansion of water technology innovation clusters requires a clear allocation of roles and responsibilities – or division of labor – between public and private partners.
5. Individual or organizational champions do facilitate the development and diffusion of water-related technologies and enhance the competitiveness of water technology innovation clusters.
6. The institutional setting of a jurisdiction does affect the development and diffusion of innovative water-related technologies.

Table 12.2 below shows the relationship between the nine cluster development strategies identified by the EPA and the research questions selected for this study.

Table 12.2. Linking the Cluster Development Strategies with the Research Questions

Strategy	Research Question					
	1	2	3	4	5	6
1	Yes	Yes	Yes			
2	Yes	Yes	Yes			Yes
3	Yes	Yes	Yes			Yes
4	Yes	Yes	Yes			Yes
5	Yes	Yes			Yes	
6	Yes	Yes	Yes	Yes		Yes
7	Yes	Yes	Yes			Yes
8			Yes	Yes		Yes
9	Yes	Yes	Yes	Yes		Yes

The empirical findings from these six case studies and the ensuing analysis therefore suggests the following:

a. Governments can and should intervene to promote the development of industrial clusters for water technology firms. The water economy is highly fragmented, lacks strong institutional arrangements, and often take long periods to develop and commercialize technologies required to protect the quantity and quality of fresh water and the efficiency with which it is collected, treated, transported and stored.

b. The nine strategies for cluster support developed by the US EPA have all been employed, whether knowingly or unknowingly, in the six case studies developed for this study. They seem to offer a robust, empirically tested framework to justify and guide public intervention in the water technology sector.

c. The more advanced water technology clusters in The Netherlands, Israel and Singapore all offer evidence of the importance of targeted government intervention. The scale and scope of the intervention depends on the local context, and the type of intervention necessarily changes as social, economic and environmental circumstances change. Government intervention is necessary, but policies must be adaptive and be guided by sound economic, financial, technological, and environmental logic.

d. Public intervention in the six case studies was both direct and indirect; however, effective and targeted government intervention requires that roles and responsibilities between the various public and private stakeholders be carefully thought-out, appropriately allocated, and clearly communicated to everyone.

As was stated earlier, water technology innovation clusters are significantly shaped by social, economic, and environmental processes which drive institutional and technological change and constantly reinvent water and wastewater regimes; and both institutions and technology act as either constraints or enablers on the development of water economies as they attempt to meet society's current and future water and wastewater needs. Government intervention is necessary in this fragmented sector with its significant role as a producer of public good and an enabler of desirable spill-over effects. Public intervention in the water economy through desirable, even necessary, must however be guided by the realities and constraints of the sector and the limitations of both the market and government.

REFERENCES

Abrahamson, E. (1991). Managerial fads and fashions: The diffusion and rejection of innovations. *Academy of management review*, *16*(3), 586-612.

Addams, L., Boccaletti, G., Kerlin, M., & Stuchtey, M. (2009). *Charting our water future: economic frameworks to inform decision-making*. 2030 Water Resources Group. New York, NY: McKinsey & Company.

Andonova, L. B. (2010). Public-private partnerships for the earth: politics and patterns of hybrid authority in the multilateral system. *Global Environmental Politics*, 10(2), 25-53.

Aharoni, Y. (2014). *The Israeli Economy: Dreams and Realities*. Oxford, UK: Routledge.

Ahlstrom, D., & Bruton, G. D. (2006). Venture capital in emerging economies: Networks and institutional change. *Entrepreneurship theory and practice*, 30(2), 299-320

Ahonen, L., & Hämäläinen, T. (2012). CLIQ: a practical approach to the Quadruple Helix and more open innovation. S.P. MacGregor and T. Carleton (eds.) In *Sustaining Innovation* (pp. 15-29). New York, NY: Springer.

Altheide, D. & Schneider, C. (2013). *Qualitative Media Analysis*. Thousand Oaks, Los Angeles: SAGE Publications.

Alves, J., Marques, M. J., & Saur, I. A. (2004). *Role of Networking in Innovation Promotion and Cluster Modernization:"House of the Future" Case*. ERSA 2004 - 44th Congress of the European Regional Science Association, Porto, 2004

Amit, H. (01 May 2015). Israel's Hazera: From Tomato Seeds to International Growth. *Haaretz*. Retrieved from www.haaretz.com/israel-news/business/.premium-israels-hazera-from-tomato-seeds-to-international-growth-1.5367269

Apfel, A. (May 2013). Liquid Asset: Halo Source's new strategy. *Seattle Business Magazine*. Retrieved from http://www.seattlebusinessmag.com/article/liquid-asset-halo sources-new-strategy.

Ahearn, A. (October 18, 2016). Puget Sound in Line For Environmental Health Boost. *KUOW.* Retrieved from http://archive.kuow.org/post/puget-sound-line-environmental-health-boos

Arrow, K. J. (1994). Methodological Individualism and Social Knowledge. *American Economic Review*, 84(2), p p. 1-9.

Arthur, W. B. (1999). Complexity and the economy. *Science*, 284(5411), 107-109.

Aquatech. (2015). Water sector investment opportunities: a venture capital perspective. Retrieved from www.aquatechtrade.com/aquatech-news/water-sector-investment-opportunities-a-venture-capital-perspective/.

A*STAR. (2005). *National Science & Technology 2005 Plan*. Agency for Science Technology and Research, Singapore.

A*STAR. (2015). *Research, Innovation and Enterprise 2020 Plan*. Agency for Science Technology and Research, Singapore.

A*STAR. (2016). *National Survey of R&D in Singapore 2015*. Agency for Science Technology and Research, Singapore.

Austin, J., & Steinman, A. D. (2014). *Michigan Blue Economy. Making Michigan the World's Freshwater and Freshwater Innovation Capital*. Retrieved from http://michiganblueeconomy.org/wp-content/uploads/2015/03/Michigan-Blue-Economy-Report.pdf

AWWA. (2012). *Buried no longer: Confronting America's water infrastructure challenge*. Denver, CO.: American Water Works Association

AWWA. (2016). *2016 State of the Water Industry Report*. American Water Works Association. Denver, CO.: American Water Works Association

Arezki, R., Bolton, P., Peters, S., Samama, F., & Stiglitz, J. (2016). From global savings glut to financing infrastructure: the advent of investment platforms. *IMF Working Paper No. 16/18*.

Babbie, E. (2007). *The Practice of Social Research*. 11th edition. Belmont, California: Thompson – Wadsworth

Bailey, S. D. (1985). *The Making of Resolution 242*. Dordrecht, The Netherlands: Martinus Nijhoff Publishers.

Barclays Impact Series. (2017). *The water challenge: preserving a global resource*. Retrieved from www.investmentbank.barclays.com /content/dam/barclaysmicrosites/ibpublic/documents/our-insights/water-report/ImpactSeries_WaterReport_Final.pdf

Barr, N. (2012). *Economics of the Welfare State*. Oxford, UK: Oxford University Press.

Barringer, F. (2014). With Data and Resolve, Tacoma Fights Pollution. *The New York Times*. Retrieved from www.nytimes.com/2014/06/13/us/with-data-and- resolve-tacoma-fights-pollution.html.

Barry, K., Brennan, M, Chen, X., Hwang, T., Pozzi, M., Rodriguez, N. (2014). Clean Tech: Visions for a New Pittsburgh Economy. Retreived from https://www.heinz.cmu.edu/ced/ file/clean-tech-visions-for-a-new-pittsburgh-economy-dec-2014.pdf

Bartlett, S, et al. (2017). *Increasing Innovation in America's Water Systems*. Infrastructure Water Task Force. Washington, DC: Bipartisan Policy

Bartram, J., Thyssen, N., Gowers, A., Pond, K., Lack, T., Danzon, M., & Jiménez-

Bates, B., Kundzewicz, Z., & Wu, S. (2008). Climate change and water. *Technical Paper of the Intergovernmental Panel on Climate Change*. Geneva: IPCC Secretariat.

Batker, D., Swedeen, P., Costanza, R., de la Torre, I., Boumans, R., & Bagstad, K. (2008). *A new view of the Puget Sound economy: the economic value of nature's services in the Puget Sound basin*. Tacoma, WA: Earth Economics.

Bauter, A. (June 20, 2014). 2014 Water Summit has everyone rethinking water. *Milwaukee Business Journal*. Retrieved from https://www.bizjournals.com/ milwaukee/blog/2014/06/2014-water-summit-has-everyone-rethinking-water.html

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The qualitative report*, *13*(4), 544-559.

Becker, N. (Ed.). (2013). *Water Policy in Israel: Context, Issues and Options*. Dordrecht Netherlands: Springer Science & Business Media.

Behm, D. (August 07, 2013). Milwaukee's deep tunnel system turns 20 on Thursday. *Milwaukee Journal Sentinel*. Retrieved from http://archive.jsonline.com /news/milwaukee/milwaukees-deep-tunnel-turns-20-on-thursday-b9970010z1-218696891.html/

Behm, D. (June 07, 2014). MMSD treated 99.8% of wastewater in 2016. *Milwaukee Journal Sentinel*. Retrieved from https://www.jsonline.com/ story/news/local/ milwaukee/2017/01/05/mmsd-treated-998-wastewater-2016/9619789 4/

Bell, J. (2009). Deal Watch: Two water contracts keep Northwest Pipe on course. *Oregon Business*. http://www.oregonbusiness.com/article/archives-2006-2009/item/5260-dealwatch-two-water-contracts-keep-northwest-pipe-on-course.

Beltrán, D. (2002). *Water and health in Europe: a joint report from the European*

Environment Agency and the WHO Regional Office for Europe. World Health Organization Regional Publications-European Series, (93).

Bennett, A. (2004). Case study methods: Design, use, and comparative advantages. In D. F. Sprinz and Y. Wolinsky-Nahmias (Ed.), *Models, numbers, and cases: Methods for studying international relations.* Ann Arbor, Michigan: University of Michigan Press. pp. 19-55

Ben-Dak, S. (2017). Top 7 smart water trends for 2017. *Water & Waste-Water International*. Retrieved from www.waterworld.com/articles/wwi/2017/01/top-7-smart-water-trends-for-2017.html.

Benson, M. H., & Garmestani, A. S. (2011). Embracing panarchy, building resilience and integrating adaptive management through a rebirth of the National Environmental Policy Act. *Journal of environmental management*, 92(5), 1420-1427.

Ben-Zoor, D. & Priampolsky, M. (2016). *Water Technology in Israel*. The Finance Division, Economics Department, Bank Leumi le-Israel

Berkhout, F., Smith, A., & Stirling, A. (2004). Socio-technological regimes and transition contexts. In Elzen, B., Geels, F. W., & Green, K. (Eds.) *System innovation and the transition to sustainability: theory, evidence and policy*. Cheltenham, UK: Edward Elgar Publishing, 44(106), 48-75.

Berry, O., & Wasserteil, D. (2014). Israel: the technology industry as an economic growth engine creating a nationwide Cluster of Innovation. In Engle, J. (Ed.), *Global Clusters of Innovation: Entrepreneurial Engines of Economic Growth around the World*, 187. Cheltenham, UK: Edward Elgar.

Bergquist, L. & Crowe, D. (June 09, 2014). Urban, rural runoff remains pollution problem for rivers today. *Winsconsin Journal Sentinel*. Retrieved from http://archive.jsonline.com/news/milwaukee/urban-rural-runoff-remains-pollution-problem-for-rivers-today-b9948756z1-262245021.html/

Bergquist, L. & Behm, D. (June 07, 2014). Getting Milwaukee's rivers to meet state water quality standards won't be easy. *The Milwaukee Journal Sentinel*. Retrieved from http://archive.jsonline.com/news/milwaukee/getting-milwaukees-rivers-to-meet-state-water-quality-standards-wont-be-easy-b9948758z1-262245161.html#!page=1&viewAll=0&sort=oldestfirst&pageSize=50

Bevir, M. (2013). *A Theory of Governance*. Retrieved from https://escholarship.org/uc/item/2qs2w3rb

Bielenberg, A., Kerlin, M., Oppenheim, J., & Roberts, M. (2016). Financing change: How to mobilize private-sector financing for sustainable infrastructure. *McKinsey Center for Business and Environment*. Boston MA.: McKinsey & Co.

Bijker, W. E. (2002). The Oosterschelde storm surge barrier: a test case for Dutch water technology, management, and politics. *Technology and Culture*, 43(3), 569-584.

BizTimes. (March March 31, 2015). The Water Council launches $5 million seed fund. *Milwaukee Business News*. Retrieved from https://www.biztimes.com/2015/ industries/banking-finance/the-water-council-launches-5-million-seed-fund/

Bloomberg. (2013). Water Losses in India Cut in Half by Smart Meters: Itron. Retrieved from www.sustainabilityoutlook.in/news/water-losses-india-cut-half-smart-meters-itron-51565.

Bloomberg. (2017). Company Overview of Hydrobee SPC Inc. *Bloomberg Snapshot*. Retrieved from www.bloomberg.com/research/stocks/private/ snapshot.asp?privcapId=272543763)

Bloomberg. (2017a). Company Overview of Hydrovolts, Inc. *Bloomberg Snapshot*. Retrieved from www.bloomberg.com/research/stocks/private/ snapshot.asp?privcapid=107083530.

Bloomberg. (2017b). Company Overview of Nelson Irrigation Corporation. *Bloomberg Snapshot*. Retrieved from www.bloomberg.com/research/stocks/private /snapshot.asp?privcapId=4546545.

Bloomberg. (2017c). Company Overview of Itron, Inc. *Bloomberg Snapshot*. Retrieved from https://www.bloomberg.com/research/stocks /private/snapshot.asp?privcapId=30323.

Bloomberg. (2017d). Company Overview of Romac Industries, Inc. *Bloomberg Snapshot*. Retrieved from https://www.bloomberg.com/research/stocks /private/snapshot.asp?privcapId=4438679.

BLS. (2017). *Economy at a Glance: Washington State*. Bureau of Labour Statistics. Retrieved from https://www.bls.gov/eag/eag.wa.htm.

Boccaletti, G., Grobbel, M. and Stuchtey, M. R. 2009. The Business Opportunity in Water Conservation. McKinsey Quarterly. McKinsey & Company. Retreived from http://www.mckinsey.com/insights/energy_resources_materials/the_business_opp ortunity_in_water_conservation

Bogardi, J. J., Dudgeon, D., Lawford, R., Flinkerbusch, E., Meyn, A., Pahl-Wostl, C., ... & Vörösmarty, C. (2012). Water security for a planet under pressure: interconnected challenges of a changing world call for sustainable solutions. Current Opinion in *Environmental Sustainability*, 4(1), 35-43.

Boh, W. F., U. De-Haan, and R. Strom (2012), *University Technology Transfer Through Entrepreneurship: Faculty and Students in Spinoffs*. Ewing Marion Kauman Foundation.

Borger G.J., Kluiving S.J., De Kraker A.M. (2011) The Impacts of Megahydraulic Engineering Projects from a Dutch Perspective. In Brunn, S. (eds) *Engineering Earth*. (pp. 1465-1480). Dordrecht, Netherlands: Springer,

Bosma, M. (2013). *The Water Technology Sector in the United States: Examining stakeholders, trends and opportunities in the American water technology sector*. Retreived from https://www.rvo.nl/sites/default/files/2013/10/The%20water%20 technology%20sector%20in%20the%20US.pdf

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative research journal*, 9(2), 27-40.

Braak, B., Kooman, A., Boomsma, C. & Schoof, S. (2017). *Singapore-The Netherlands: Partnerships for Water Challenges*. The Hague, The Netherlands: Netherlands Water Partnership.

Bradford, K. (2010). Puget Sound Partnership isn't winning public trust. *The News Tribune.* Retreived from http://blog.thenewstribune.com/opinion/2010/08/21/ puget-sound-partnership-isn%E2%80%99t-winning-public-trust/

Breznitz, D. (2007). *Innovation and the state: Political choice and strategies for growth in Israel, Taiwan, and Ireland*. Boston, USA: Yale University Press.

Briceno, T., Schundler, G. 2015. *Economic Analysis of Outdoor Recreation in Washington State*. Tacoma, WA: Earth Economics

Briscoe, J., & Malik, R. P. S. (2006). *India's Water Economy: Bracing for a turbulent future*. Washington, DC: World Bank

Brown, P. (2013). Wellspring 2012 Tacoma. Wellspring. Retreived from http://urbanh2oplanner.com/2013/01/29/wellspring-2012-tacoma/

Brusco, S. (1990). The idea of the industrial district: its genesis. In F. Pyke, O. Becattini, & W. Sengenberger (Eds.), *Industrial districts and inter-firm co-operation in Italy*, 10-19. Geneva: International Bureau of Labour Statistics.

Burgess, P. (1916). The Development of Rapid sand Filters in Ohio. *Journal (American Water Works Association), 3*(1), 175-183.

Caballero-Anthony, M., & Hangzo, P. K. K. (2012). From water insecurity to niche water diplomacy: The Singapore experience. *NTS Insight,* November. Singapore: RSIS Center for Non-traditional Security Studies.

Calvert. (September 2008). *Calvert White Paper: Unparalleled Challenge and Opportunity in Water*. Retrieved from http://www.venturecenter.co.in /water/pdf/waterwhitepaper-8219.pdf

Cargill, C. (2016). *Agriculture: The cornerstone of Washington's economy*. Washington Policy Center. Retrieved from www.washingtonpolicy.org/publications/detail/ agriculture-the-cornerstone-of-washingtons-economy.

CBS. (2007). *Statistical Abstract of Israel 2007*. Retrieved from http://www.cbs.gov.il/ reader/ shnaton/shnatone_new.htm?CYear=2007&Vol=58&CSubject=4

Center for Urban Waters. (2016). *Clean water engineering*. Retrieved from https://www.urbanwaters.org/what-we-do/clean-water-engineering/.

Chard, T. (2010). How Hydrovolts' $250k Development Deal Could Turn into a $20M Contract and Global Market. *Xconomy*. Retrieved from http://www.xconomy.com/seattle/2010/09/13/how-hydrovolts-250kdevelopment-deal-could-turn-into-a-20m-contract-and-global-market/2.

Chasan, D.J. (September 6, 2010). Fixing the group that's supposed to fix Puget Sound. *Crosscu*t. Retrieved from https://crosscut.com/2010/09/fixing-group-thats-supposed-fix-puget-sound

Chasan, D.J. (December 21, 2010). Puget Sound Partnership reaches a crossroad. *Crosscu*t. Retrieved from https://crosscut.com/2010/12/puget-sound-partnership-reaches-crossroads

Chasan, D.J. (June 5, 2012). After 5 years, Gregoire's Puget Sound progress is uncertain. *Crosscut*. Retrieved from http://crosscut.com/2012/06/puget-sound-cleanup-gregoire-governor/

Chawaga, P. (December 1, 2016) The Water Council Wants to Find Your Next Great Technology. *Water Online*. Retrieved from https://www.wateronline.com/doc/the-water-council-wants-to-find-your-next-great-technology-0001

Chew, M. Y., Watanabe, C., & Tou, Y. (2010). Technology Leapfrogging: Findings from Singapore's Water Industry. J*ournal of Technology Management for Growing Economies*, 1(2).

Christian-Smith, J., Gleick, P. H., Cooley, H., Vanderwarker, A., & Allen, L. (2012). *A twenty-first century US water policy*. Oxford, UK: Oxford University Press.

City of Milwaukee. (2017). *City of Milwaukee 2017-18 Federal Legislative Priorities 115th United States Congress*. Office of Intergovernmental Relations. Retreived from https://city.milwaukee.gov/ImageLibrary/Groups/IRD/pdfs/2017-18FederalLegislativePriorities-Final.pdf

City of Tacoma. (2011). *Urban Clean Water Tech IPZ Business Plan*. Retrieved from http://choosewashingtonstate.com/wp-content/uploads/2012/10/Tacoma-Business-Plan2.pdf

City of Tacoma. (2013). *Environmental Services*. Retrieved from http://www.cityoftacoma.org/cms/One.aspx?portalId=169&pageId=12027.

City of Tacoma. (2013a). *Thea Foss Waterway Cleanup*. Retrieved from https://www.cityoftacoma.org/government/city_departments/environmentalservices/ surface_water/restoration_and_monitoring/thea_foss_waterway_cleanup.

City of Tacoma. (2013b). *Surface Water System*. Retrieved from https://www.cityoftacoma.org/government/city_departments/environmental services/ surface_water/surface_water_system.

City of Tacoma. (2013c). *Center for Urban Waters Brochure & Fact*s. Retrieved from https://www.cityoftacoma.org/ cms/one.aspx?portalId=169&pageId=17425.

City of Tacoma. (2013d). *Restoration and Monitoring*. Retrieved from http://www.cityoftacoma.org/government/city_departments/environmentalservices/surfacewater/ restoration_and_monitoring/.

City of Tacoma. (2013e). *Point Defiance Regional Stormwater Treatment Facility*. https://www.cityoftacoma.org/government/city_departments/environmentalservices/surface_water/green_stormwater_infrastructure__gsi_/gsi_projects/point_defiance_regional_stormwater_treatment_facilily.

City of Tacoma. (2015). *Urban Clean Water Tech IPZ Business Plan*. Retrieved from http://choosewashingtonstate.com/wp-content/uploads/2015/11/IPZ-Clean-Water-Tech-biz-plan.pdf

Clark, G. L., Monk, A. H., Orr, R., & Scott, W. (2012). The new Era of infrastructure investing. *Pensions: An International Journal*, 17(2), 103-111.

CleanTechAlliance. (2015a). *Showcase Presenting Company: Hydrobee SPC*. Retrieved from http://www.cleantechalliance.org/?page=cts_hydrobee.

CleanTechAlliance. (2015b). *Showcase Presenting Company: APANA*. Retrieved from http://www.cleantechalliance.org/?page=cts_apana.

CleanTechAlliance. (2017c). Make Clean Tech Connections that Make a Difference. Retrieved from http://www.cleantechalliance.org/?page=AboutAlliance.

Clustermappingus. (2017). *Cincinnati Region*. Retrieved from http://www.clustermapping.us/region

Cody, B. A., Schneider, J., Tiemann, M., & Relf, G. (2012). *Selected Federal Water Activities: Agencies, Authorities, and Congressional Committees*. Washington, DC: Congressional Research Service

Cohen, N. (2008). Israel’s national water carrier. *Present Environment and Sustainable Development*, 2(1), 15-27.

Collis, J. & Hussey, R. (2009). *Business Research: A practical guide for undergraduate and postgraduate students*, 3rd edition. New York, NY: Palgrave Macmillan.

Connelly, J. (March 4, 2017). Trump proposal: Slash Puget Sound cleanup money by 93 percent. *Seattle PI*. Retrieved from www.seattlepi.com/local/politics/ article/Trump-propsal-Slash-Puget-Sound-cleanup-money-10976143.php

Conroy, T. & Deller, S. (March 8, 2017). Investing in Innovation Is Key to Boosting Wisconsin's Business Prospects: Long-Term Economic Growth Requires "Quality Competition. Wiscontext. Retrieved from https://www.wiscontext.org/investing-innovation-key-boosting-wisconsins-business-prospects

Conti-Ramsden, M. (2011). A Water-Sector Lab to Market Story – Innovating in the UK Water Sector. *John Hopkins Water Magazine*. Retrieved from water.jhu.edu/magazine/a-water-sector-lab-to-market-story-innovating-in-the-uk-water-sector

Conway, G., Waage, J., & Delaney, S. (2010). *Science and innovation for development* (p. 380). London: UK Collaborative on Development Sciences.

Conway, D., Dechezleprêtre, A., Haščič, I., & Johnstone, N. (2015). Invention and diffusion of water supply and water efficiency technologies: insights from a global patent dataset. *Water Economics and Policy*, 1(04), 1550010.

Cook, J. (2013). Hydrovolts on brink of liquidation, ex-CEO resigns from board. *Geek Wire*. Retrieved from www.geekwire.com/2013/hydrovolts-brink-liquidation-ceo-resigns-board/Turbine maker.

Copenhaver, C. (2016). Northwest Pipe looks to benefit from infrastructure investments. Retrieved from https://www.vbjusa.com/news/spotlight/business/northwest-pipe-looks-benefit-infrastructure-investments/.

Cosgrove, M. H., & Hushak, L. J. (1972). Costs and quality of water in Ohio cities. *Research Bulletin.* Ohio Agricultural Research and Development Center, Wooster, Ohio

Coy, D. (2002). Looking at Water: A View from Wall Street. In N. Spangenberg (Ed.) *Water Resources IMPACT,* 4(1), 14-19
.
Cunneff, T. (June 24, 2014). States partner to spur innovation in new industries. *CNBC*. Retrieved from https://www.cnbc.com/2014/06/24/ner-to-spur-innovation-in-new-industries.html

Daigneau, E. (May 2013). How Milwaukee Became a Center for Water Innovation. *Governing*. Retrieved from http://www.governing.com/topics/transportation-infrastructure/gov-milwaukee-water-innovation-center.html

Davis, U., Maks, A. E., & Richardson, J. (1980). Israel's water policies. *Journal of Palestine Studies*, 3-31.

Daykin, T. (June 8, 2014). RiverWalk, condo developments transformed Milwaukee riverfront. *Milwaukee Journal Sentinel*. Retrieved from http://archive.jsonline.com /news/milwaukee/riverwalk-condo-developments-transformed-milwaukee-riverfront-b9948754z1-262244291.html/

Daykin, T. (January 25, 2017). Zurn opens new headquarters in Reed Street Yards Tom Daykin. *Milwaukee Journal Sentinel*. Retrieved from https://www.jsonline.com /story/money/real-estate/commercial/2017/01/25/zurn-opens-new-headquarters-reed-street-yards/96992084/

DeHaan, U. (2008). A hotbed for entrepreneurship and innovation. In Hulsink, W. & Dellapenna, J. W., & Gupta, J. (2009). *The evolution of the law and politics of water*. Dordrecht, The Netherlands: Springer.

Delgado, M., Porter, M. E., & Stern, S. (2010). Clusters and entrepreneurship. *Journal of economic geography*, 10(4), 495-518.

Dellapenna, J. W., & Gupta, J. (Eds.) (2009). *The evolution of the law and politics of water*. Dordrecht: Springer.

Deltawerken.com. (2004). The Delta Works. Retrieved from http://www.deltawerken.com /The-Delta-Works/1524.html

DeMocker, M. J. (2003). *Benefits and Costs of the Clean Air Act 1990-2020: Revised Analytical Plan for EPA's Second Prospective Analysis*. Cambridge, MA.: Industrial Economics Incorporated

Denscombe M. (1998). *The Good Research Guide: For Small-scale Social Research Projects*. Buckingham, UK: Open University Press.

Department of Commerce. (2017). *Mastering the digital world*. Washington State Department of Commerce. Retrieved from http://choosewashingtonstate.com/why-washington/our-key-sectors/ict/.

Department of Environmental Quality. (2014). *Michigan State of the Great Lakes 2014*. Office of the Great Lakes, Michigan Department of Environmental Quality.

Dhalla, A. M. (2017). Developing a Global Hydrohub: Singapore's Leadership in Water Innovation. In Ahuja, S. (Editor), *Chemistry and Water: The Science Behind Sustaining the World's Most Crucial Resource* (pp. 541-552).

Di Palma, M & Huizinga, W. 2012. *Cluster development in Friesland: the role of Wetsus as a European Water Hub*. Retrieved from. www.cliqproject.eu/filebank/655-Case_Leeuwarden, Cluster_development.pdf

Dobosz, J. (2011). Itron Grows with Smart Grid, Prepaid Electricity. *Forbes*. Retrieved from https://www.forbes.com/sites/johndobosz/2011/04/29/itron-grows-with-smart-grid-prepaid-electricy/#7833b5567655.

DOI. (2017). *Plan to Accelerate Technology Transfer and Commercialize Federal Research and Innovation*. Retreived from https://www.nist.gov/sites/default/files/documents/2017/05/09/DOI-Tech-Transfer-Plan.pdf

Dooley, K. J. (1997). A complex adaptive systems model of organization change. *Nonlinear dynamics, psychology, and life sciences*, *1*(1), 69-97.

Douglas, N. (1991). Institutions. *Journal of Economic Perspectives*, 5(1), 640-655.

Dreizin, Y., Tenne, A., & Hoffman, D. (2008). Integrating large scale seawater desalination plants within Israel’s water supply system. *Desalination,* 220(1-3), 132-149.

Drucker, P. F. (1998). The discipline of innovation. *Harvard Business Review*, 76(6), 149-157.

Drucker, P. (2014). *Innovation and entrepreneurship*. Oxford, UK: Routledge.

Drucker, P. F. (1998). The discipline of innovation. *Harvard Business Review*, 76(6), 149-157.

Drucker, P. (2014). *Innovation and entrepreneurship*. Oxford, UK: Routledge.

Dunagan, C. (2013). Director leaving Puget Sound Partnership after brief tenure. *Kitsap Sun*. Retrieved from http://archive.kitsapsun.com/news/environment/director-leaving-puget-sound-partnership-after-brief-tenure-ep-416715862-356315541.html/

Dunagan, C. (2016). Concerns rise over rogue chemicals in the environment. *Encyclopedia of the Puget Sound*. University of Washington Tacoma: Puget Sound Institute.

Dutchwatertechnology.com. (2017). The *Story of Dutch Water Technology*. https://www.dutchwatertechnology.com/our-story. (Accessed 17 November, 2017).

Dutchwatersector.com. (2017a). *About Us*. Retrieved from https://www.dutchwatersector.com/ about-us/.

Dutchwatersector.com. (2017b). *Our History*. Retrieved from https://www.dutchwatersector.com/our-history/.

Dyson, J. (2016). 'One Water': Concept for the Future. Water World. Retrieved from https://www.waterworld.com/articles/print/volume-32/issu8/departments/wwema/one-water-concept-for-the-future.html.

Earth and Water Group. (2016). *Value of Water Coalition Partners Announce Big Commitments at White House Water Summit.* Retreived from https://earthandwatergroup.com/value-of-water-coalition-partners-announce-big-commitments-at-white-house-water-summit/

Ebbekink, M., & Lagendijk, A. (2017). 5. The sustainable water campus in Leeuwarden: towards an anchoring milieu or a 'hollow term'?. In L Kebir et al. (Eds), *Sustainable Innovation and Regional Development: Rethinking Innovative Milieus*. Cheltenham, UK: Edward Elgar Publishing Limited.

ECY. (n.d.). Saving the Sound. Washington State Department of Ecology. Retrieved from http://www.ecy.wa.gov/puget_sound/overview.html.

Eisenhardt, K. M. & Graebner, M. E. (2007) Theory building from cases: Opportunities and challenges. *Academy of Management Journal*, 50(1), 25-32.

Edler, J., Georghiou, L. 2007. Public procurement and innovation-Resurrecting the demand side. *Research Policy* 36, 949-963.

Elke, V. (1998). *Irrigation in arid and semi-arid environments*. IMAROM Working Paper Series no. 1. University of Amsterdam.

Elliott, D., Mitchell, L., & Salmi, S. (2010). *Innovation Partnership Zones: First Steps toward a More Collaborative Approach to Economic Development*. Washington State Department of Commerce Retrieved from http://choosewashingtonstate.com/ wp-content/uploads/2012/10/2010 ipzreport.pdf.

Elliott, R., & Timulak, L. (2005). Descriptive and interpretive approaches to qualitative research. In (Eds) *A handbook of research methods for clinical and health psychology*, 147-159.

Ffowcs-Williams, I. F. O. R. (2000, June). Policy for inter-firm networking and clustering: a practitioner's perspective. In paper for *OECD/Italian Ministry of Industry Bologna Conference for Minister*s.

EPA. (2012). *Technology Innovation for Environmental and Economic Progress: An EPA Roadmap*. Office of Science and Technology, Office of Water. Washington, DC: EPA

EPA. (2013). *Blueprint for Integrating Technology Innovation into the National Water Program* (Version 1.0). Office of Science and Technology, Office of Water. Washington, DC: EPA

EPA. (2014). *Promoting Technology Innovation for Clean and Safe Water: Water Technology Innovation Blueprint – Version 2.0*. Office of Science and Technology, Office of Water. Washington, DC: EPA

EPA. (2015). *Promoting Innovation for a Sustainable Water Future: A Progress Report*. Retrieved from https://www.epa.gov/sites/production/files/2015-07/documents/promoting-innovation-report-2015.pdf.

EPA. (2016a). Saving Water in Washington. *Water Sense*. Retrieved from https://www.epa.gov/sites/production/files/2017-02/documents/ws-ourwater-washington-state-fact-sheet.pdf.

EPA. (2016b*). Electrochemical Nutrient Extraction from Digestate.* Retreived from https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/10756/report/0

EPA. (2017a). Puget Sound Grants Issued 2010-2015. Retrieved from https://www.epa.gov/puget-sound/puget-sound-grants- issued-2010-2015

EPA. (2017b). Funding and Grants for Puget Sound. https://www.epa.gov/puget-sound/funding-and-grants-puget-sound

EPA Water technology Clusters Leaders. (n.d.). *Clusters: Overcoming Barriers to Water innovation in the US.* Retreived from https://www.wef.org/globalassets/assets-wef/3---resources/environmmental-tech-clusters-program/general-materials/overcoming_barriers_to_water_innovation_in_the_unitest_states_of_america.pdf

Eskaf, S, (2015*) Four trends in government spending on water and wastewater utilities since 1956*. UNC Environmental Finance Center.

European Environment Agency. (2013). *Assessment of cost recovery through water pricing*. Copenhagen, Denmark: Publications Office of the European Union. EEA Technical report No 16/2013.

European Environment Agency. (2016). *The Problems of Water Stress*. Retrieved from https://www.eea.europa.eu/publications/92-9167-025-1/page003.html

European Environment Agency. (2018). *Water use in Europe — Quantity and quality face big challenges*. Retrieved from https://www.eea.europa.eu/signals/signals-2018-content-list/articles/water-use-in-europe-2014

European Innovation Partnership on Water (EIP Water). (2014). *Barriers and bottlenecks for Innovation in the Water Sector*. Final Report, including comments from the Steering Group. January 2014.

EWI. (2011). *Tap in Spngapore's Pool of Resources*. Environment and Water Industry Programme Office

FAO. (1993) *The state of Food and Agriculture 1993*. FAO Agriculture Series No. 26. Rome, Italy: FAO

Farr, A. (2015). Northwest Pipe Co. Expands Its Market in Trenchless. *Trenchless Technology*. Retrieved from https://trenchlesstechnology.com/northwest-pipe-co-expands-market-trenchless/.

Falkenmark, M., Lundqvist, J., & Widstrand, C. (1989). Macro-scale water scarcity requires micro-scale approaches. In *Natural resources forum (Vol. 13, No. 4, pp. 258-267)*. Blackwell Publishing Ltd.

FDI Alliance. (2017). *Big ideas create big opportunities in Wisconsin*. Retrieved from http://www.fdiallianceint.com/FDI_Issue7_ARTICLE_BigIdeasWS.html

Federal Laboratories Consortium. (2017). *Confluence, a Water Technology Innovation Cluster*. Retrieved from https://www.federallabs.org/successes/awards/awards-gallery/2017/confluence-a-water-technology-innovation-cluster

Feenstra, E. (2016). *One Water Roadmap*. US Water Alliance. Washington, DC: USA

Feinleib, D. (2011). *Why startups fail: and how yours can succeed*. New York, NY.: Springer.

Feitelson, E. (2013). The four eras of Israeli water policies. In *Water Policy in Israel* (pp. 15-32). Dordrecht, The Netherlands: Springer.

Felder, J. (2002). *Focus on Israel: Israel's Agriculture in the 21st Century*. Israel Ministry of foreign Affairs

Feldman, M. P., & Francis, J. (2002). The entrepreneurial spark: Individual agents and the formation of innovative clusters. In *Complexity and industrial clusters* (pp. 195-212). Physica-Verlag HD.

Feldman, M. P., & Francis, J. L. (2004). Homegrown solutions: Fostering cluster formation. *Economic Development Quarterly*, *18*(2), 127-137.

Feldman, M., Francis, J., & Bercovitz, J. (2005). Creating a cluster while building a firm: Entrepreneurs and the formation of industrial clusters. *Regional Studies*, *39*(1), 129-14.

Feldman, M., & Francis, J. L. (2006). Entrepreneurs as agents in the formation of Industrial clusters. *Clusters and Regional Development: Critical Reflections and Explorations.* London/New York: Routledge, 115-136.

Fedler, J. (2009). *Israel's Agriculture in the 21st century*. Universitätsbibliothek Johann Christian Senckenberg.

Feldman, D. L. (2017). *Water politics: governing our most precious resource*. John Wiley & Sons. Cambridge: UK.

Fieldsteel, M. (2013) *Building a Successful Technology Cluster*. Environmental Technology Innovation Clusters Program. Office of Research and Development. Washington, DC: USA. Environmental Protection Agency.

Fishman, C. (2016). The White House Wants to Spend $300 Million On A Water Revolution. *Fast Company*. Retrieved fromwww.fastcompany.com/3056430/the-white-house-is-investing-in-water-innovation-for-the-first-time.

Florida, R., & Smith Jr, D. F. (1993). Venture capital formation, investment, and regional industrialization. *Annals of the Association of American Geographers*, 83(3), 434-451.

Forster, M. (2014). *Tacoma fights air pollution and improves economic potential.* Washington State Department of Ecology. Retreived from http://ecologywa.blogspot.ca/2014/09/tacoma-fights-air-pollution-and.html

Foss-Mollan, K. (2001). *Hard Water: Politics and Water Supply in Milwaukee, 1870-1995*. West Lafayette, Indiana: Purdue University Press

Frenkel, A., Shefer, D., & Miller, M. (2008). Public versus private technological incubator programmes: privatizing the technological incubators in Israel. *European Planning Studies*, 16(2), 189-210.

Freedom Foundation. (January 10, 2014). Why we must abolish the Puget Sound Partnership Scam. *Liberty Blog*. Retrieved from https://www.freedomfoundation.com/blog/liberty-live/detail/why-we-must-abolish-the-puget-sound-partnership-scam

Friedler, E. (2001). Water reuse—an integral part of water resources management:: Israel as a case study. *Water policy,* 3(1), 29-39.

FWDA. (2014). *Cooperation Brings Economic Growth Back to the Foss*. Foss Waterway Development Authority. Retrieved from https://www.theafoss.com/history-thea-foss-waterway

Gallager, K. (August 26, 2014). Water Council land JP Morgan Chase grant. *Milwaukee Journal Sentinel*. Retrieved from https://www.pressreader.com/usa/milwaukee-journal-sentinel/20140826/282243778768559

Galnoor, I. (1978). Water policy making in Israel. *Policy Analysis*, 339-367.

Garb, Y. (2010). Desalination in Israel: status, prospects, and contexts. In Tal, A.& Rabbo, A., (Eds.), *Water Wisdom: Preparing the Groundwork for Cooperative and Sustainable Water Management in the Middle East*. Piscataway, USA: Rutgers University Press,

Gates, J. & Ryan, J. (2010). Inside the Puget Sound Partnership. *KUOW*. Retreived from https://www2.kuow.org/specials/pugetsoundpartnership.php

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research policy*, 31(8-9), 1257-1274.

Geels, F. (2005). Co-evolution of technology and society: The transition in water supply and personal hygiene in the Netherlands (1850–1930)—a case study in multi-level perspective. *Technology in society*, 27(3), 363-397.

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research policy*, 36(3), 399-417.

Gerring, J. (2007). *Case study research: Principles and practices*, Cambridge, UK: Cambridge University Press.

Gleick, P. H., Wolff, G., Chalecki, E. L., & Reyes, R. (2002). *The new economy of water*. *The Risk and Benefits of Globalization and Privatization of Fresh Water.* Pacific Institute, Oakland/Ca (http://www. pacinst. org/reports/new_economy. htm.).

Global Water Partnership (GWP). (2002). *Introducing effective water governance*. Stockholm: Sweden

Globe News Wire. (March 26, 2014). *Tauriga Sciences Inc. Launches $1,700,000 USD Commercial Pilot Test with the EPA and the Metropolitan Sewer District of Greater Cincinnati*. Retrieved from https://globenewswire.com/news release/2014/03/26/621700/10074175/en/Tauriga-Sciences-Inc-Launches-1-700-000-USD-Commercial-Pilot-Test-With-the-EPA-and-the-Metropolitan-Sewer-District-of-Greater-Cincinnati.html

Goldman Sachs. (2013). *Sustainable Growth: Taking a Deep Dive into Water*. The Global Markets Institute, Goldman Sachs Global Investment Research. Retrieved from https://www.goldmansachs.com/insights/clean-technology-and-renewables/cohen/report.pdf

Goodrick, D. (2014). Comparative case studies. *Methodological Briefs: Impact Evaluation, 9*. Florence, Italy: UNICEF Office of Research.

Grants.gov. (2016). What Is a Cooperative Agreement? Retrieved from https://blog.grants.gov/2016/07/19/what-is-a-cooperative-agreement/.

Green, C., Woodson, J., & Zerr, R. (2016). Innovation Partnership Zone Program: 2016 Biennial Report. Washington State Department of Commerce. Retrieved from http://www.commerce.wa.gov/wp- content/uploads/2016/12/Commerce-IPZ-2016.pdf

Grix, J. (2001). *Demystifying Postgraduate Research*, Birmingham, UK: University of Birmingham University Press.

Grotenbreg, S., & van Buuren, A. (2018). Realizing innovative public waterworks: Aligning administrative capacities in collaborative innovation processes. *Journal of Cleaner Production*, 171, S45-S55.

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. *Handbook of qualitative research, 2*(163-194), 105.

GWI. (2015). *Market Profile: Global trends in water spending*. Oxford, UK: Global Water Intelligence.

Haddaway, A. (June 3, 2015). Wastewater Industry Gets a LIFT with Collaborate Innovation Program. *WaterWorld*. Retrieved from https://www.waterworld.com/ articles/print/ volume-31/issue-6/features/wastewater-industry-gets-a-lift-with-collaborate-innovation-program.html

Hakim, C. (1987). *Research Design, Strategies and Choices in the Design of Social Research*, Boston: Allen and Unwin.

Han, W. W. (2014). accumulated international projects totaling around S$10 billion. *Today Online*. http://www.todayonline.com/singapore/tide-rising-singapores-water-industry.

Hanemann, W. M. (2006). The economic conception of water. In P. Rogers, M. Llamas & L. Martínez-Cortina (Eds.) *Water Crisis: myth or Reality*. Taylor & Francis

Hans, D. (Eds). Pathways to High-Tech Valleys and Research Triangles: Innovative Entrepreneurship, Knowledge Transfer and Cluster Formation in Europe and the United States, 24,79.

Hardin, G. (1968). The Tragedy of the Commons. *Science*, Vol. 162 (1968), pp. 1243–1248

Harvard Business School. (September 29, 2014) *Harvard's Michael Porter Unveils New Tool to Improve Economic Development*. Retrieved from http://www.hbs.edu/ news/ releases/Pages/michael-porter-improve-economic-development.aspx.

Hardin, G. (1968). The Tragedy of the Commons. *Science*, Vol. 162 (1968), pp. 1243–1248

Haščič, I., & Migotto, M. (2015). *Measuring environmental innovation using patent data*. Paris: OECD.

Hébert, R. F., & Link, A. N. (1989). In search of the meaning of entrepreneurship. *Small business economic*s, 1(1), 39-49.

Hellegers, P., Zilberman, D., & van Ierland, E. (2001). Dynamics of agricultural groundwater extraction. *Ecological Economics*, 37(2), 303-311.

Herdendorf, C. E. (1996). Ohio Science and Technology: A 200-Year Heritage of Discovery and Innovation. *Ohio J. Sci*. 96 (4/5): 66-71, 1996

Herzberg, R. Q. (2015). Governing their commons: Elinor and Vincent Ostrom and the Bloomington School. *Public Choice*, 163(1-2), 95-109.

Hess, A. & Frohlich, C. (2014). The 10 states with the best quality of life. *USA Today*. Retrieved from https://www.usatoday.com/story/money/business/2014/10/11/24-7-wall-st-states-quality-of- life/16960973/.

Hisham, S. (December 30, 2015). A country built by innovation: The Netherlands. *Geospatial World.* Retrieved from https://www.geospatialworld.net/article/a-country-built-by-innovation-the-netherlands/

Hodgson, G. (2007). Meanings of Methodological Individualism. *Journal of Economic Methodology* 14(2), June, pp. 211–26

Holland Trade & Invest. (2017). *Water Technology*. Retrieved from https://www. hollandtradeandinvest.com /key-sectors/water/water-technology.

Holmes, D. (January 21, 2015). Freshwater Mecca: Milwaukee's Clean Water Advantage. *Urban Milwaukee.* https://urbanmilwaukee.com/2015/01/21/ freshwater-mecca-milwaukees-clean-water-advantage/

Hourihan, M., & Parkes, D. (2017*). Federal R&D in the FY 2016 Budget: An Overview*. American Association for the Advancement of Science.

Howard, M. (2015). Milwaukee's 'blue' revolution. In *Cities for the future: Innovative and principles-based approaches to urban equity, sustainability and governance*. Global Compact Cities Program.

Hubbard, D. W. (2014). *How to measure anything: Finding the value of intangibles in business*. John Wiley & Sons.

IEICI . (2017). About us. Israel Export and International Cooperation Institute Retrieved from http://www.export.gov.il/eng/About/About/.

IPP. (2013). Technology transfer and commercialization. The Innovation Policy Platform, The OECD and World Bank. Retreived from https://www.innovationpolicyplatform.org/content/technology-transfer-and-commercialisation

Irvine, K., Chua, L., & Eikass, H. S. (2014). The Four National Taps of Singapore: A holistic approach to water resources management from drainage to drinking water. *Journal of water management modeling*, 1-11.

Israel, J. (2016). *Making History in Puget Sound and in our Kitchen. Puget Sound Conservation*. Retrieved from http://www.washingtonnature.org/fieldnotes /2016/10/18/making-history-in-puget-sound-and-in-our-kitchen.

Isaac, J., & Shuval, H. (Eds.). (1994). *Water and peace in the Middle East (Vol. 58)*. Amsterdam, The Netherlands: Elsevier.

Isenberg, D. J. (2010). *How to start an entrepreneurial revolutio*n. Harvard business review, 88(6), 40-50.

Israel Innovation Authority. (2017). About Us. Retrieved from http://www.matimop.org.il/ about_authority.html.

Israel New Tech. (2013). Hutchison Water Acquires Kinrot Ventures. Ministry of Industry Trade & Labour. Retrieved from israelnewtech.com /2012/11/11/kinrot-hutchison/.

Israel NewTech. (2017a). *Israel's Water Ecosystem*. Ministry of Economy & Industry. Retrieved from http://israelnewtech.gov.il/english/water/pages/aboutus.aspx.

Israel New Tech. (2017b). Kinrot Ventures, “Not a drop is wasted”. Ministry of Economy & Industry. Retrieved from israelnewtech.gov.il/ English/SuccessStories /Pages/Kinrot-

Israel Science & Technology Directory (2017). Agriculture companies: irrigation. Retrieved from https://www.science.co.il/agriculture/Companies.php?s=irrigation.

Jabareen, Y. (2009). Building a conceptual framework: philosophy, definitions, and procedure. *International Journal of Qualitative Methods*, *8*(4), 49-62.

Jaccard, M. (2005). Hybrid energy-economy models and endogenous technological change. In *Energy and environment* (pp. 81-109). Boston, MA.: Springer,

Janssen, M., Erven, B., Den Hertog, P., & Jonkers, K. (2016). *RIO Country Report 2015: The Netherlands* (No. JRC101205). Directorate Growth & Innovation and JRC-Seville, Joint Research Centre.

Jerome, S. (2015). New Tech Filters Stormwater Runoff. *Water Online*. Retrieved from https://www.wateronline.com/doc/new-tech-filters-stormwater-runoff-0001.

JLARC. (2011). *Puget Sound Partnership Performance Audit*. Washington State Joint Legislative Audit and Review Committee.

JLARC. (2016). Preliminary Report: Puget Sound Partnership. Washington State Joint Legislative Audit and Review Committee. Retrieved from http://leg.wa.gov/jlarc/reports/2017/PSPartnership 2016/p/print.htm

Johnson, J. (2016). *Planting the Seeds of Innovation: EPA Awards Contracts to 13 Small Businesses to Support Environmental Research*. Retrieved from https://blog.epa.gov/blog/2016/12/planting-the-seeds-of-innovation/

Jones, J. A. A. (2009). Threats to Global Water Security: Population Growth, Terrorism, Climate Change, or Commercialisation?. In *Threats to global water security* (pp. 3-13). Dordrecht, The Netherlands: Springer.

Joo, Y. M., & Heng, Y. K. (2017). Turning on the taps: Singapore's new branding as a global hydrohub. *International Development Planning Review*, 39(2), 209-227.

Juanico, M., & Shelef, G. (1994). Design, operation and performance of stabilization reservoirs for wastewater irrigation in Israel. *Water Research*, 28(1), 175-186.

Kasperowicz, P. (2013). Next in the House: Bipartisan water resources bill. The Hill. Retreived from https://thehill.com/blogs/floor-action/house/329061-next-in-the-house-bipartisan-water-resources-bill

Kartin, A. (2001). Water scarcity problems in Israel. *GeoJournal*, 53(3), 273-282.

Kelly, T. (2015). Company developing way to filter out stormwater pollution upstream. Retrieved from http://www.kitsapsun.com/story/money/business/business-journal/2015/02/09/company-developing-way-to-filter-out-stormwater-pollution-upstream/95726684/.

Kelley, K., Clark, B., Brown, V., & Sitzia, J. (2003). Good practice in the conduct and reporting of survey research. *International Journal for Quality in Health Care*, 15(3), 261-266.

Khoo, T. C. (2009). Singapore water: yesterday, today and tomorrow. In A. K. Biswas. C. Tortajada & R. Izquierdo (Eds.), *Water management in 2020 and beyond*, pp. 237-250. Berlin, Germany: Springer.

KickStarter. (2017). Hydrobee Harvests Water Energy for USB Power to Go. Retrieved from https://www.kickstarter.com/projects/burthamner/harvest-natures-energy-for-usb-power-to-go.

Kiparsky, M., Sedlak, D. L., Thompson Jr, B. H., & Truffer, B. (2013). The innovation deficit in urban water: the need for an integrated perspective on institutions, organizations, and technology. *Environmental engineering science, 30*(8), 395-408.

Kislev, Y. (2001). *The Water Economy in Israel*. Hebrew University of Jerusalem, Department of Agricultural Economics and Management, Center for Agricultural Economic Research.

Kirzner, I. (1973). *Competition and Entrepreneurship*. Chicago, IL: University of Chicago Press.

kkl-jnf. (n.d. a). *Our History*. Retrieved from kkl-jnf.org/about-kkl-jnf/our-history/fifth-decade-1941-1950/

kkl-jnf. (n.d. b). *Water Technology*. Retrieved from kkl-jnf.org/water-for-israel/water-technology/.

kkk-jnf.org. (n.d. c). *KKL-JNF Reservoirs Provide Priceless Benefits*. Retrieved from http://www.kkl-jnf.org/water-for-israel/water-reservoirs/.

Knight F. 1921. *Risk, uncertainty and profit*. New York, NY: Augustus Kelley.

Knoester, M. (1984). Introduction to the Delta case studies. *Water science and technology*, 16(1-2), 1-9.

Koh, W. T. (2005). Promotion of Entrepreneurship and the Development of the Venture Capital Industry in Singapore. In Klein, E. (Ed.) *Capital Formation, Governance, and Banking*. New York, NY: Nova Science Publishers, Inc.

Koh, W. T., & Wong, P. K. (2005). Competing at the frontier: The changing role of technology policy in Singapore's economic strategy. *Technological Forecasting and Social Change*, 72(3), 255-285.

Kortum, S., & Lerner, J. (2001). Does venture capital spur innovation?. *The RAND Journal of Economics*, Vol. 31, No. 4. (Winter, 2000), pp. 674-692

Kotkin, J. (2013). A Map of America's Future: Where Growth Will Be Over the Next Decade. *Forbes*. Retreived from https://www.forbes.com/sites/joelkotkin/2013/09/04/a-map-of-americas-future-where-growth-will-be-over-the-next-decade/2/#15b79a593c6f.

Kruckeberg, A. R. (1991). *The natural history of Puget Sound country*. Washington State: University of Washington Press.

Krugman, P. R. (1991). *Geography and trade.* Cambridge, Ma: MIT Press.

Kunen-Jones, M. (2011). UC a Lead Partner in New Water Technology Innovation Cluster. *UC Foundation News.* Retreived from https://www.uc.edu/news/articles/legacy/enews/2011/01/e12994.html

Larson, A. (2011). *Sustainability, innovation, and entrepreneurship*. Creative Commons: The Saylor Foundation.

Laschever, E. S. (1998). An Overview of Washington's Growth Management Act. *Pac. Rim. L. & Policy J.*, 7, 657.

Laster, R., & Livney, D. (2009). Israel: the evolution of water law and policy. In Dellapenna, J. W., & Gupta, J (Eds), *The evolution of the law and politics of water*, 121-137. Dordrecht, The Netherlands: Springer.

Lazaroms, R., & Poos, D. (2004). The Dutch water board model. *Journal of Water Law*, 15(3), 137-140.

Lee, Y. (2017). Singapore Venture Capital Surges as Startups Seek Room to Grow. *Bloomberg*. Retrieved from www.bloomberg.com/news/articles/2017-10-22/singapore-venture-capital-surges-as-startups-seek-room-to-grow.

Lemarchand, G. A., Leck, E., & Tash, A. (2016). *Mapping research and innovation in the State of Israel* (Vol. 5). Paris, France: UNESCO Publishing.

Lescop, D., & Lescop, E. (2013). Platform-based ecosystem and firm/market equivalency: the case of Apple iPhone. In Letaifa, S. B., Gratacap, A., & Isckia, T (Eds.), *Understanding Business Ecosystems: How firms succeed in a new world of convergence*. Bruxlles, Belgium: De Boeck Superieur

Levine, M. V. (2009). *The False Promise of the Entrepreneurial University. Selling Academic Commercialism as an "Engine" of Economic Development in Milwaukee*. Milwaukee, WI: University of Wisconsin - Milwaukee

Levy, J. S. (2008). Case studies: Types, designs, and logics of inference. *Conflict Management and Peace Science*, 25(1), 1-18.

Libecap, G., Grafton, R. Q., Landry, C., McGlennon, S., & O'Brien, R. (2010). An Integrated Assessment of Water Markets: Australia, Chile, China, South Africa and the USA. Working Paper No. 32/2010. International Center for Economic Research.

Lide, S. (2017). Water Management Strategy Singapore. In Carvalho, L., van den Berg, L., Galal, H., & Teunisse, P. (Eds.). (2016). *Delivering Sustainable Competitiveness: Revisiting the Organising Capacity of Cities*. Oxford, UK: Routledge.

Lietz, K. (September 27, 2016). *The Water Council Launches New Research Commercialization Initiative*. Retrieved from https://wedc.org/blog/water-council-launches-new-research-commercialization-initiative/

Lim, H. S., & Lu, X. X. (2016). Sustainable urban stormwater management in the tropics: An evaluation of Singapore's ABC Waters Program. *Journal of Hydrology*, 538, 842-862.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry* (Vol. 75). Beverly Hills, CA: Sage.

Lintsen, H. (2002). Two centuries of central water management in the Netherlands. *Technology and Culture*, 43, 549-568.

Lipsky, R. S., & Ryan, C. M. (2011). Nearshore restoration in Puget sound: understanding stakeholder values and potential coalitions. *Coastal Management*, 39(6), 577-597.

Longworth, R. (April 29, 2015). Commentary: A greedy look at Lake Michigan. *Chicago Tribune*. Retrieved from https://www.chicagotribune.com/news/opinion /commentary/ct-lake-michigan-jobs-economics-water-great-lakes-economy-perspec-0430-jm-20150429-story.html

Lonnquest, J. (Ed.). (2015). *Two centuries of experience in water resources management: A Dutch-US retrospective*. Government Printing Office.

Low, J. (2012). Sustaining the value of water. In Gwee, J., (Ed.), *Case Studies in Public Governance: Building Institutions in Singapore*, 94-120. Oxford, UK: Routledge.

Low, L. (2001). The Singapore developmental state in the new economy and polity. *The Pacific Review*, 14(3), 411-441.

Low, J., & Kalafut, P. C. (2002). I*nvisible advantage: how intangibles are driving business performance*. Cambridge. MA: Perseus Books Group.

Lowe, M. (March 07, 2013). Look to the lake: Milwaukee's economy depends on freshwater technology. *Fox6now*. Retrieved from https://fox6now.com/2013/03/03/can-water-save-milwaukees-economy/

Lye, D. & Waits, A. (2013). *Technologies and innovative solutions for harvesting and nonpotable use of rain and stormwater in urban settings*. Meeting Summary Report. Gaithersburg, Maryland: The Scientific Consulting Group.

Lydersen, K. (April 11, 2011). Milwaukee pioneers innovative stormwater controls. *WMEAC*. Retrieves from https://wmeac.org/milwaukee-pioneers-innovative-stormwater-controls/2011/

Ma'alot Standard & Poor. (2015). *Mekorot Credit Rating*. Tel Aviv.

Marin, P., Tal, S., Yeres, J. & Ringskog, K. (2017). *Water Management in Israel: Key Innovations and Lessons Learned for Water-Scarce Countries*. Washington, DC: World Bank.

Martin, L. (2014). *The Top 12 Water Technology Hotspots In America*. Water Online. https://www.wateronline.com/doc/innovation-nation-the-top-water-technology-hotspots-in-america-0001.

Marx, K. (2014). Clean Water Conference Driving Change: Through Collaboration, Tacoma is Making a Difference. *Water Conditioning & Purification Magazine*. http://www.wcponline.com/2014/12/10/clean-water-conference-driving-change-through-collaboration-tacoma-is-making-a-difference/

Marques, R. C. (2010). *Regulation of water and wastewater services*. London, UK: IWA Publishing.

Markusen, A. (1996) Sticky places in slippery space: A typology of industrial districts, *Economic Geography* 72, 293-313

Mattoon, R., & Wang, N. (2014). Industry clusters and economic development in the Seventh District's largest cities. *Economic Perspectives*, 38(2), 52-67.

Maupin, M. A., Kenny, J. F., Hutson, S. S., Lovelace, J. K., Barber, N. L., & Linsey, K. S. (2014). *Estimated use of water in the United States in 2010* (No. 1405). US Geological Survey.

May, L. (September 23, 2013). *Liquid assets: Why a local nonprofit wants this region to be the Silicon Valley of water: Abundance of water and smarts make it possible*. Retrieved from https://www.wcpo.com/news/local-news/hold-water-liquid-assets-why-a-local-nonprofit-wants-this-region-to-be-the-silicon-valley-of-water

McDearmon, B. (July 2018). *Rethinking Cluster Initiatives: Case Study Milwaukee Water Technolog*y. Metorpolitan Polity Program, Brookings.

McMillan, G. S. (2011). *Mapping Report on Proposed Water Cluster in Cincinnati Region*. Cincinnati, Ohio: General Informatics, LLC.

Megersa, G., & Abdulahi, J. (2015). Irrigation system in Israel: A review. *International Journal of Water Resources and Environmental Engineering*, 7(3), 29-37.

Meola, A. (2016). IoT For Utilities: Smart Water, Gas & Electric Utilities Coming Soon. *Business Insider*. Retrieved from www.businessinsider.com/internet-of-things-utilities-water-electric-gas-2016-10.

Menahem, G. (1998). Policy paradigms, policy networks and water policy in Israel. *Journal of Public Policy*, 18(3), 283-310.

Menkhoff, T., & Evers, H. D. (2011). *The governance of Singapore's knowledge clusters: off shore marine business and waterhub*. Munich, Germany: Munich Personal RePEc Archive

Merkorot.co. (2017). WaTech Innovation and R & D Center. Retrieved from http://www.mekorot.co.il/Heb/ newsite/Watech/Pages/HomePage.aspx.

Metz, T., & van den Heuvel, M. (2012). *Sweet & Salt: Water & the Dutch*. The Netherlands: nai010 publishers

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Sage.

Miller, K. (2014). HaloSource and the Future of Water Technology. CleanTechAlliance. Retrieved from cleantechalliance.org/news /206506/HaloSource-and-the-Future-

Miller, K. (2017). Tacoma needs PhDs for tech to boom here. *The News Tribune*. Retrieved from http://www.thenewstribune.com/opinion/article159831834.html.

Mibourn, C. (2016). *EPA Announces $1.3 Million to Small Businesses to Support the Nation's Green Economy*. US EPA. Retreived from https://19january2017 snapshot.epa.gov/newsreleases/epa-announces-13-million-small-businesses-support-nations-green-economy-0_.html

Miller, K. (2014). HaloSource and the Future of Water Technology, CleanTechAlliance. Retreived from http://www.cleantechalliance.org/news/206506/HaloSource-and-the-Future-of-Water-Technology.htm.

Miller, K. (2017). Tacoma needs PhDs for tech to boom here. *The News Tribune*. Retrieved from http://www.thenewstribune.com/opinion/article159831834.html.

Mills, K. G., Reynolds, E. B., & Reamer, A. (2008). *Clusters and competitiveness: A new federal role for stimulating regional economies*. Washington, DC: Brookings Institution.

Milwaukee 7. (2007). *Economic Asset & Opportunity Analysis*. Milwaukee, WI: Vandewalle & Associates, Inc

Milwaukee 7. (2014). Framework for Economic Growth. Retrieved from http://www.mke7.com /clientuploads/mke7frameworkforecongrowth04_14.pdf

Miner, B. (May 24, 2010). The weight of water. *Milwaukee Magazine*. Retrieved from https://www.milwaukeemag.com/TheWeightofWater/

Miranda, G., & Potter, J. G. (2009). *Clusters, innovation and entrepreneurship*. OECD Publishing Service.

Mises. L. V. (1949). *Human action: A treatise on economics*. New Haven, CT: Yale University Press

Mitra, J. (2011). *Entrepreneurship, innovation and regional development: an introduction*. Oxford, UK: Routledge.

Mke.com. (2017). *The Water Council*. Retrieved from http://www.mke7.com /index.php?src=gendocs&ref=TheWaterCouncil&category=Milwaukee7

Monnard, A., Leete, & Auer, J., (2014). *The evaluation of the US small business administration's regional cluster initiative*. College Park, MD: Optimal Solutions Group.

Morag, N. (2001). Water, geopolitics and state building: the case of Israel. *Middle Eastern Studies*, 37(3), 179-198.

Morelix, A., Reedy, E. J., & Russell-Fritch, J. (2016). *Kauffman Index: Growth Entrepreneurship Metropolitan Area and City Trends*.

Morgan, G. (2014). *Why we must abolish the Puget Sound Partnership scam*. Freedom Foundation. Retreived fromhttp://archive.myfreedomfoundation.com/blog/liberty-live/detail/why-we-must-abolish-the- puget-sound-partnership-scam.html

Ministry of Economic Affairs & Climate Policy. (2017). *Encouraging Innovation*. Retrieved from www.government.nl/topics/enterprise-and- innovation/.

Mokyr, J. (2000). The Industrial Revolution and the Netherlands: Why did it not happen? *De Economist*, 148(4), 503-520.

Moore, J. F. 1993. Predators and Prey: A New Ecology of Competition. *Harvard Business Review*. 71(3), 75-86.

Moore, J. F. 1996. *The Death of Competition: Leadership & Strategy in the Age of Business Ecosystems*. New York: Harper Business.

Morgan, G. (2014). Why we must abolish the Puget Sound Partnership scam. *Freedom Foundation*. Retrieved from http://archive.myfreedomfoundation.com /blog/liberty-live/detail/why-we-must-abolish-the-puget-sound-partnership-scam.html

MSDGC & GCWW. (2013). City of Cincinnati Using Abundance of Water to Attract Interest in Industrial Site. *News Release*. Retreived from https://www.cincinnati-oh.gov/water/news/city-using-abundance-of-water-to-attract-interest-in-industrial-site/

Muller, J. (2013). The Capital of Water. In Dan Bignman (Ed.*), Reinventing America: The Men and Women Sparking A New Industrial Revolution.* Forbes Media Series.

Municipal Sewer & Water. (2013). Clean-Water Conference Makes a Splash. Retrieved from mswmag.com/online_exclusives/2013/11/clean_water_ conference_makes_a_splash

Muro, M. (2013). *Regional innovation clusters begin to add up*. Brookings. Retreived from https://www.brookings.edu/blog/up-front/2013/02/27/regional-innovation-clusters-begin-to-add-up/#page-content

Municipal Sewer & Water. (November 19, 2013). Clean-Water Conference Makes a Splash. *Treatment Plant Operator*. Retrieved from https://www.tpomag.com/online_exclusives/2013/11/clean_water_conference_makes_a_splash

Muro, M., & Katz, B. (2010). *The new 'cluster moment': how regional innovation clusters can foster the next economy*. Washington, DC: Brookings Institute.

Murphy, B. (January 6, 2015). Milwaukee's Miraculous Water Hub. *Urban Milwaukee*. Retrieved from https://urbanmilwaukee.com/2015/01/06/murphys-law-milwaukees-miraculous-water-hub/

Musick, N., & Petz, A. (2015). *Public Spending on Transportation and Water Infrastructure, 1956 to 2014*. Washington, DC: Congressional Budget Office.

Myer, T. (2010). Puget Sound Partnership should prioritize environmental benefit, not Politics. Retrieved from http://www.seattletimes.com/opinion/puget-sound-partnership-should-prioritize-environmental-benefit-not-politics/

Myers, T. (2010). Puget Sound Partnership should prioritize environmental benefit, not politics. *Seattle Times*. http://old.seattletimes.com/html/ opinion/ 2012764293_guest31myers.html

Myers, T. (2012). Puget Sound Partnership: Can anybody here figure out a plan? Washington Policy Center. http://www.washingtonpolicy.org/ publications/detail/puget-sound-partnership-can-anybody-here-figure-out-a-plan

Myer, T. (2017). Legislature Should Fund Puget Sound Partnership's Science-Based Auditing. Washington Policy Center. http://www.washingtonpolicy.org/ publications/detail/legislature-should-fund-puget-sound-partnerships-science-based-auditing

Najm, I., & Trussell, R. R. (1999). *New and emerging drinking water treatment technologies. Identifying future drinking water contaminants*. Washington, DC: National Academies Press.

Nanyang Technological University. (2016). Launch of new S$30 million national centre to speed up commercialisation of separation and filtration technologies. Retrieved from http://media.ntu.edu.sg/NewsReleases/Pages/newsdetail.aspx?news= 40d60834-a60b-46f3-8bdb-80547103cdef.

National Geographic. (n.d.). Estuary. Retrieved from https://www.nationalgeographic.org encyclopedia/estuary/.

National Research Council. (1998). *Separation Technologies for the Industries of the Future* (Vol. 487, No. 3). Washington, DC: National Academies Press.

National Research Council. (2004a). *Confronting the Nation's Water Problems: The Role of Research*. Washington, DC: The National Academies Press

National Research Council. (2004b). *Adaptive Management for Water Resources Project Planning*. Washington, DC: The National Academies Press

Najm, I., & Trussell, R. R. (1999). New and emerging drinking water treatment technologies. *Identifying future drinking water contaminants*, 220. National Academy of Sciences.

National Research Council. (2012). *Rising to the Challenge: U.S. Innovation Policy for Global Economy*. Prepared by C. Wessner & A. Wolff (Eds.). Washington, DC: National Academies Press

Nelson. (2017). *Innovation in irrigation: a tradition of excellence*. Retrieved from http://www.nelsonirrigation.com/company/history/.

Netherlands Water Partnership. (2016). *Dutch Water Sector: 2014-15*. Schiedam, The Netherlands: Rinus Vissers

Newberger, R. G., & Toussaint-Comeau, M. (2015). Revitalizing Inner Cities: Connecting Research and Practice. Chicago Fed Letter, (346), 1.

Nunnally, D. (August 22, 2016). A decade on, the Foss cleanup shines. *The News Tribune*. Retrieved from http://www.thenewstribune.com/news/local/article96913742.html

Newman, J. (May 10, 2013). Ten Wisconsin companies make the Fortune 500 list for 2013. *Wisconsin State Journal.* Retrieved from https://madison.com/wsj/business/ten-wisconsin-companies-make-the-fortune-list-for/article_b0bf5377-7fa6-5eef-95bb-1deb8a3352e8.html

Nirenberg, L. (2009). Hydrating the planet through business innovation: a study of Israel’s water industry. (Doctoral dissertation, Beedie School of Business-Segal Graduate School. York University, Canada)

NIST. (2016). *Water Measurement Science*. Retreived from https://www.nist.gov/programs-projects/water-measurement-science

NOAA. (2017). What is an estuary? Retrieved from oceanservice.noaa.gov/facts/estuary.html.

Nunnally, D. (August 20, 2016). A decade on, the Foss cleanup shines. *The News Tribune*. Retrieved from https://www.thenewstribune.com /news/local/article96913742.html

Nusser, S. (May 13, 2015). The MMDS story: How the Sewerage District Came of Age. *Urban Milwaukee*. Retrieved from https://urbanmilwaukee.com/2015/05/13/the-mmsd-story-how-the-sewerage-district-came-of-age/

NWIFC. (2015). Introducing Northwest Treaty Tribes. Retrieved from https://nwifc.org/ introducing- northwest-treaty-tribes/.

NWP. (2015). What is the NWP. Retrieved from https://www.netherlandswaterpartnership.com /what-is-nwp

OECD. (1999). Boosting Innovation: The Cluster Approach. *OECD Proceedings*. OECD Publication Service, 418.

OECD. (2000). Science, Technology and Innovation in the New Economy. *Policy Brief*, Paris, France: OECD Observer.

OECD. (2009). *Clusters, Innovation and Entrepreneurship, Local Economic and Employment Development (LEED)*, Paris, France: OECD Publications.

OECD. (2011). *Benefits of Investing in Water and Sanitation: An OECD Perspective.* OECD Studies on Water, OECD Publishing, Paris. Retrieved from https://doi.org/10.1787/9789264100817-en.

OECD. (2014). *OECD Reviews of Innovation Policy: Netherlands – Overall Assessment and Recommendations*. Paris, France: OECD Publications.

Olson, M. (1965). *The logic of collective action: Public goods and the theory of groups*. Cambridge, Mass: Harvard University Press.

Ostrom, E. (1990). *Governing the commons: the evolution of institutions for collective action.* Cambridge, UK: Cambridge University Press

Ostrom, E. (1995). *Understanding institutional diversity*. Princeton, New Jersey: Princeton University Press.

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences*, 104(39), 15181-15187.

Ostrom, E. (2010). Beyond markets and states: polycentric governance of complex economic systems. *American Economic Review* 100 (June 2010): 641–672

Ostrom, V., Tiebout, C. M., & Warren, R. (1961). The organization of government in metropolitan areas: a theoretical inquiry. *American political science review*, 55(04), 831-842.

Paytas, J., Gradeck, R., & Andrews, L. (2004). *Universities and the development of industry clusters*. Carnegie Mellon University, Center for Economic Development.

Partners in Science. (2015). *Singapore*. Retrieved from https://sea-eu.net/facts/ sea/singapore.

Patrick, A. (2016). *Collaboration Spotlight: Washington Stormwater Center*.Washington State University. Retrieved from economicdevelopment. wsu.edu/2016/02/26/2319/

Paytas, J., Gradeck, R., & Andrews, L. (2004). *Universities and the development of industry clusters*. Carnegie Mellon University, Center for Economic Development.

Pettersen, I. B., Aarstad, J., Høvig, Ø. S., & Tobiassen, A. E. (2015). Business incubation and the network resources of start-ups. *Journal of Innovation and Entrepreneurship*, 5(1), 7.

Peled, D. (2001). *Defense R&D and economic growth in Israel: a research agenda*. Israel: Samuel Neaman Institute for Advanced Studies in Science and Technology, Technion.

Picou, S. C. (2014). Building Louisiana's Water Cluster. *Proceedings of the Water Environment Federation, 2014*(14), 55-84.

Platt, J. (1981). 'Evidence and Proof in Documentary Research', *Sociological Review*, Vol. 29, No. 1, 31-52.

Porter, M. E. (1990). *Competitive advantage of nations: creating and sustaining superior performance*. New York, NY: Simon and Schuster.

Porter, M. E. (1998). Clusters and the new economics of competition. *Harvard Business Review* (Vol. 76, No. 6, pp. 77-90).

Porter, M. E. (2000). Location, competition, and economic development: Local clusters in a global economy. *Economic development quarterly*, 14(1), 15-34.

Porter, M. (2008, January). Clusters, innovation, and competitiveness: New findings and implications for policy. In Presentation given at the *European Presidency Conference on Innovation and Clusters in Stockholm* (Vol. 23).

Porter, M. E., & Kramer, M. R. (2011). The big idea: Creating shared value. *Harvard business review*, 89(1), 2.

Portman, R. (2017). *Portman's Bipartisan Bill to Combat Harmful Algal Blooms and Hypoxia Passes Committee*. (May 18, 2017). Retrieved from https://www.portman.senate.gov/public/index.cfm/2017/5/portman-s-bipartisan-bill-to-combat-harmful-algal-blooms-and-hypoxia-passes-committee

PSRC. (2016). *Data at PSRC: Census and American Community Survey*. Puget Sound Regional Council. https://www.psrc.org/data-and-resources/data-psrc.

PUB. (2016). *Our Water, Our Future*. Singapore: Public Utilities Board.

PUB. (2017). Singapore Water Story. Retrieved from https://www.pub.gov.sg/ watersupply/singaporewaterstory.

PUB. (2018). *Innovation in Water: Singapore 2018*. Vol. 10, July, 2018. Retrieved from https://www.pub.gov.sg/Documents/Innovation_in_Water_Singapore_Vol10.pdf

Puentes, R., & Sabol, P. (2015). *Opportunities for Infrastructure Reform: Improving America's Procurement System*. Washington, D.C.: Brookings.

Puget Sound Action Team. (2004). Transition Briefing – October 2004. http://wsldocs.sos.wa.gov/ library/docs/gov/govtrans/govtrans/pdf/7500PS.pdf

Puget Sound Partnership. (July 17, 2017). Puget Sound Partnership Science Panel to discuss draft 2017 State of the Sound report. *Press Release Puget Sound Partnership*. Retrieved from https://content.govdelivery.com/ accounts/WAPSP/bulletins/1aaa28b

Puget Sound Partnership. (2008). Bold cleanup plan to save Puget Sound gets green light. *Press Release Puget Sound Partnership*. Retrieved from http://www.psp.wa.gov/pressreleases/partnership_release.php?id=96.

Puget Sound Water Quality Action Team. (2000). *Puget Sound Water Quality Management Plan 2000*. State of Washington: Office of Governor.

PWC. (2016). *Utilities and Power Companies 2016*. Norwalk, CT: PriceWaterhouseCoopers.

Quinn, T., (2010). An environmental and historical overview of the Puget Sound ecosystem, in Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., and Dinicola, R.S., eds., 2010, *Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop*, May 2009: U.S. Geological Survey Scientific Investigations Report 2010-5254, p. 11-18.

Rabinovitch, A. (2012). *Israel's Mekorot targets world water market*. Reuters. Retrieved from https://www.reuters.comarticle/us-israel-mekorot/israels-mekorot-targets-world-water-market- idUSBRE8560HA20120607.

Raphaeli, N. (1965). Israel's water economy. *Land Economics*, 41(4), 361-364.

Reisman, A. (2005). *Israel's economic development: The role of institutionalized technology transfer*. Retrieved from https://papers.ssrn.com /sol3/papers.cfm?abstract_id=579883

Rice, J. (2013). Wellspring Conference at UW Tacoma looks at clean water technology October 24-25. Pacific Sound Institute. Retrieved from http://www.pugetsoundinstitute.org/2013/09/wellspring-conference-will-be-held-october-24-25/.

Ringenberg, D. T., Wilson, S. D., & Dvorak, B. I. (2017). State Barriers to Approval of Drinking Water Technologies for Small Systems. *Journal ‐ American Water Works Association*, 109(8), E343-E352.

Roelandt, T. J., Den Hertog, P., van Sinderen, J., & van den Hove, N. (1999). Cluster analysis and cluster policy in the Netherlands. In J. Guinet (Ed), *Boosting Innovation: The Cluster Approach*. pp. 315-338. Paris, France; OECD Proceedings.

Rogers, J. D. (2003). *Innovative Solutions for Water Wars in Israel, Jordan and the Palestinian Authority*. University of Missouri-Rolla, Department of Geological Engineering.

Rogers, P., De Silva, R., & Bhatia, R. (2002). Water is an economic good: How to use prices to promote equity, efficiency, and sustainability. *Water policy*, 4(1), 1-17.

Rogers, P., & Hall, A. W. (2003). *Effective water governance* (Vol. 7). Stockholm: Global Water Partnership.

Rogers, E. M., Medina, U. E., Rivera, M. A., & Wiley, C. J. (2005). Complex adaptive systems and the diffusion of innovations. *The Innovation Journal: The Public Sector Innovation Journal*, *10*(3), 1-26.

Rosegrant, M. W., & Cline, S. (2002). The politics and economics of water pricing in developing countries. *Water Resources Impact*, 4(1), 6-8.

Romano, B. (2013). On the Cusp of Commercialization, Hydrovolts Runs Out of Cash. *Xconomy*. Retrieved from http://www.xconomy.com/seattle/2013/02/20/on-the-cusp-of-commercialization-hydrovolts-runs-out-of-cash/.

Romell, R. (May 18, 2017). For third straight year, Wisconsin ranks last in business startup activity. *Milwaukee Journal Sentinel*. Retrieved from https://www.jsonline.com /story/money/2017/05/18/third-straight-year-wisconsin-ranks-last-business-startup-activity/328803001/

Roudi-Fahimi, F., Creel, L., & De Souza, R. M. (2002). Finding the balance: Population and water scarcity in the Middle East and North Africa. *Population Reference Bureau Policy Brief*, 1-8.

Rouyer, A. R. (1996). Zionism and water: influences on Israel's future water policy during the pre-state period. *Arab studies quarterly*, 25-47.

Rowley, J. (2002). Using case studies in research. *Management Research News*, 25(1), 16-27.

Rubin, A., & Babbie, E. R. (2009). *Essential research methods for social work*: Bemont, CA: Cengage Learning Inc.

Rutledge, M. (2016). Hamilton leaders seek fountain of water innovation. *Journal News*. Retrieved from http://www.journal-news.com/news/hamilton-leaders-seek-fountain-water-innovation/ethAoCfraoKCznw8J3tDBM/.

Sagar, M. (2017). Singapore is well-positioned to be a living lab for smart cities solutions. *Open Government Asia*. Retrieved from https://www.opengovasia.com/ articles/6742-singapore-is-well-positioned-to-be-a-living-lab-for-smart-cities-solutions.

Sadan, E., & Ben-Zvi, R. (1987). The value of institutional change in Israel's water economy. *Water Resources Research*, 23(1), 1-8

Saha, D., Fikri, K., & Marchio, N. (2014). *FDI in US metro areas: the geography of jobs in foreign-owned establishments*. June 2014. Washington, DC: Brookings Institution

Sallet, J., Paisley, E., & Masterman, J. (2009). The geography of innovation: The federal government and the growth of regional innovation clusters. *Science Progress*, *6*.

Saxenian, A. (1994). Regional networks: industrial adaptation in Silicon Valley and route 128. *Cityscape: A Journal of Policy Development and Research* • Volume 2, Number 2

Schmid, J. (March 7, 2009). Floating some big ideas. *The Journal Sentinel*. Retrieved from http://archive.jsonline.com/business/40878037.html

Schmid, J. (April 27, 2009). Milwaukee a water technology hub. *The Journal Sentinel*. Retrieved from http://archive.jsonline.com/business/43835922.html

Schmid, J. (February 21, 2011). Milwaukee group to be recognized for water work. *The Journal Sentinel.* Retrieved from http://archive.jsonline.com/business /116630258.html/

Schmid, J. (December 28, 2012). Water Council drops 'Milwaukee' from name. *The Journal Sentinel.* Retrieved from http://archive.jsonline.com/business/water-council-drops-milwaukee-from-name-p586f6j-185107501.html/

Schmid, J. (July 21, 2017). Milwaukee Water Council picks water-tech startups for incubator. *The Journal Sentinel.* Retrieved from https://www.jsonline.com /.../2017/.../milwaukee-water-council-picks-water-tech-startu...

Schnoor, J. L. (2010). *Water sustainability in a changing world*. National Water Resarch Institute.

Schuyler, D. (June 23, 2015). Chase awards second small business grant for Global Water. *Milwaukee Business Journal*. Retrieved from https://www.bizjournals.com /milwaukee/news/2015/06/23/chase-awards-second-small-business-grant-for.html

Schumpeter, J. A. (1912). The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest and the Business Cycle. *Trans. Redvers Opie*. Cambridge, MA: Harvard University Press.

Schumpeter, J. A. (1939). *Business cycles* (Vol. 1). New York, NY: McGraw-Hill.

Schumpeter, J. (1942). *Creative destruction. Capitalism, socialism and democracy*. New York, NY: Harper

Schwab, K., & Sala-i-Martin, X. (2016). The Global Competitiveness Report 2016. In *World Economic Forum*.

Schwartz, K., & Blokland, M. (2002). Government-Owned Public Limited Companies in the Dutch Water Sector. In *Reinventing Water and Wastewater Systems: Global Lessons for Improving Water Management*, 221.

Scott, J. (1990). *A Matter of Record, Documentary Sources in Social Research,* Cambridge, UK: Polity Press.

Sea Grant. (2008). *A Partnership Approach: Washington Sea Grant Takes an Active Role in the New Action Agenda for Puget Sound*. University of Washington. Retrieved from https://wsg.washington.edu/wordpress/wp-content/uploads/seastar/sp08.pdf

Seattle Audubon. (2017). *Puget Sound Partnership*. Retrieved from http://www.seattleaudubon.org/sas/About/ Conservation/RegionalConservation/ PugetSoundPartnership.aspx

Selviaridis, K. (2016). *Public procurement and innovation: a review of evidence on the alignment between policy and practice*. Department of Management Science, Lancaster University Management School. Retrieved from https://www.researchgate.net/profile/Kostas_Selviaridis/publication/305386808_Public_procurement_and_innovation_a_review_of_evidence_on_the_alignment_between_policy_and_practice/links/578bbb3c08ae5c86c9a149cb/

Sen, A. (1993). Markets and freedoms: achievements and limitations of the market mechanism in promoting individual freedoms. *Oxford Economic Papers*, 519-541.

Sherwood, C. (2013). Northwest Pipe Co. hopes higher profits are in the pipeline. The Columbian. http://www.columbian.com/news/2013/sep/22/profits-pipeline-northwest-pipe-vancouver/.

Shelef, G., Juanico, M., & Vikinsky, M. (1987). Reuse of stabilization pond effluent for agricultural irrigation in Israel. *Water science and technology*, 19(12), 299-305.

Siegel, S. M. (2015). *Let There Be Water: Israel's Solution for a Water-Starved World*. New York, NY: Macmillan.

Silverman, D. (2000). *Doing qualitative research*. London, UK: Sage Publications.

Singapore Department of Statistics. (2017). *Yearbook of Statistics, 2017*. Department of Statistics, Ministry of Industry & Trade, Republic of Singapore.

SIWI. (2005). *Making water a part of economic development*. Stockholm, Sweden. Stockholm International Water Institute.

Sluyterman, K. E. (2013). Dutch multinational trading companies in the twentieth century. In *The multinational traders* (pp. 100-115). Routledge.

Smilor, R. W., Gibson, D. V., & Kozmetsky, G. (1989). Creating the technopolis: high-technology development in Austin, Texas. *Journal of Business Venturing,* Volume 4, Issue 1, 1989, Pages 49-67

Smith, J. A., & Osborn, M. (2003) Interpretative phenomenological analysis. In JA Smith (Ed.) *Qualitative psychology: a practical guide to research methods.* London, UK: Sage

Smith, C. (2013). *City water, city life: Water and the infrastructure of ideas in urbanizing Philadelphia, Boston, and Chicago. Chicago*, USA: University of Chicago Press.

Smith, C.S. (December 7, 2014). Local group takes on toxic algae head on. Retrieved from https://www.cincinnati.com/story/news/2014/12/07/greater-cincinnati-effort-toxic-algae/20071331/

Smith, D. R., King, K. W., & Williams, M. R. (2015). What is causing the harmful algal blooms in Lake Erie?. *Journal of Soil and Water Conservation*, 70(2), 27A-29A.

Smith, C.B. (2015). NASA gets involved in local toxic algae struggle. *The Enquirer*. Retrieved from https://www.cincinnati.com/story/news/2015/09/26/ohio-river-algae-nasa-

Sokolowsky, J., (2012). *State gives $13.5M to Innovation Partnership Zones projects*. *Puget Sound Business Journal*. Retrieved from https://www.bizjournals.com/seattle/news/2012/04/27/state-gives-135m-to-innovation.html.

Solomon, S. (2011). *Water: The Epic Struggle for Wealth, Power, and Civilization*. New York, NY: Harper Perennial

Sowa, T. (2005). Itron to move to Liberty Lake, buy Telect building. *The Spokesman-Review*. Retrieved from http://www.spokesman.com/stories/2005/oct/29/itron-to-move-to-liberty-lake-buy-telect-building/.

Speight V. L. (2015). Innovation in the water industry: barriers and opportunities for US and UK utilities. *WIREs Water 2015*. doi: 10.1002/wat2.1082

Spiritos E. & Lipchin, C. (2013) Desalination in Israel. In Becker N. (eds) *Water Policy in Israel*. *Global Issues in Water Policy, vol 4*. Dordrecht, The Netherlands: Springer.

Starr, J. R. (1991). Water wars. *Foreign policy*, (82), 17-36.

Statistics Netherlands. (2012). *Statistics Yearbook of the Netherlands 2012*. Retrieved from https://www.cbs.nl/en-gb/publication/2012/26/statistical-yearbook-2012

Steffan, K. (2016). Milorganite. *Enclycopedia of Milwaukee*. Retrieved from https://emke.uwm.edu/entry/milorganite/

Stewart, S., & Springs, S. (2015). 5. United States of America United States of America. *UNESCO science report: towards 2030*, 129. Paris, France: UNESCO

Stiffler, L. (2005). State of Puget Sound troubling: Development continues to overtake cleanup efforts, report finds. *Seattle Post-Intelligencer Reporter*. Retrieved from http://www.seattlepi.com/local/article/State-of-Puget-Sound-troubling-1164494.php

Stiffler, L. (2010). Troubled Waters for Puget Sound Partnership. *Sightline Institute*. Retrieved from http://www.sightline.org/2010/08/31/troubled-waters-for-puget-sound-partnership/

Stiglitz, J. E. (1989). Markets, market failures, and development. *The American Economic Review, 79*(2), 197-203.

Stiglitz, J. E., & Rosengard, J. K. (2015). *Economics of the Public Sector: Fourth International Student Edition*. New York, NY: WW Norton & Company.

Still, T. (November 26, 2016). UW-Madison's R&D ranking is cause for concern. *Wisconsin Journal Sentinel*. Retrieved from https://www.jsonline.com/story/money/columnists/tom-still/2016/11/26/still-uw-madisons-rd-ranking-cause-concern/94407392/

Strauss, K. (April 20, 2013). Foreign Business, Meet Cincinnati. *Forbes*. Retrieved from https://www.forbes.com/sites/karstenstrauss/2013/04/20/foreign-business-meet-cincinnati/#1f765a1d195e

Stroo, H. (2014). Water: The Economic Development Opportunity Hiding in Plain Sight. *Plan Washington*. Retrieved from http://planwashington.org/blog/archive/water-the-economic-development-opportunity-hiding-in-plain-sight/.

Tal, A. (2002). *Pollution in a Promised Land: An Environmental History of Israel*. Berkeley: University of California Press.

Tal, A. (2006). Seeking sustainability: Israel's evolving water management strategy. *Science*, 313(5790), 1081-1084.

Tal, A. (2007). To make a desert bloom: The Israeli agricultural adventure and the quest for sustainability. *Agricultural History*, 228-257.

Tan, Y. S., Lee, T. J., & Tan, K. (2009). *Clean, green and blue: Singapore's journey towards environmental and water sustainability*. Singapore: Institute of Southeast Asian Studies.

Tether, B.S. & Storey, D.J. (1998) Smaller firms and Europe’s high technology sectors: a framework for analysis and some statistical evidence. *Research Policy*, 26(9), 947–971

Tenne, A. (2010). Sea Water Desalination in Israel: Planning, coping with difficulties, and economic aspects of long-term risks. *Shared Borders, Shared Waters*, 263.

Tenne, A., Hoffman, D., & Levi, E. (2013). Quantifying the actual benefits of large-scale seawater desalination in Israel. *Desalination and Water Treatment*, 51(1-3), 26-37.

The Economist. (May 20, 2010). *Liquid Gold*. London, UK: The Economist Newspaper.

The Economist. (May 12, 2011). *Water Technology: Striking the Stone*. London, UK: The Economist Newspaper.

The Olympian. (2006). History of Puget Sound cleanup efforts. Retrieved from http://www.theolympian.com/ news/local/article25225273.html

Thomas, B. (1999). *How Israel was won: a concise history of the Arab-Israeli conflict*. Maryland, USA: Lexington Books.

Thomas, B. (2009). *The Dark Side of Zionism: The Quest for Security through Dominance*. Maryland, USA: Lexington Books.

Thomas, D. & Ford, R. (2016). *The crisis of innovation in water and wastewater*. Cheltenham, UK: Edward Elgar Publishing.

Thompson, A. (September 24, 2013). Liquid Assets: How Cincinnati became a world water leader. *WVXU Cincinnati*. Retrieved from http://www.wvxu.org/post/liquid-assets-how-cincinnati-became-world-water-leader#stream/0.

Thompson, A. (September 23, 2013). Liquid Assets: Cincinnati hopes to cash in on H2O. *WVUX*. Retrieved from http://www.wvxu.org/post/liquid-assets-cincinnati-hopes-cash-h2o#stream/0

Tichy, G. (1998), Clusters: less dispensable and more risky than ever, in M. Steiner (ed), *Clusters and Regional Specialisation*, London: Pinter, pp. 226-237.

Tol, R. S., & Langen, A. (2000). A concise history of Dutch river floods. *Climatic change*, 46(3), 357-369.

Top Team Water. (2011). *Water deserses it: advice for water top sector*. Government of The Netherlands.

Tortajada, C. (2006a). Water management in Singapore. *Water Resources Development*, 22(2), 227-240.

Tortajada, C. (2006b). *Singapore: an exemplary case for urban water management. Additional Paper*, Human Development Report, United Nations Development Programme, New York.

Tortajada, C., Joshi, Y., & Biswas, A. K. (2013). *The Singapore water story: sustainable development in an urban city state*. Oxford, UK: Routledge.

Townsend, S. E. (2014). Bart Nelson is 'just one of the players' at Nelson Irrigation Company. *Columbia Basin Herald*. Retrieved from columbiabasinherald.com/ basin_business_journal/ ag_news/article_65b2f09a-8e7f-11e3-9a67-001a4bcf887a.html.

Trimarco, M., Woodson, J., & Zerr, Robb. (2014). Innovation Partnership Zone Program: 2014 Biennial Report. Washington State Department of Commerce. http://choosewashingtonstate.com/wpcontent/uploads/2015/05/Commerce-IPZ-2014.pdf.

Turner, W. (1981). Tacoma Pollution on '110 Worst' List. *The New York Times*. Retrieved from http://www.nytimes.com/1981/11/08/us/tacoma-pollution-on-10-worst-list.html

UNDP. (2006). *The Millennium Development Goals Report 2006*. Department of Economic and Social Affairs. United Nations: New York.

UNDP. (2015). *The Millennium Development Goals Report 2015*. Department of Economic and Social Affairs. United Nations: New York.

UNESCO. (2006). *Water: a shared responsibility; the United Nations world water development report 2*. Paris, France: UNESCO Publishing.

UNESCO. (2015). *UNESCO Science Report: towards 2030*. Paris, France: UNESCO Publishing.

UN Water-FAO. (2007). Water, U. N. (2007). Coping with water scarcity: challenge of the twenty-first century. Prepared for *World Water Day*. Rome: Italy.

UWT. (2012). Funding for UW Tacoma and WSU Puyallup labs to fuel economic Development. Retrieved from http://www.tacoma.washington.edu/ news/article/funding-uw-tacoma-and-wsu-puyallup-labs-fuel-economic-development.

UWT. (2015). About the Encyclopedia of Puget Sound. Center for Urban Waters. Retrieved from https://www.eopugetsound.org/about.

UWT. (2015). How It Works: Prairie Line Trail Stormwater Treatment.Retrieved from https://www.tacoma.uw.edu/ news/article/how-it-works-prairie-line-trail-stormwater-treatment.

UWT. (2017a). Puget Sound Institute. Center for Urban Waters. Retreived from http://www.tacoma.washington.edu/center-urban-waters/puget-sound-institute.

UWT. (2017b). *Clean Water Innovation Laboratory*. Retreived from http://www.tacoma.washington.edu/center-urban-waters/clean-water-innovation-laboratory

Van den Brink, M. A. (2009). *Rijkswaterstaat on the horns of a dilemma*. Eburon Uitgeverij BV.

Van der Brugge, R., Rotmans, J., & Loorbach, D. (2005). The transition in Dutch water management. *Regional environmental change*, 5(4), 164-176.

Van der Steen, M. (1999). *Evolutionary systems of innovations: a Veblian-oriented study into the role of the government factor*. Uitgeverij Van Gorcum.

Van der Veen, G. (2010). *EIO country brief 2010: The Netherlands*. Eco-Innovation Observatory

Van der Vleuten, E. & Disco, C. (2004) Water wizards: reshaping wet nature and society, *History and Technology*, 20:3, 291-309

Verbeten, S. (2016). Initiating Water Culture Through Water Clusters. *Treatment Plant Operator Magazine*. Retrieved from https://www.tpomag.com/online_ exclusives/2016/12/ initiating_ water_culture_through_water_clusters.

Veolia. (2017). Veolia Annual Results 2017. Retrieved from https://www.veolia.com/ sites/g/files/dvc181/f/assets/documents/2018/02/PR-RA2018-Veolia-220218-ENG.pdf

Vewin. (2016). Drinking watr factsheet 2016. Association of Dutch water companies.

Virgin, B. (July 2015). Water Tech: the Next Emerging Business Cluster? *Seattle Business Magazine*. Retrieved from http://www.seattlebusinessmag.com /article/water-tech-next-emerging-business-cluster

Virgin, B. (May 2016). The 2016 Washington Manufacturing Awards: Manufacturer of the Year, Large Firms. *Seattle Business Magazine*. Retrieved from http://seattlebusinessmag.com/article/2015-washington-manufacturing-awards-manufacturer-year-large-firms.

Vossestein, J. (2014). *The Dutch and their Delta. Living below sea-level*. The Hague, The Netherlands: X Pat Scriptum.

Vorosmarty, C.J.; Green, P.; Salisbury, J.; Lammers, R.B. Global water resources: Vulnerability from climate change and population growth. *Science 2000*, 289, 284–288.

Waits, A. (April 2015). *Water Cluster Leaders Meeting Report*. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/161.

Waits, A. (2014). U.S. EPA Water Technology Innovation Cluster Leaders Meeting. – *Successfully Supporting Early-Stage Companies: The Role of Technology Testing: Meeting Summary Report*. U.S. Environmental Protection Agency, Washington, DC, EPA/600/S-14/190.

Wallen, D., Cohen, S., Nickell, A., & Salmi, S. (2012) Innovation Partnership Zones 2012 Report: Toward a More Data-Driven Assessment. Washington State Department of Commerce. Retrieved from http://choosewashingtonstate.com/wp-content/uploads/2013/02/2012-IPZ-Report.pdf.

Washington Department of Ecology. (2010). By the Numbers – How Water Supports WashingtonJobs. Department of Ecology, State of Washington. Retrieved from http://www.ecy.wa.gov/managingwater/jobs.html.

Washington State Department of Commerce. (Undated). Key Sectors Bring Focus to High Growth Industries.Retrieved from http://www.commerce.wa.gov/growing-the-economy/ key-sectors/.

Waterapplicationcenter.com. (2017). Water Application Center: Home. Retrieved from http://www.waterapplicationcentre.com/home.

Water Citizen. (September 12, 2013). Clusters Form to Support Water Technology Innovation. *Water Citizen News*. Retreived from http://watercitizennews.com/ clusters-form-to-support-water-technology-innovation/Water Citizen |

WATEC. (2017). WATEC 2017. Retrieved from http://watec-israel.com/#.

Water Alliance. (2016). *Innovation, now and later.* Retrieved from https://wateralliance.nl/druk-bezocht-watercampus- business-cafe/.

WaterAlliance.nl. (2017). Vision, Mission, and Strategy. Retrieved from https://wateralliance.nl/en/about-us/mission *vision/.*

Watercampus.nl. (2014). *Leeuwarden participates in UN Global Compact Cities Programme*. Retrieved from http://watercampus.nl/en/nieuws/leeuwarden-participates-in-un-global-compact-cities- programme/.

Watercampus.nl. (2017). *About WaterCampus.* Retrieved from http://watercampus.nl/en/about-watercampus/.

Water Commission. (2012). Israel Water Sector Master Plan. Retrieved from http://www.water.gov.il/Hebrew/ Professional InfoAndData /2012/09-Israel-Water-Sector-Master-Plan-2050.pdf.

Water Council. (2016). *2016 Annual Report*. Retrieved from https://thewatercouncil.com /wp-content/uploads/TWC_Annual-Report_WEB_FINAL_4-7-17.pdf

Water Council. (2017). 2017 Annual Report. Retrieved from https://thewatercouncil.com /wp-content/uploads/AR_2017_WEB_Version.pdf

WaterTectonics. (2017). About us. Retrieved from http://www.watertectonics.com/.

WaterWorld. (March 1, 2010). Drinking water treatment technology from Halosource recognized by Frost & Sullivan. *Water World*. Retrieved from https://www.waterworld.com /articles/2010/03/drinking-water-treatment-technology-from-halosource-recognized-by-frost-and-sullivan.html.

WaterWorld. (May 07, 2012). Water tecnnology company Halosource partners with Chinese suppliers. Water World. Retrieved from https://www.waterworld.com /articles/2012/05/water-company-halosource-partners-with-chinese-supplier.html

Wear, Andrew (2008). "Innovation and community strength in Provincial Victoria". *Australasian Journal of Regional Studies*. 14 (2): 195

Wessner, C. W. (Ed.). (2012). *Clustering for 21st Century Prosperity: Summary of a Symposium*. National Academies Press.

Wetsus. (2016). *Business Plan: 2016-2020*. Leeuwarden, The Netherlands: Wetsus, European Centre of Excellence for Sustainable Water Technology.

Wetsus. (2017). *Wetsus 2017: combining scientific excellence with commercial relevance*. Leeuwarden, The Netherlands: Wetsus, European Centre of Excellence for Sustainable Water Technology.

Wehn, U., & Montalvo, C. (2017). Exploring the dynamics of water innovation: Foundations for water innovation studies. *Journal of Cleaner Production* 171 (2018) S1eS19

White, S.B. (November 1, 2010). *Water Markets of the United States and the World: A Strategic Analysis for the Milwaukee Water Council*. University of Wisconsin-Milwaukee.

White House. (2009). *A strategy for Amerivan innovation: Driving towards sustainable growth and quality jobs*. National Economic Council, Council of Economic Advisors, and Office of Science and Technology Policy. Retreived from http://www.dtic.mil/dtic/tr/ fulltext/u2/a524201.pdf

White House. (2011a). *A strategy for American innovation: Securing our economic growth and prosperity*. National Economic Council, Council of Economic Advisors, and Office of Science and Technology Policy. Retreived from https://obamawhitehouse.archives.gov/sites/default/files/uploads/InnovationStrategy.pdf

White House. (2011b). Presidential Memorandum -- Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses. *Office of the Press Secretary*. Retreived from https://obamawhitehouse.archives.gov/the-press-office/2011/10/28/presidential-memorandum-accelerating-technology-transfer-and-commerciali

White House. (2015). *A strategy for American innovation.* National Economic Council, Council of Economic Advisors, and Office of Science and Technology Policy Retreived from https://obamawhitehouse.archives.gov/sites/ default/files/strategy_for_american_innovation_october_2015.pdf

White House. (2016). Working Together to Build a Sustainable Water Future. *Office of the Press Secretary*. Retreived from https://obamawhitehouse.archives.gov/the-press-office/2016/03/22/fact-sheet-working-together-build-sustainable-water-future

Winsconsin Economic Development Coropration. (September 2017). *Expeertise in water technology runs deep in Winconsin*. Madison, WI: WEDC.

WHO/UNICEF. (2008). Progress on drinking water and sanitation: Special focus on sanitation. In *Progress on drinking water and sanitation: special focus on sanitation*. WHO/JMP.

WHO/UNICEF Joint Water Supply, Sanitation Monitoring Programme, & World Health Organization. (2014). *Progress on drinking water and sanitation: 2014 update*. World Health Organization.

Wijedasa, N. (December 01, 2013). Netherlands looks beyond dykes for flood protection. *Sri Lanka Business Times*. Retrieved from http://www.sundaytimes.lk/131201/ business-times/netherlands-looks-beyond-dykes-for-flood-protection-74685.html.

Wines, M. (March 14, 2013). Spring rain, then foul algae in ailing Lake Erie. *The New York Times*. Retrieved from https://www.nytimes.com/2013/03/15/ science/earth/algae-blooms-threaten-lake-erie.htm

Wines, M. (August 4, 2014). Behind Toledo's Water Crisis, a Long-Troubled Lake Erie. *New York Times*. Retrieved from https://www.nytimes.com/2014/08/05/us/lifting-ban-toledo-says-its-water-is-safe-to-drink-again.html

Wines, M. (September 13, 2015). Toxic Algae Outbreak Overwhelms a Polluted Ohio River. *The New York Times*. Retrieved frohttps://www.nytimes.com/2015/10/01/ us/toxic-algae-outbreak-overwhelms-a-polluted-ohio-river.html

World Water Commission. (2000). *A Water Secure World: Vision for Water, Life, and the Environment. World Water Vision Commission Report*. Paris, France: Thanet Press.

Wong, L. (2015). Three decades after the Asarco smelter shutdown, its toxic legacy Surprises Tacoma newcomers. *The News Tribune*. Retrieved from http://www.thenewstribune.com/news/local/article43503663.html

Wong, S. (2006) The Business and Sustainability of Water Supply in Singapore: The Case of Hyflux. In J.D. Gatrell & N. Reid (eds), *Enterprising Worlds. The GeoJournal Library, vol 86*. Dordrecht, Netherlands: Springer.

World Economic Forum. (2015). *Global Risks 2015* (10th Edition). World Economic Forum: Geneva, Switzerland.

WSU. (2016a). Solving the stormwater problem through teamwork. Retrieved from https://stormwaterone.com/articles/solving-the-stormwater-problem-through-teamwork-washington-state-university.

WSU. (2016b). Solving the stormwater problem through teamwork. Retrieved from https://stormwaterone.com/articles/solving-the-stormwater-problem-through-teamwork-washington-state-university.

Wulkan, B. T. (2015). Puget Sound Partnership's LID Technical Assistance Program: 2009-2011 Update. In Low Impact Development Technology: Implementation and Economics: LID: Implementation and Economics (pp. 5-16).

Yangchen, L. (2012). *Singapore at the front line of water innovation*. Straight Times. http://www.straitstimes.com/singapore/spore-at-the-front-line-of-water-innovation

Yangchen, L. (2017). Keeping Singapore's taps flowing in the quest for a robust water supply. (March12, 2017). *The Straight Times*. Retrieved from https://www.straitstimes.com/singapore/keeping-the-nations-taps-flowing

Yew, L. K. (2012). *From third world to first: The Singapore story, 1965-2000* (Vol. 2). Marshall Cavendish International Asia Pte Ltd.

Yin, R. K. (2003). *Case study research: Design and methods*, 3rd edition, London, UK: SAGE Publications.

Yin, R. K. (2003). *Case study research: Design and methods*, 3rd edition, London, UK: SAGE Publications.

Young. (2017). *Proposed Strategic Plan for Washington State: Clean Technology Sector 2017-2019*. Washington State Department of Commerce, Office of Economic Development and Competitiveness.

Young. (2017). *Proposed Strategic Plan for Washington State: Clean Technology Sector 2017-2019*. Washington State Department of Commerce, Office of Economic Development and Competitiveness.

Yue, C. S. (2001). Singapore: Towards a knowledge-based economy. In Masuyama, S., Vandenbrink, D., & Yue, C. S. (Eds.), *Industrial restructuring in East Asia: Towards the 21st century* (Vol. 25). Institute of Southeast Asian Studies.

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