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The Connections Between Innovation, Culture, and Expertise in Water Infrastructure Organizations

Alice Brawley-Chesworth
Portland State University

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by

Alice Brawley-Chesworth

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Dissertation Committee:
Connie P. Ozawa, Chair
Thaddeus R. Miller
Jennifer H. Allen
Judith A. Ramaley

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ABSTRACT

Infrastructure organizations are notoriously conservative and resistant to change, even when faced with wicked problems that cannot be solved with the same thinking used in the past. In the water sector, this resistance to change has been linked to an industry culture that is based in a single, engineering-oriented knowledge system. Scholars have suggested that diversification of knowledge systems is necessary for implementation of innovations that will move the sector forward to solve wicked problems.

This research used a qualitative case study approach comparing two water sector organizations in Portland, Oregon. One organization included members who shared an engineering knowledge system, and the other had members oriented toward engineering as well as members with an ecological knowledge system. This research focused on implementation of a common innovation at both organizations, asset management. Asset management in the water sector developed within an engineering context and is seen by people within the sector as being compatible with an engineering way of thinking. Implementation of asset management prompts the reexamination of the assumptions, management structures and decision processes of the organization. This research found that implementation has been faster and more straightforward at the organization with only the engineering knowledge system because it was compatible with the organizational culture. Implementation at the organization with the more diverse knowledge system has been slower, more contentious, and has involved a reinvention process. The research examines how the underlying assumptions and orientations of these two knowledge systems are influencing adoption of asset management and reinventing what asset management means.

This research shows that the relationships between innovation, culture, and expertise at organizations are more complex than the literature proposes. Contrary to the innovation literature, it suggests that an organization cannot be judged to be more or less innovative outside the context of what types of innovations are being discussed. Organizations with a stable knowledge system based in one professional orientation may be more likely to implement some innovations, ones that are compatible with their knowledge system. Organizations with a more heterogeneous knowledge system may be more likely to adopt radical innovations and engage in reinvention processes, but adoption of the innovation can be slower and more contentious.

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as a quintessential engineer, you'd probably be baffled by all this social stuff. To my mom, Henrietta Grosz, thank you for modeling completing a graduate degree later in life. Your going back to school after your children had left the house, while continuing to work full time, was an inspiration.

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PREFACE

This journey began for me at a meeting several years ago during a standard workday. A group of employees and consultants, mostly engineers but also some operations people, were sitting around a table to decide on a treatment technology to use at our wastewater treatment plant. This was the last in a series of meetings; the team had previously decided which technologies would be considered in our analysis and the criteria we would use to judge them. When the consultants showed the results of the analysis, a technology we hadn't used before, but had been used for years by other organizations, especially in Europe, came out on top. Our usual technology was in second place. After some discussion one of the engineers said, in reference to the technology with the highest score, "well, I just think it's too new." And that ended the discussion. The "new" technology was dropped and we went with the same old one that we had been using for decades. There were likely other, and very valid, reasons why the decision was made to go with the "old" technology. But to me, the fact that "it's just too new" was the clinching argument to be taken as the last word was incredibly frustrating and baffling. How could we possibly adapt to a changing world with this attitude? Would we just continue making the same mistakes over and over again? Why was nobody else in the room shocked by this?

Of course, if that had been an isolated incident it wouldn't have mattered. I wouldn't have committed to a seven-year process to pursue another degree. I've worked in the water sector for about 30 years and have experienced a willingness to tackle new problems and come up with new solutions in some contexts, and a stubborn resistance to change in other contexts. Troubleshooting and solving problems was at the core of all our work in the water sector, yet somehow our solutions seemed to usually look the same. Everyone I worked with were intelligent, creative, and dedicated professionals who were trying to do the right thing. What was going on? Why were we only sometimes willing to innovate? Why did the results of all this problem solving and creativity rarely change the infrastructure we built?

As a chemist I've been in spaces where colleagues complained about engineers belittling and ignoring everyone else in the organization. As an engineer I've been in spaces where colleagues complained about environmental scientists being too politically oriented and ignoring "the laws of physics." As a policy analyst I've been in spaces where colleagues complained about the naivete of scientists and engineers who think government decisions can be objective and dictated by science. And, as a combination of all of the above, I've been in other spaces where people with different professional training have learned from each other and appreciated different points of view. Most of the more open and creative decisions I've participated in have involved groups of people with varying training and professional orientations, and most of the more intense and conflict-filled conversations have also involved groups of people with varying training and professional orientations. Was having a diversity of professional training a key to innovation? If so, how could we do a better job of bringing multiple different professions together to collaborate? And, most importantly, what could we do to increase the chance that we'd implement the innovations necessary to tackle big problems like climate change? That long history is the real reason why I began this journey. This dissertation outlines some of what I've learned along the way.

Chapter 1 - INTRODUCTION

New, innovative approaches to urban infrastructure provision are needed to ensure that the cities of the future meet the needs of their residents. One driver of this need for change is the changing climate. Climate change is the defining environmental issue of our time, affecting all regions of the globe. At the local level, urban leaders are looking at options to increase resilience so that the community can prepare for and respond to an uncertain, and more variable, future. This conversation is becoming more urgent as people realize that it is too late to fully mitigate climate impacts, and that some of those impacts are already being felt. In addition, organizations working on environmental improvement across the United States, including water sector organizations, have recognized that efforts aimed at environmental improvement often harm low-income communities and communities of color and are trying to address these inequities. This is a particular challenge for the water sector as both flooding and drought, and their impacts on front line communities, are expected to increase as a result of climate change. However, the water sector is known for being conservative and resistant to change (Lach, Ingram, and Rayner 2004; Thomas and Ford 2005; Brown, Ashley, and Farrelly 2011; Herrick and Pratt 2012; Ajami, Thompson Jr, and Victor 2014). In some cases, more resilient technologies exist, but are not being adopted, leading some scholars to suggest that organizational culture change is a necessary precondition to widespread adoption of newer, resilient, and equitable technologies, processes, and structures (Thomas and Ford 2005; Herrick and Pratt 2012). One element of water sector culture that has been proposed to hinder innovation is a narrow view of what types of expertise are appropriate to consider in water management decisions (Lach, Ingram, and Rayner 2004). Scholars have said that new types of expertise are needed in the water sector, and in infrastructure organizations in general, if wicked problems[1] such as climate change are going to be solved.

Multiple barriers to innovation exist within the water sector, including cost and financial risk, regulatory barriers and disincentives, path dependency, and the long life of existing infrastructure (Ajami, Thompson Jr, and Victor 2014; Kiparsky et al. 2016). Another potential barrier, as suggested by scholars, is the culture of the industry based in a fear of failure to protect human health and the environment (Herrick and Pratt 2012; Kiparsky et al. 2016). Water managers are uncomfortable with uncertainty and will often use a tried-and-true method to solve a problem, rather than looking to see if a better solution exists (Herrick and Pratt 2012; Kiparsky et al. 2013; Ajami, Thompson Jr, and Victor 2014). This has led scholars to suggest that the culture of water management must change if the types of innovations necessary to tackle the issues noted above are to occur in the industry (Herrick and Pratt 2012). Some innovation has occurred in the industry, notably the adoption of green infrastructure and intact watersheds to protect drinking water sources and manage stormwater runoff and promotion of water

[1] Wicked problems are problems that are "inherently resistant to a clear definition and an agreed solution" (Head and Alford 2015, 714).

conservation as a way to reduce the need for acquiring additional water supply. Looking at organizations that have changed as these innovations have been adopted allows for the study of what happens to culture and orientations toward expertise when new technologies and professions are brought into a water organization.

Research Questions and Concept Map

Conceptually, scholars have proposed that the water industry operated in a steady state from its founding in the late 19th century until the early 1990s. During that time traditional grey infrastructure (which uses concrete, steel, and other anthropogenic materials and technologies) and civil engineering culture (based on control of nature) reinforced each other. As shown in Figure 1, this stability is being disturbed by the challenges brought on by public pressure, climate change, new regulations, and other external changes in society. These combine to create external pressure to change because traditional infrastructure cannot solve these problems (Brown, Ashley, and Farrelly 2011), and so the industry is pushed into a state of change. This process of change is the subject of my study. According to this model, as new solutions are needed, new types of professions are brought into the industry, which leads to an internal willingness to innovate. The red boxed area in Figure 1 shows the processes which are not currently well understood and will be the focus of the research. These include the process by which external pressures influence organizational culture change and addition of new expertise, and how these changes to culture and expertise create an internal willingness to innovate.

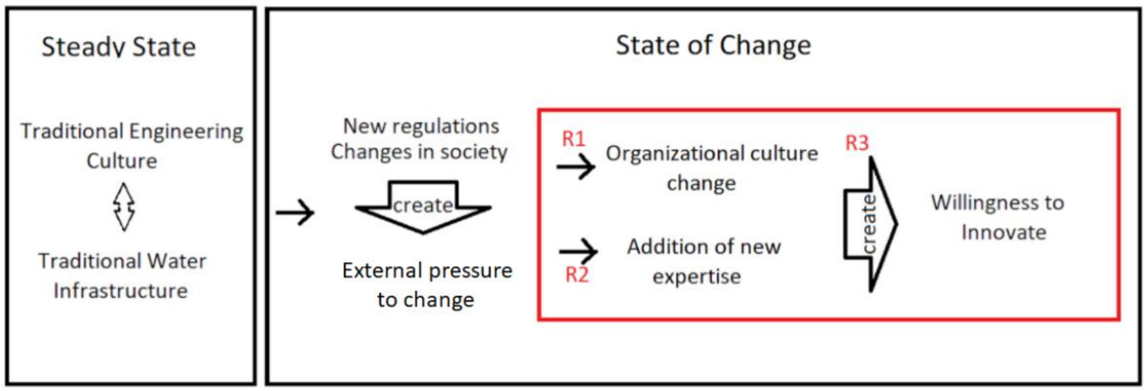

Figure 1: Conceptual Model of Water Industry Innovation

From this, my research questions are:

> R1: How does external pressure to innovate change an infrastructure organization's culture?
>
> R2: How does external pressure to innovate change what expertise is valued in an infrastructure organization?
>
> R3: How do changes in an organization's culture and expertise interact to change the internal willingness to innovate?

The research itself is a comparative case study of two water sector organizations. The Portland Bureau of Environmental Services (BES) was an early adopter of green infrastructure solutions for stormwater management, bringing in new employees trained in biology, ecology, landscape architecture, and other professions that were not traditionally found in the water industry. The Portland Water Bureau (PWB) has also innovated over the years but has not brought those same new professionals into the organization in significant numbers. The adoption of green infrastructure is thus a very important element of the study because it is the reason that BES brought in new professionals. It is not, however, the main focus of the research because adoption cannot be compared between the two organizations. Instead, this study focused on a common innovation that both bureaus started implementing after BES had started implementing green infrastructure: asset management. Asset management is being examined because it is possible to see what is different about the organizational cultures at the two bureaus by comparing how implementation of a common innovation differs. If the cultures of the two organizations, which were quite similar prior to green infrastructure adoption at BES, was influenced by the influx of new professionals, then how they adopted asset management should differ. That is what this research examines.

This study asks how culture changes, particularly in relation to expertise, when organizations adopt innovations in response to external pressure, and what that means for their subsequent innovations. The research compared BES and PWB, two sister bureaus within the same city governmental structure, that have both changed in response to outside pressures over the last several decades. Only one of these bureaus added a significant number of employees who have a type of expertise that is not found in traditional water organizations. This allows for a comparison of two otherwise similar organizations.

This research found that the addition of ecologically oriented employees into BES changed the organizational culture. The culture around expertise, or knowledge systems, was no longer dominated by engineering, but was becoming a mixture of engineering and applied ecology/environmental science. The Water Bureau had an engineering-based knowledge system, as do many organizations in the water sector. This research argues that innovation is more complex than the literature suggests. In some ways, the Water Bureau could be said to be more innovative. They decided to implement asset management, a process innovation that was compatible with an engineering knowledge system and have been successful in doing so. Asset management has been growing in influence and continues to develop and improve over time. A solid base in asset management principles is now seen by many employees as allowing further innovations to move forward. BES has had less success in implementing asset management and is still arguing over some of the fundamental aspects of it. In some ways, this suggests that BES could be seen as less innovative than the Water Bureau. But BES is reinventing asset management as it implements, and that reinvention could change how other organizations make infrastructure decisions. In a way, that makes BES more innovative because it moves the innovation forward in a new and more radical way, and it has the potential to lead to more innovative and radical infrastructure decisions in the future.

Dissertation Structure

This dissertation is structured much like a traditional scientific research paper with Introduction (chapters 1-4), Methodology (chapter 5), Results (chapters 6-7), and Analysis (chapters 8-9) sections. Chapters 1-4 serve as the introductory chapters that explain concepts important to the study. This current chapter, Introduction, explains why I undertook this research and why studying innovation, expertise, and organizational culture in the water sector is important. Chapter 2 is an orientation to the water sector, examining how water organizations in the United States and Europe evolved and grew over time. The chapter also includes a discussion of the sector's orientation to innovation, highlighting two areas where innovation has occurred that will be important in subsequent chapters – the inclusion of green infrastructure as a water management tool and the adoption of asset management programs. Chapter 3 is a literature review of innovation and organizational culture – two of the key concepts that are important to understand the topic and why I structured the research the way I did. Chapter 4, Knowledge Systems, is the final introductory chapter. Knowledge Systems is a key concept that will be used for analysis of the study findings. In the chapter I provide a literature review of knowledge systems and the two main professional knowledge systems that are interacting in the water sector: engineering and ecology.

Chapter 5, Methodology, outlines why I took a qualitative case study approach and why I selected the two cases. It also outlines the reasoning behind the data collection and analysis methods. Chapters 6 and 7 present the results of the study. The two chapters establish what happened at the two organizations and are primarily descriptive. Chapter 6, Background of Portland's Water Utilities, establishes the organizational culture of the two case studies prior to 1990 and how they changed over the last several decades, particularly focusing on the decade leading up to the 2000s, when asset management was brought into both bureaus. Chapter 7, Asset Management and Portland's Water Infrastructure, covers events around the adoption of asset management for both case studies, the main focus of this research.

The analysis sections of the dissertation are Chapters 8 and 9. This is where I tie the events presented in Chapters 6 and 7 into the frameworks outlined in the introductory chapters. Chapter 8 examines the interplay of the engineering and ecological knowledge systems within one of the case study organizations, the Bureau of Environmental Services, and how that influenced the adoption of asset management. Chapter 9 presents the overall conclusions of the research and analyzes what this means for innovation in the water sector, and for other public infrastructure organizations, answering the research questions presented in Chapter 1.

Chapter 2 – THE WATER SECTOR

The purpose of this chapter is to provide the reader with a background and context of the water sector and how that has influenced the sector's relationship to innovation. While the findings of this study do not necessarily only apply to a single sector, a knowledge of the evolution of the water sector over time is important to understanding the context of the research and the two organizations I examined. After a general introduction and history, I outline what scholars say about innovation in the water sector. The chapter concludes with two examples of recent water sector innovations, both of which will be discussed in future chapters.

Introduction to the Water Sector

Water is essential for life. People use it for drinking, cooking, bathing, and disposing of waste. It also has spiritual significance and is used in rituals around the world. It symbolizes the purity of nature and helps cleanse the soul as well as the body (Rawson 2004). But water is not only benign and helpful from a human perspective, it also has the power to destroy, when it is overabundant there is flooding and when it is scarce there is drought (Agnew 2011). Water is an essential infrastructure service in urban areas since humans cannot go more than a few days without it.

Community water systems have existed since as early as 6500 BC (Butler, Scammell, and Benson 2016). Famously, the Roman empire had piped water and sophisticated drainage systems in their territories, but until the 1800s individual households in Europe and the US mostly had the responsibility to obtain water and dispose of waste themselves according to what they could afford; having clean water and sanitation was a sign of high social status (Rawson 2004). The widespread acceptance of the germ theory of disease in Europe and North America in the 1880s changed the relationship to water (Kaika and Swyngedouw 2000; Lofrano and Brown 2010). Being clean was no longer just a sign of moral standing, but also began to be perceived as a necessity for all, and the sanitation movement was born in the US and Europe (Melosi 2008). While people in earlier eras had been satisfied with allowing individual landowners to make decisions about water supply and sanitation, 19th century reformers in Europe and North America were not. Water supply in cities became a moral duty that society must provide in order to be considered developed and successful for residents (Joseí E. Castro, Kaika, and Swyngedouw 2003). Water and sanitation were becoming necessary infrastructures for modern cities in the west, making them public instead of private responsibilities.

When providing clean water and disposing of wastes became public responsibilities, professionals were needed to provide them. In the United States this role was filled by civil engineers who, along with urban planners, was a new type of public service professional that was developing at that time (Gandy 2003; Melosi 2008; S. Bell 2015). Engineers focused on improving society through technology. One way to do this was by building water systems that would last beyond their lifetimes (Gandy 2003; Melosi 2008; Brown, Keath, and Wong 2009; Karvonen 2011). This was not happening in isolation, but was part of a larger movement to rationalize cities; in the late 19th and early 20th centuries roads, parks, and other urban infrastructure in the west were all becoming public goods provided by a technical elite (Gandy 2003).

US society's relationship to and view of urban infrastructure changed again in the late 20th century. Since the late 19th century the water sector had been a public good, often provided free to urban residents as a basic human right (Melosi 2008). During the recession in the US during the 1970s and afterwards, this changed for many public services, including water. Public budgets were reduced and communities began to focus on conducting public services more like businesses. Water was now often thought of as a product, privatization was occurring, and even public water organizations were expected to be managed and organized as though they were private companies (Swyngedouw, Kaika, and Castro 2002; Joseí E. Castro, Kaika, and Swyngedouw 2003). People's relationship to water changed. It was no longer only what flowed in streams, fell from the sky, and came from the faucet, but was also something that was purchased as a commodity (Lach, Rayner, and Ingram 2005).

Today water management is highly technical and specialized, and engineers are at the top of the hierarchy of essential experts in providing, cleaning, and managing it

(Herrick and Pratt 2012; Andersen 2018). The urban[2] water industry today provides three services, illustrated in Figure 2: drinking water provision, wastewater collection and treatment, and stormwater management.

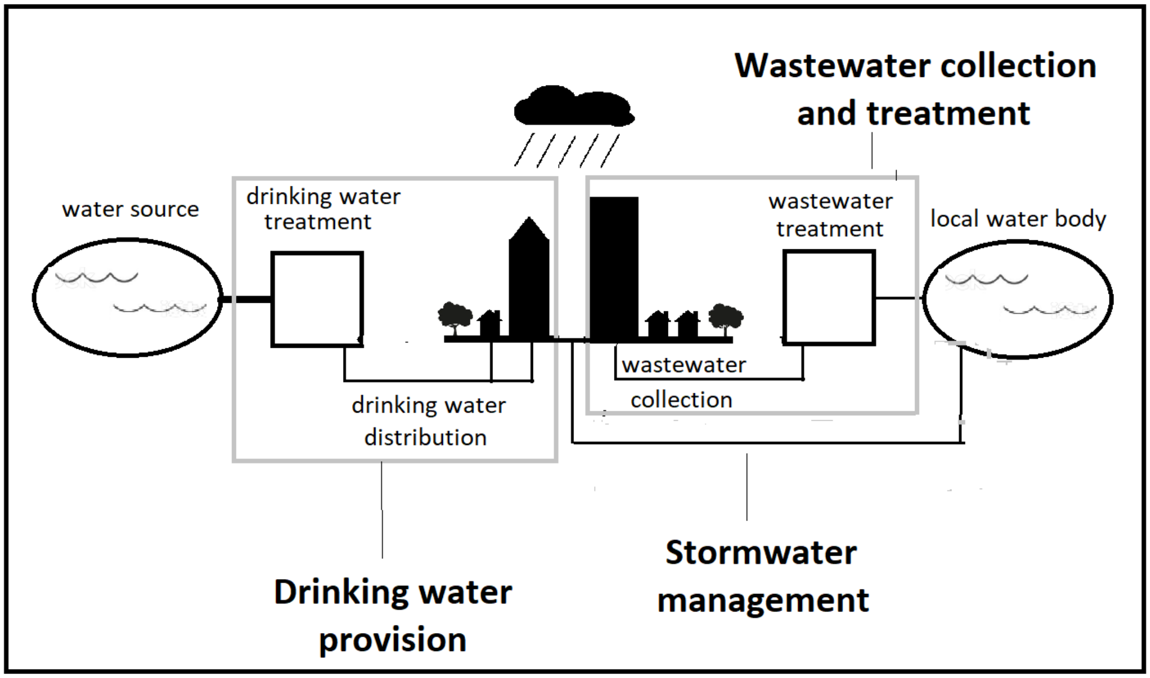

Figure 2: The Water Industry

Historical Innovation in the Water Sector

As explained above, the modern water industry in the west was born in the 19th century due to a combination of growing industrialization and the acceptance of the germ theory of disease (McGuire 2006; P. F. Cooper 2007). Every new human endeavor

[2] The three services discussed in this paper are infrastructure services related to supplying or collecting water in developed areas of the US and Europe. I have not included water services that are primarily found in rural areas, such as agricultural irrigation, or flood control services.

requires new technologies and procedures when they are first established. The water industry was no exception. While pipes had been used for millennia to convey water to and from urban areas, in the 1800s people were starting to realize that drinking water needed to be “cleaned” in many cases (McGuire 2006). The need to purify drinking water was beginning to be recognized before the germ theory of disease was widespread, with filtration being used in the early 1800s in a few large cities in Europe (McGuire 2006; Lofrano and Brown 2010). In the United States, filtration, which is the physical process of removing solids from a liquid by passing the liquid through a porous medium (Reynolds and Richards 1995), was seen as a necessity by the 1880s for large cities that were downstream of other urban areas, mainly because wastewater was not being treated and the prominent theory of the time – that dilution and natural attenuation would solve the problem – was not working to keep people healthy (Lofrano and Brown 2010; Sedlak 2014). Disinfection, the process of killing infectious microorganisms in water, came later than filtration, with some urban areas in the US starting to chlorinate drinking water in the early 1900s after several court cases relating to public health determined filtration alone was insufficient (McGuire 2006). Even then, however, uptake was slow because of the aesthetic problems with chlorination, which has a distinct odor and taste; it took until the 1940s for 85% of water treatment plants in the US to adopt both filtration and disinfection of drinking water (Sedlak 2014). Those two technologies are still what are primarily used today in the industry. The industry’s knowledge about their drinking water systems and how to optimize the amount of chlorine used, as well as adoption of other types of disinfectants, has grown over time, but the basic filtration/chlorination formula for drinking water treatment is still predominant in the US (McGuire 2006).

Treatment of wastewater, also known as sewage[3], came a little later. Prior to the 1800s in many places urban sewage was collected and used on farms as fertilizer (Lofrano and Brown 2010). This changed in Europe and the US during the industrial revolution and the accompanying growth of cities. There was now too much sewage for the surrounding farmland to receive; discharge of sewage into local rivers and streams became common (Lofrano and Brown 2010; Sedlak 2014). Even before the germ theory of disease was accepted, some experimentation was done in the 1700s with adding chemicals to sewage to make it less putrid[4] (Schneider 2011). Biological treatment, where natural microbial processes are sped up and concentrated into a smaller footprint in order to kill microorganisms, started to be implemented in the 1800s (P. F. Cooper 2007; Schneider 2011). However, these systems were fairly uncommon in the US until after World War II, and were only adopted consistently across the county after federal funding was made available for local communities to construct wastewater

[3] Wastewater is a broader term used to mean domestic sewage (which is generated at the household level), industrial discharges to water, and any stormwater that makes its way into an urban area's wastewater collection system. Colloquially, the terms sewage and wastewater are interchangeable, and both are used in this paper to refer to water that is discharged from urban areas into sewers.

[4] The common theory of disease at the time, the miasma theory, associated foul odors with disease. Thus, treating wastewater made sense under that theory (Benidickson 2007).

infrastructure after passage of the Clean Water Act in the 1970s that mandated treatment (P. F. Cooper 2007; Sedlak 2014).

Management of stormwater has long been a necessity for cities, but the technology for that had not changed significantly for thousands of years. The predominant model until very recently has been to get the water away from people as quickly and efficiently as possible (P. F. Cooper 2007; Karvonen 2011). Starting in the 1980s in the US, regulations have been pushing stormwater managers to be more open to innovation (Karvonen 2011). As with many things, necessity is the mother of invention, and the water industry generally hasn't seen the need to innovate unless regulations change. Looking at the history of innovation in the modern water sector shows that regulations are often the main drivers of innovation, along with improved analytical methods that make it possible to detect contaminants in ever-smaller amounts and the availability of funding at the state or federal level to increase affordability for local communities (Lofrano and Brown 2010).

Regulations, the Water Sector, and Innovation

The relationship between regulations and innovation has been mostly studied in the private sector. I will outline first how that literature developed before discussing how this relates to the public sector, and the water sector in particular. Until the early 1990s, it was taken for granted among economists that environmental regulations were bad for business (M. E. Porter and van der Linde 1995; Ambec et al. 2013). Many people believe that all forms of regulations, including standards, permits, and taxes, impose a burden on businesses that reduce their competitiveness in a global market (Ambec et al. 2013). If anything, according to this way of thinking, regulations stifle innovation because they divert money away from research and development budgets toward compliance (Ambec et al. 2013). At its most extreme, some people believe this causes pollution-intensive industries to move overseas to areas with more lax environmental laws, a way of thinking knowns as the "pollution haven" hypothesis (Dechezleprêtre and Sato 2017).

This conventional wisdom was challenged in the 1990's by Harvard Business School professor Michael Porter in what has come to be known as the "Porter Hypothesis" (Ambec et al. 2013). The Porter Hypothesis instead states that "properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with" regulations (M. E. Porter and van der Linde 1995, 98). This is most effective when the regulations are strict enough to force innovation (M. E. Porter and van der Linde 1995; Ambec et al. 2013; Dechezleprêtre and Sato 2017). In addition, the regulation must be flexible, leaving it up to the individual companies to figure out how to comply with the strict standards (M. E. Porter and van der Linde 1995; Ambec et al. 2013). According to Porter and van der Linde (1995), properly designed regulations can do six things, they can: 1. Signal inefficiencies in resource use, 2. Increase information-gathering that leads to identification of potential improvements, 3. Reduce uncertainty about the long-term viability of environmental investments, 4. Create pressure to innovate, 5. Level the playing field between firms within the jurisdiction being regulated, and 6. Force compliance when financial offsets are not large enough to balance expenditures for environmental improvement. The type of innovation that Porter and van der Linde say can save a company money are ones that can improve the competitiveness of a product while also reducing environmental harm, which they admit will not be possible for all industries. But, “in many cases, emissions are a sign of inefficiency and force a firm to perform non-value-creating activities such as handling, storage and disposal” (M. E. Porter and van der Linde 1995, 105), all of which cost a firm money.

Studies have been conducted to see whether the Porter Hypothesis can be seen to work in industry. These studies have been complicated due to the many variables involved, which include measures of regulatory stringency, flexibility, and asymmetry between jurisdictions, as well as the many different ways competitiveness and innovativeness can be measured in organizations (Ambec et al. 2013; Dechezleprêtre and Sato 2017). In summary, the studies have shown that negative impacts from regulations are concentrated in certain sectors and tend to be small, and in some cases regulations have increased competitiveness for firms (Ambec et al. 2013; Dechezleprêtre and Sato 2017). For innovation specifically, Dechezleprêtre & Sato (2017) and Ambec et al. (2013) found strong evidence that well-designed regulations lead to more innovation. However, these innovations tend to be associated with pollution control technologies (i.e. end-of-pipe) rather than fundamental changes to production, except in the case of energy efficiency (Kemp, Parto, and Gibson 2005; Dechezleprêtre and Sato 2017).

This leads to the question: what types of regulations are most encouraging of innovation? Economists have argued that market-based instruments, for example emissions taxes or cap-and-trade systems, are preferable to command-and-control or technology-based regulations (M. E. Porter and van der Linde 1995; Ambec et al. 2013; Dechezleprêtre and Sato 2017). This is because they are assumed to allow firms the freedom to reduce their compliance costs however they see fit. The empirical evidence of this has been mixed with some studies showing that market-based mechanisms spur innovation, while other showing they do not. All do agree, however, that technology-based standards, where specific technologies are required, restrict innovation (M. E. Porter and van der Linde 1995; Ambec et al. 2013; Dechezleprêtre and Sato 2017).

There is little research focusing specifically on how regulations impact innovation in the public sector. But, as explained above, since the 1970s the water industry has been expected to operate much like a private business. Profit is not important, but responsible use of public and ratepayer funding is. Because of this, it is likely that the types of regulations that encourage innovation in general will also encourage innovation in the water sector. For the water sector in particular, there is evidence that the Safe

Drinking Water Act (SDWA), which regulates drinking water utilities in the US, and the Clean Water Act (CWA), which regulates wastewater disposal and stormwater management, were designed to force the development of new technologies (McGarity 1993; Copeland 2016). This is especially true of the CWA, which “has been termed a technology-forcing statute because of the rigorous demands placed on those who are regulated by it to achieve higher and higher levels of pollution abatement” (Copeland 2016, 2). National standards are set in consideration of the currently available technologies, but they do not dictate which technology should be used, allowing innovation in efficiencies to meet those requirements (Ajami, Thompson Jr, and Victor 2014). The SDWA, while generally being based on technology standards, also does not dictate specifically which technologies to use, and includes a program for innovative technology grants (Tiemann 2017). Both laws contain provisions that instruct the agencies to tighten regulations and add new standards when new information or new technology becomes available (Copeland 2016; Tiemann 2017).

On the other hand, both laws have elements that do not support innovation. The technology-forcing standards in the 1972 amendments of the CWA were focused on “forcing the industrial laggards to install better-than-average technologies in five years and top-of-the-line technologies in ten years” (McGarity 1993, 944). They were not really focused on high-achievers or on forcing continued innovation (McGarity 1993; Glicksman and Batzel 2010). Both laws have provisions that allow for either the size or the financial situation of a community to be considered in whether standards have to be met or technologies have to be adopted (McGarity 1993; Copeland 2016; Tiemann 2017). And, in my view, the state-by-state determination of use-based water quality standards means that an individual state passing stricter-than-normal standards will not be able to force technological innovation because of the limited application of any new technological development to only regulated entities within that state. This is because pollution-control technology is generally invented by specialized firms who will only invent new technologies when the market would allow for payback of their investments (Kemp, Parto, and Gibson 2005). The CWA is more technology-based that some other environmental regulations, such as the Clean Air Act, with the federal government taking a backseat to states in driving innovation (Glicksman and Batzel 2010).

Having said this, new or updated regulations have forced innovation in the water sector. A good example of this is the 1987 amendments to the CWA that imposed new regulations on urban stormwater runoff (Melosi 2008; Karvonen 2011; Copeland 2016). New requirements were put on contaminant levels and hydrologic alteration (Roy et al. 2008). Water managers in the US started to focus on vegetated facilities, infiltration of rainwater, and other innovative solutions to the stormwater problems that the regulations were meant to address (Melosi 2008; Roy et al. 2008; WERF n.d.). This is explained more below in the section on recent innovations in the water sector.

Regulations provide some barriers to innovation, but also help water managers overcome some of the non-regulatory financial and path-dependency-related barriers that exist in the industry. This dual impact of regulations is consistent with the literature on regulations and innovation in the private sector. Water regulations have elements that fit Porter's criteria (such as water quality standards that do not dictate specific technologies) and other elements that do not (such as setting standards based on best available technologies and including affordability elements) (McGarity 1993; Glicksman and Batzel 2010; Copeland 2016; Tiemann 2017). Overall, regulations in the water sector provide both barriers and incentives to innovation.

Innovation in the Water Sector Today

Today, water infrastructure managers see themselves as working for public health (Brown and Clarke 2007; Brown, Ashley, and Farrelly 2011). Water is seen as unpredictable, dangerous and risky to manage, yet communities expect full reliability in water service (Lach, Ingram, and Rayner 2004; Brown, Keath, and Wong 2009; Karvonen 2011). Scholars have found the water managers first priority is reliability, followed by quality and cost (Lemos 2008). This orientation causes them to be very risk averse with a conservative approach to risk and decision making, causing a mental path dependency where they are unwilling to try things that are considered new (Brown, Ashley, and Farrelly 2011; Ajami, Thompson Jr, and Victor 2014; S. Bell 2015).

Despite their risk aversion, water managers do say they value innovation. They see it as necessary to move the industry forward and overcome new challenges (Kiparsky et al. 2016). In surveys, Kiparsky et al. (2016) found that water managers in California valued innovation, but had a "skewed perception of their own innovativeness" (p. 1209); they characterize small, incremental and reactive changes within their own organizations as being innovative. These "innovations" are actually small modifications to technology or processes that could better be characterized as adaptive management than innovation (Lach, Ingram, and Rayner 2004; Lemos 2008). Managers think they are on the cutting edge of the industry when making small tweaks to their systems such as using moderately different pipe materials or construction techniques (Lach, Rayner, and Ingram 2005).

If water organizations value innovation, what prevents them from actually innovating? One of the major factors is cost, since public water systems are under constant pressure to keep rates low, and water managers see innovation as potentially providing long-term benefits, but short-term risks (Kiparsky et al. 2016). This contributes to risk aversion in the water sector. One area where innovation has occurred has been in the shift from waste disposal to resource recovery, which has obvious financial benefits (Kiparsky et al. 2016). Creating new revenue streams through selling water, biogas (natural gas generated from the processing of biological solids collected during the wastewater treatment process), or biosolids (sold as fertilizer), the cost barriers are overcome. This innovation can be accomplished without impacting reliability of the primary water provision and wastewater treatment missions. Resource recovery happens at the "end of pipe", after the main mission has been fulfilled and can be seen as a side-project that generates revenue rather than a change to the fundamental water provision and wastewater treatment processes.

Risk aversion, as mentioned above, is another major barrier to innovation in the water industry. This is a cultural barrier that directly relates to the focus on reliability and fear of failure. Studies have shown that even when new technologies are available, they are often not adopted within the industry because of this risk aversion (Brown and Farrelly 2009; Brown, Ashley, and Farrelly 2011; Herrick and Pratt 2012; Kiparsky et al. 2013). Scholars have also linked risk aversion to a desire for "control, stability, security and safety" (Farrelly and Brown 2011, 729) and it is associated with more hierarchical management structures (Davis 2018). Risk aversion has been noted by a number of scholars who have investigated innovation in the water sector as being one of the major barriers to trying new things (Roy et al. 2008; Kiparsky et al. 2016; 2013; Cantor et al. 2021). This is partially, but not entirely, due to asset durability and lock-in from earlier times (Marlow et al. 2013; Kiparsky et al. 2016). Lock-in continues to happen due to the industry's focus on solving discrete, immediate problems and on building durable infrastructure (Melosi 2008; Kiparsky et al. 2016).

The water industry culture is not oriented toward experimentation (Farrelly and Brown 2011). Water managers do not look at other industries for ideas, but tend to only implement changes that have been successful at other water organizations, which necessarily limits innovation when nobody is willing to be the first to try something new (Ajami, Thompson Jr, and Victor 2014). Researchers have seen this insularity play out in who has influence within water organizations; they have observed that an employee needs to be with the organization for several years before they are "allowed" to propose changes (Lach, Ingram, and Rayner 2004; Lemos 2008). One outside voice that people in the industry do listen to is regulators. But, as explained in the previous section, regulations are seen as both a barrier and an instigator of innovation by water managers (Ajami, Thompson Jr, and Victor 2014; Speight 2015; Quezada, Walton, and Sharma 2016). Sometimes regulations are used as an excuse for conservatism when the real barrier is risk aversion (Cantor et al. 2021).

Recent Innovations – Green Infrastructure

Stormwater management is one area where innovation has happened in the water sector in the last several decades and is an exception to the incremental nature of most innovations in the sector. Early development of stormwater infrastructure followed the same technologically focused paradigm based in the control of nature that wastewater infrastructure followed. Stormwater was perceived as a nuisance or danger that needed to be removed from the area as quickly and efficiently as possible (Lach, Rayner, and Ingram 2005; Brown, Keath, and Wong 2009; Karvonen 2011). Routing rainwater to pipes and concrete-lined channels was the norm. This was part of a larger worldview prominent at the turn of the 19^{th} century that nature should be expelled from cities, except in highly-controlled environments such as parks (Gandy 2003; Karvonen 2010).

This started to change in the 1960s and 1970s with the rise of the environmental movement when some people in the US began to question the environmental choices that had been made by previous generations and started to push to preserve and expand nature in cities (Lachmund 2013). After the 1983 amendments to the Clean Water Act forced cities to change stormwater management practices, some agencies started to think about stormwater differently (Karvonen 2011). Instead of viewing it solely as a waste, stormwater started to be seen as a resource that could be used to support nature and bring multiple benefits to communities. This led to one of the rare innovations in the water sector – the adoption of green infrastructure for stormwater management.

The definition of green infrastructure is highly variable depending on location, context, and use. Scholars have pointed out that the flexible definition has enabled it to be applied to multiple scenarios from a landscape scale down to the scale of an individual planter box (Mell 2013). I am defining green infrastructure as it is used in the US in relation to stormwater infrastructure as: vegetated facilities, either intentionally designed or not, that are used to manage the flow, volume, or quality of stormwater. This definition includes anything from large landscape features that are prevented from being developed to small vegetated curbside planters that are highly engineered and built as part of a paved street. This definition includes many different types of features as long as they include both vegetation and provide a function related to stormwater management, including features on private property that are not owned or managed by the local utility, but excludes some dispersed stormwater infrastructure, such as dry wells, that do not include vegetation.

The use of green infrastructure is now considered to be a good tool in the water industry, but even though it has been in use for over thirty years in the US it is still not considered mainstream (Abhold, Loken, and Grumbles 2011; Matsler 2017). This is at least partially because it does not fit neatly into the way water utilities are structured and funded in many locations. Drinking water and wastewater utilities are generally funded by collecting fees for providing a service; the more water you use, the more you pay. This is not as easy to do for stormwater management, so finding funds for implementation of green infrastructure solutions can be a challenge (Cousins 2017). In addition, the water industry tends to be very siloed and hierarchical with specialized expertise focused on traditional “grey” infrastructure such as pipes, pump stations and other highly-engineered non-vegetated facilities, making it hard to introduce something that takes a very different type of expertise to build and manage (Lach, Rayner, and Ingram 2005).

Implementation of green infrastructure requires the expertise of such professionals as landscape architects, biologists and ecologists (for brevity, in this dissertation I will use the terms ecologists or environmental scientists to signify these types of expertise), who have a very different orientation to nature than engineers (Karvonen 2011; Mell and Clement 2020). The characteristics of ecologists and engineers will be provided in Chapter 4; this section will outline what the scholarly literature says about the tensions between the two types of experts in the context of green infrastructure. This tension exists because water organizations were built around an engineering view of the world, as discussed above, that conflicts with the ecologist's view (Brown, Keath, and Wong 2009; Matsler 2017).

During the 1990s as the implementation of green infrastructure for stormwater management was getting started, newly-hired ecologists and environmental scientists in water organizations began to question the basic decision structures and performance indicators, the focus on reliability and cost, and the relationship between nature and people (Lach, Rayner, and Ingram 2005; Matsler 2017). As highlighted in Chapter 4, the field of ecology is more holistic with a focus on the structure and overall functioning of biological communities (Mell 2009; Matsler 2017). Engineers in the water sector, on the other hand, have traditionally focused only on stormwater flow and water quality when looking at green infrastructure (Abhold, Loken, and Grumbles 2011). Some ecologists have tended to push back against the human/nature division that is at the heart of the engineering tradition (Merchant 1980).

One important note about green infrastructure is that it is not seen by all as entirely beneficial. In many areas, green infrastructure is associated with eco-gentrification, where new vegetated amenities adds to displacement of lower-income communities and communities of color through rising property values (Long 2014; Safransky 2014; Haffner 2015). This increase in property values is often promoted as a desirable impact of green infrastructure, making it more acceptable to growth advocates and property developers (Horwood 2011; Long 2014). It is also criticized in examinations of Detroit (Safransky 2014), Austin (Long 2014), and Pittsburgh (Finewood, Matsler, and Zivkovich 2019), as not being truly "green", but rather just a visually pleasing add-on to infrastructure that is still based in the capitalist growth and development paradigm of urban areas.

The question of whether, and how much, cultural change has occurred in the water industry due to adoption of green infrastructure is at the heart of my research. Several scholars have examined this question in case studies in Seattle (Karvonen 2010), Pittsburgh (Finewood 2016; Finewood, Matsler, and Zivkovich 2019), and Chicago (Cousins 2017). They have concluded that introduction of green infrastructure has not fundamentally changed water organizations. As summarized by Finewood (2016), green infrastructure “serves not as an alternative, but a new form of the status quo” (p. 1016). This is because green infrastructure is being implemented under existing engineering and capitalist-based decision structures that use nature to solve human problems in the most cost-effective way (McCauley 2006; Ernstson and Sörlin 2013; Matsler 2017; Finewood, Matsler, and Zivkovich 2019; Matsler, Miller, and Groffman 2021). According to these studies, using existing water industry epistemologies, money is privileged in decision processes designed to solve one problem at a time, discounting any more holistic benefits of vegetated facilities (Matsler, Miller, and Groffman 2021; Welden, Chausson, and Melanidis 2021). They have found that ecological practices have been added on top of existing engineering practices, and only in ways that are compatible with the engineering knowledge system in the communities they studied (Karvonen 2010; Finewood 2016; Cousins 2017; Finewood, Matsler, and Zivkovich 2019). Chapter 8 will examine whether that has been the case in Portland.

Recent Innovations – Asset Management

Another recent innovation in the US water sector started in the 1990s, when some utilities started implementing asset management (AM) programs. Prior to the adoption of asset management as a tool, water sector decision making was more reactive and less focused on the sustainability of their systems (Ugarelli, Di Federico, and Sægrov 2007; Pathirana, Heijer, and Sayers 2021). First applied to pipe rehabilitation prioritization in the water industry in the early 2000s, AM is now being applied to other types of decisions (Grigg 2012; Alegre and Coelho 2013). The main shift has been in risk perception among water managers; asset management involves using a triple bottom line approach where financial, environmental, and community risks are all considered (Marlow, Beale, and Burn 2010; Grigg 2012; Marlow et al. 2013). In the infrastructure context, asset management is implemented,

> to ensure that infrastructure performance corresponds to service targets over time, that risks are adequately managed, and that the corresponding costs, in a lifetime cost perspective, are as low as possible (Alegre and Coelho 2013, 49).

Definitions of AM differ in what is emphasized. Most definitions include several key features, including focusing on asset condition, evaluation of success in meeting service targets known as Levels of Service, risk management and risk reduction, and examining the cost effectiveness or return on investment of infrastructure decisions using lifecycle costs and benefits (Amadi-Echendu et al. 2010; Marlow, Beale, and Burn 2010; Alegre and Coelho 2013; Grigg 2012; Pathirana, Heijer, and Sayers 2021).

The first references in the academic literature to “asset management” are in the finance and management contexts, with some evidence that it originated in accounting and economics (Alegre and Coelho 2013; Manase 2016). In the 1970s it started being applied to infrastructure systems, starting with the oil and gas industry (Manase 2016). In the literature, this type of asset management is generally referred to as “engineering” asset management or “infrastructure” asset management. The basic elements of asset management had been used in the infrastructure world for a long time. The asset management concept combined them into a framework that could be applied as a coherent program (Amadi-Echendu et al. 2010; Manase 2016; Grigg 2012). Asset management was interdisciplinary from the start, combining concepts used in finance, engineering, utility operations and maintenance, and management (Amadi-Echendu et al. 2010; Marlow, Beale, and Burn 2010; Grigg 2012). However, these disciplines were already present in the water sector prior to asset management, so adopting asset management does not require an organization to employ any new types of professionals or challenge the engineering dominance in the industry.

Asset management became attractive to water managers in the US after Federal funding was reduced in the 1980s and agencies had to rely more on local rate funding, causing the financing of water infrastructure to became more resource constrained (Pathirana, Heijer, and Sayers 2021). The previous focus on short-term financial valuation and likelihood of failure was becoming unsustainable (Ugarelli, Di Federico, and Sægrov 2007; Amadi-Echendu et al. 2010). Prioritization of maintenance and replacement activities became important, and asset management offered a way to do that by using the risk of failure of an asset to drive investment decisions (Ugarelli, Di Federico, and Sægrov 2007; Grigg 2012).

One aspect of asset management programs that will become particularly important in the discussion in Chapter 8 is the quantification of disparate risks, costs, and benefits using dollars. This orientation toward using dollars as a common metric in the water industry comes from the use of Benefit-Cost Analysis (BCA). BCA is defined as a "systematic approach to estimating the *Life Cycle Costs* and benefits of an alternative (or set of alternatives) to determine if an investment is justified and, if so, the value it will provide" (American Water Works Association 2018, 19 italics in original). It is a tool that is used to make decisions in a constrained environment in a way that is seen as rational and objective (Dorfman 1978; T. M. Porter 1996). In the US, BCA was first developed for water project decision making by the US Army Corps of Engineers (Dorfman 1978; T. M. Porter 1996). That is interesting for this study because it places the genesis and development of BCA within an engineering-based organization that implemented water infrastructure projects. However, it was not a purely engineering concept for long, as economists picked it up and helped to develop it (Dorfman 1978). BCA is not only used in to justify projects, but also regulations by organizations such as the Environmental Protection Agency who have used risk-based BCA to justify environmental regulations (Sunstein 2005; Demortain 2020).

Benefit-cost analysis is a technique of quantification. Practitioners try to quantify the value of all the costs and all the benefits of a project in commensurate terms, which is not always easy, or even possible (T. M. Porter 1996; Mazur 2013). Quantification is popular in science and engineering because of the perception of objectivity and rigor that numbers bring (T. M. Porter 1996; Mazur 2013). As historian Theodore Porter (1996, 8) pointed out, "quantification is a way of making decisions without seeming to decide." It separates a decision from the expertise needed to make it and black boxes all assumptions that go into quantification (T. M. Porter 1996; Demortain 2020). In addition, as many scholars have pointed out, quantification privileges those things that can more easily be represented numerically and removes the numbers from the context in which they were obtained (T. M. Porter 1994; Espeland 1998). This is one of the main critiques of expressing risk in dollars and using the BCA methodology, that because it relies on quantification, it only compares the easily measurable elements of a project. In response to this, economists and engineers try to find ways to quantify intangibles such as feelings and perceptions, which is always contentious (T. M. Porter 1996).

Another critique of expressing everything in dollar terms is that infrastructure decisions are more political than technical or economic. By putting everything in the same numeric terms, there is an implicit assumption that all of the risks, costs and benefits being compared are morally equivalent and should be compared on a like basis (Weaver 1980; Sunstein 2005). Some would also argue that there are situations where quantification and monetization should not be used, examples of which include when human lives are at stake or to prevent the extinction of a species (Sunstein 2005; Winner 2010).

Recently, a big challenge has been in bringing green infrastructure assets into the asset management framework, as well as trying to consider equity and a changing climate when making decisions using asset management (Pathirana, Heijer, and Sayers

2021). To do this, the practice of asset management is becoming transdisciplinary, bringing together expertise in ecological economics, engineering, operations and maintenance, and others. Asset managers are also encouraging water sector managers to focus less on maintaining the status quo of water services, and more on adapting and preparing for change (Pathirana, Heijer, and Sayers 2021).

Summary

With roots in the sanitation movement of the 1800s, the water industry in the United States developed alongside the newly emerging discipline of civil engineering. As water provision, wastewater collection and treatment, and stormwater management became public services in urban areas, the engineering-dominated organizations developed an orientation toward reliability and risk aversion. Scholars now agree that innovations are rare in the sector. Some innovations have occurred, notably the use of green infrastructure for stormwater management and the movement to implement asset management programs. This research will focus on examining those innovations to better understand innovation in water organizations. In order to do that, we must first understand more about innovation and organizational culture, which are the topics of the next chapter.

Chapter 3 – INNOVATION AND ORGANIZATIONAL CULTURE

One of the key concepts for this study is innovation. This chapter will highlight some of what scholars know about innovation, including how it is initiated and how it is adopted, starting on the individual level and then moving into the organizational context. This will lead into another key concept for the study, organizational culture. How organizational culture and innovation intersect is discussed, as well as some of the essential elements of culture that will be examined in later chapters.

Innovation

Despite being an active topic of study for the last several decades, there is no set scholarly definition of innovation. This is likely due to the fact that innovation is studied within multiple disciplines for many different purposes (Fagerberg, Mowery, and Nelson 2005). A good start for a definition was proposed by Rogers (2003, 12) as "an idea, practice, or object that is perceived as new by an individual or other unit of adoption." This definition, however, misses an important distinction between modest, incremental changes and large innovations that lead to radical changes (Kiparsky et al. 2013). There is a continuum between modest incremental changes, such as a new method for digging trenches, to radical changes, such as rethinking centralized water treatment. For a very conservative organization, even a small change will be considered new, and that organization may think of themselves as very innovative, even when they are far behind what others in the same industry are doing. Similarly, a risk averse industry may be continually making small adjustments that never add up to anything significant, but still think of themselves as begin innovative. For my study, instead, following the definition of radical innovations proposed by Dewar & Dutton (1986, 1422), I define the word "innovation" to be only associated with those more impactful changes that include "clear departures from existing practice."

This does not mean that I think incremental innovations are unimportant, however, as they can add up over time into important changes, and things that start as radical innovations are often seen as incremental to later adopters because they have subsequently become the industry standard (Dewar and Dutton 1986). Scholars have also pointed out that all innovation is a new combination of existing ideas, skills, and resources into a new formulation, making all innovations fall onto a spectrum between radical and incremental (Fagerberg 2003; Büschgens, Bausch, and Balkin 2013). This is because innovation involves seeing new connections and finding new opportunities that can be exploited (Tidd, Bessant, and Keith 2005). In public organizations, innovations tend to be incremental (Walker 2007).

Over the years, several different theories about innovation have been published in the academic literature. The most cited theory is the "diffusion of innovations" theory proposed by Rogers. Rogers (2003, 5) says that diffusion "is the process in which an innovation is communicated through certain channels over time among the members of a social system." In the theory, there are five phases of innovation diffusion: knowledge, persuasion, decision, implementation, and confirmation (Rogers 2003; de Vries, Bekkers, and Tummers 2016). These phases are not always discrete, but can blend into each other and happen in a non-linear manner (Fagerberg 2003).

Characteristics of the innovation itself are an important component of its diffusion, these are: the perceived advantage, trialability, observability, compatibility and complexity of the innovation (Rogers 2003). The perceived advantage of the innovation is the first important consideration in the diffusion process; this is not based in objective data on the benefits of the innovation but rather on the experience of "near peers" who have experience with the innovation (Rogers 2003; Wisdom et al. 2014). Associated with this is the trialability and observability of the innovation; if an innovation can be tested and seen to work, then it is more likely to diffuse out to the social networks of early adopters (Rogers 2003; Wisdom et al. 2014; de Vries, Tummers, and Bekkers 2018). If the innovation is seen to be compatible with existing technologies, processes, or services, it is also more likely to be adopted (Rogers 2003; de Vries, Tummers, and Bekkers 2018). The compatibility element relates not only to the new innovation itself, but also what it is replacing; lock-in, or path dependence, can occur when an existing technology or system is very hard to replace or augment with a compatible innovation (Allenby and Sarewitz 2011). Finally, the complexity of the innovation is important; the harder it is to learn and understand, the less likely it will be adopted quickly (Rogers 2003; Wisdom et al. 2014; de Vries, Tummers, and Bekkers 2018).

The original diffusion of innovation theory has been modified over time. One update to the theory is inclusion of a reinvention process. Scholars noticed that innovations are not always adopted in the exact form or way that inventors envisioned (Rogers 2003). Rather, the innovation itself is changed, or the social meanings and uses of the innovation are changed as it diffuses through a system (McLoughlin, Badham, and Couchman 2000; Rogers 2003). This modification of diffusion of innovation theory is compatible with ideas about technological change in the science and technology studies literature (see, for example Pinch and Bijker 1984; Hughes 1987; Bijker 1995; MacKenzie and Wajcman 1999; Edwards et al. 2007; Allenby and Sarewitz 2011). Innovation scholars have pointed out that this is usually a process of mutual adaptation, where an innovation is adapted to a person or organization and the organization or person also adapts to the innovation (McLoughlin, Badham, and Couchman 2000; Rogers 2003).

Another later addition to the diffusion of innovations theory was an examination of innovation in organizations. What makes an organization innovative is different than what makes an individual innovative. In organizations, Rogers (2003) found that leaders orientation toward innovation mattered, but was not the only variable. Characteristics of the organizational structure and the external environment mattered as well. The characteristics of an organization that positively correlate with innovativeness include the complexity of the organization, interconnectedness, organizational slack (i.e. having uncommitted resources available) and size (Rogers 2003). Negatively correlated were centralization and formalization (Rogers 2003). Also Important for this research, West (2002) found that creativity was enhanced in teams that had a diversity of knowledge and skills. Innovation within organizations also depends on the organizational culture, which will be explored more in the section below.

Introducing an innovation into an organization can be challenging because it must compete with existing technologies that have gone through incremental improvements over the years (Rip and Kemp 1998). It can be very hard for the new technology to compete in this environment. Creation of a niche, which Rip and Kemp (1998, 389) define as a “relatively protected space in which a new technology can be developed and applied,” can help during this early phase of innovation development so that the existing path dependency can be overcome. Allowing a team to work on a pilot project is another way to think about niches in organizations (Farrelly and Brown 2011). But, while creation of a niche can help an innovation get off the ground, for widespread adoption across the organization and beyond, it must break out of that niche (Brown and Clarke 2007).

Organizational Culture

Organizational culture is consistently identified by scholars as an important element of innovation theory (Rogers 2003; Crossan and Apaydin 2010; Eveleens 2010;

Büschgens, Bausch, and Balkin 2013; Wisdom et al. 2014; de Vries, Tummers, and Bekkers 2018). Rogers (2003) discusses elements of organizational culture that can influence diffusion of innovations, such as the orientation toward risk, the value placed on connections with social groups outside the organization, and formality of communication pathways. Büschgens, Bausch, and Balkin (2013, 763–64) say that an organization's culture is the "key to innovation success." In addition, for an innovation to be adopted, the culture of the organization often has to change and adapt to the new technology, process, or service (McLoughlin, Badham, and Couchman 2000; Rogers 2003; Perrow 2014).

To discuss organizational culture, we first need to define what is meant by culture. This is no trivial task, as there is no settled definition (Smircich 1983; Schein 1985; 1996; Martin 2002; Alvesson 2012). Even the essential elements are in dispute. Scholars do generally agree is that there are multiple elements of organizational culture; some of the elements most frequently mentioned in the literature are that culture is shared among members of an organization, that it relates to beliefs and values within the organization, that it consists of taken-for-granted assumptions that underlie structures of knowledge, that it includes symbols and acceptable actions or behaviors, and that leadership has a role in setting and changing organizational culture. In addition, there is an instability to aspects of organizational culture, organizational cultures exist within the larger societal culture, and there are negative as well as positive aspects of organizational culture.

Many scholars define organizational culture as being the basic beliefs and values of the members (Smircich 1983; Schein 1984; 1985; Martin 2002; W. R. Scott and Davis 2007). These beliefs include understandings about appropriate ways to relate to the external environment, the nature of reality and truth, and beliefs about human nature and relationships (Schein 1984; W. R. Scott and Davis 2007). Organizations in the United States usually have shared values of efficiency and orderliness (Smircich 1983), but other values can differ; a few examples are the beliefs about whether people should work independently or collaboratively, how decisions should be made, and whether employees are inherently dishonest (W. R. Scott and Davis 2007). Inspirational values can help motivate workers to perform for the organization; within public organizations one motivating factor is a desire to work for the public good; this value is seen as a core element of any public organization (Rainey 2014).

Organizational cultures develop because they work for people and for organizational goals; assumptions and structures develop over time because they have been useful in helping members of the organization solve problems and be successful (Schein 1984; Gersick 1991; Trice and Beyer 1993; W. R. Scott and Davis 2007; Argyris 2010; Alvesson 2012). But not everything about organizational culture is positive and helpful. One aspect of cultures is that they can limit thinking among members because of their unconscious, taken-for-granted nature; innovations can be stifled, and necessary changes are not made when environmental conditions require it (Smircich 1983; Trice and Beyer 1993; Argyris 2010; Alvesson 2012). In addition, homogeneity is encouraged, creating an environment that can be hostile to minorities of all types, including those with different opinions and knowledge systems (Schein 1984; Espeland 1998). This unity of perspective can be especially problematic when there is a dynamic external environment that impacts the organization (Argyris and Schon 1978; DiMaggio and Powell 1983; Schein 1984). It also ignores that fact that any situation can often be approached from various perspectives that could each give acceptable, though different, answers (Argyris and Schon 1978).

An important aspect of organizational culture that is not part of the definition is the fact that culture changes all the time (Alvesson 2012). There are stable elements to cultures (Schein 1984; Gersick 1991; Schein 1996), but cultures are also constantly evolving (DiMaggio and Powell 1983; Schein 1984; Gersick 1991; Alvesson 2012). This is not contradictory; the basic, most taken-for-granted elements of cultures remain stable, but gradual change is always happening as new members come in, environmental factors change, and members of the organization come up with new solutions to problems (Schein 1984; S. D. N. Cook and Yanow 1993; Trice and Beyer 1993; Alvesson 2012). Innovation scholars point out that often the implementation of a new innovation requires a change to the structure and culture of an organization, which often prevents innovative changes because of this culturally-based path dependency (Levitt and March 1988; King and Anderson 1995; Rogers 2003).

This does not mean that innovation is impossible within organizations with a strong, stable culture. As discussed above, even fairly stable cultures do change over time (Alvesson 2012), and organizational learning does occur. Some organizations have a culture of continuous learning, one of the stable elements in those cultures is comfort with change and ambiguity (Zaltman, Duncan, and Holbek 1973; Levitt and March 1988). In addition, as Levitt and March (1988) point out, enculturation and managerial control are not perfect; lessons and routines can be forgotten and new members can question old ways of doing things, opening the door to innovation even in the most change-resistant organization.

An important element of organizational cultures is that it consists of taken-for-granted assumptions that are unconscious to the members of the organization (Schein 1984; S. D. N. Cook and Yanow 1993; Argyris 2010). Often there are elements of culture that are so taken for granted that they cannot be discussed; asking about them is considered to be crazy or inappropriate, and questioning deep-seated assumptions is a reason for exclusion from full membership in the culture (Schein 1984). One of these often unspoken aspects are the beliefs about how knowledge should be structured and acquired within an organization, which relates to the epistemic community, or professional technical culture, to which the members belong (Smircich 1983; Hughes

1987; Espeland 1998; Knorr Cetina 1999; Alvesson 2012). This topic will be discussed more in the next chapter, where professional expertise and knowledge systems will be explored.

Public Sector Bureaucracy and Organizational Culture in the Water Sector

As explained in Chapter 2, water organizations are mostly public organizations with larger bureaucracies. Since the mid-20th century they have been expected to operate much like private businesses, but they generally are public sector organizations, which influences their cultures (Moe 1984; Swyngedouw, Kaika, and Castro 2002; Morgan and Shinn 2013). Morgan and Shinn (2013) point out that government cannot be run the same way a business is run because of the different services that they provide, as well as different pressures of accountability and fairness. There has been some privatization in the water sector, but research has shown that privatization does not change the pressures on the industry because it is still a monopoly service that is subject to the same public pressures as government services (José Esteban Castro 2008). The movement toward trying to run a water organization as a private business, therefore, can only go so far.

According to Perrow (2014), bureaucracies exist in order to increase fairness in practices such as hiring and customer treatment. Bureaucracies establish clear rules to counteract things like nepotism and corruption. The goal is for decisions to be more rational and to guard against hiring practices based in familiarity which tend to select for those that think the same way as the existing employees (Perrow 2014). In theory, this means that bureaucratic practices should facilitate more diversity in hiring, but scholars point out that this is more a goal than actual practice (DiMaggio and Powell 1983; Herzfeld 1993; Perrow 2014).

Most importantly for this study is the literature on how organizational culture in the public sector relates to innovation, especially in water organizations. Scholars have found that the public sector has slightly different drivers for innovation than the private sector (Newbold 2014; Davis 2018). Although there is some evidence that public sector organizations share the same risk orientation as in the private sector (Bozeman and Kingsley 1998), they are more conservative in their response to risks, especially in the water sector (Lemos 2008; Kiparsky et al. 2013). Kiparsky et al (2013) state that this is because, “downside risk, or the risk of bad outcomes, drives conservatism in the public sector, where the negative outcomes are not offset by corresponding rewards for strong upside performance,” and that conservatism is sensible under these conditions. This means that change is usually incremental and adaptive rather than radical (Lemos 2008).

Public bureaucracies are known for copying each other, which means that a new innovation has a hard time entering a sector, but can spread once it has be shown to work in the sector (DiMaggio and Powell 1983; Walker 2007; Eveleens 2010). This means that more cooperation and information sharing is necessary in public organizations than in private (Walker 2007; Newbold 2014; Davis 2018). The water sector has been found to look only to other water organizations for ideas to innovate (Ajami, Thompson Jr, and Victor 2014). In addition, public support for innovation is important for water organizations (Speight 2015).

Summary

This chapter has included a review of what scholars have said about innovation and organizational culture that are important for this research. Innovations exist along a spectrum from small incremental, or even trivial, changes to more radical departures from existing practices. But even small changes can add up over time to produce large shifts in an industry. Innovation theory has identified the characteristics of organizations that make them more or less innovative as well as characteristics of innovations that make them more or less likely to be adopted. One of the important characteristics that will influence the innovativeness of an organization is its orientation toward risk, which is a cultural element of the organization. The culture of an organization influences the tolerance of risk and experimentation. There are usually core stable elements of an organization's culture along with other elements that shift and change all the time. One of these core elements tends to be the organization's knowledge system. The concept of knowledge systems, and a summary of the two that are most important for understanding the water sector are outlined in the next chapter.

Chapter 4 – KNOWLEDGE SYSTEMS

New, innovative knowledge comes from combining different knowledges (Choo 1996; Berkes et al. 2006). Innovation is all about learning a new way of doing things (W. G. Scott 1961); innovation "is about knowledge – creating new possibilities through combining different knowledge sets" (Tidd, Bessant, and Keith 2005, 15). This chapter is about knowledge. The next section will outline what scholars have discovered about knowledge and learning – how they relate to each other and how different knowledge systems are created in professions. That information is included to provide context for the subsequent discussion of the two main knowledge systems that exist currently in the water sector: ecology/environmental science and engineering.

Knowledge, Learning, and Knowledge Systems in Organizations

First, how do scholars define "knowledge?" In a 2015 review of the knowledge management literature, Omotayo says knowledge is a body of information that is generated through experiences, values, context, insight, and interpretation. An out-of-context fact is not knowledge until it is given some meaning through interpretation. This means that knowledge exists in the social sphere since social processes influence how information is interpreted (Bloor 1991; Hacking 1999; Taylor 2014). As Shapin and Schaffer (1989, 225) explain,

> Any institutionalized method for producing knowledge has its foundations in social conventions: conventions concerning how the knowledge is to be produced, about what may be questioned and what

> may not, about what is normally expected and what counts as an anomaly, about what is to be regarded as evidence and proof.

De Long and Fahey (2000) theorize that there are three types of knowledge: human, social, and structured. Human knowledge is the skills and expertise of an individual; social, or collective knowledge is the tacit knowledge that is shared by people who work together; and structured knowledge is explicit shared knowledge (De Long and Fahey 2000). Tacit knowledge is the type of knowledge an individual possesses that cannot be, or has not been, explained or written down (Jasanoff 2004). Choo (1996) says that all knowledge starts as tacit, but it can only be fully useful to an organization if it is made explicit. Once it is explicit it can be shared, and then other members of the organization can acquire it as tacit knowledge (Choo 1996). Another way that scholars have categorized knowledge is based on where it is "stored." Omotayo (2015, 5 italics in original) talks about organizational knowledge in particular as being "*embodied* and *embrained* in the staff, *embedded* in routines/common tasks, *encultured* among the staff, and *encoded* in manuals, guidelines and procedures."

Knowledge is produced through learning, whether formal or informal. Learning has been defined in multiple different ways for different contexts, most of which include that learning is behavior change that results from experience (Barron et al. 2015). Some learning within an organization is aimed at getting employees to adopt the organization's "point of view" or "organizational doctrine" (Selznick 1957). If this process of acculturation is successful, the organization will not need to employ managerial controls – the employees will have internalized the values and beliefs of the organization (Selznick 1957; Foucault 2003). In hiring people trained in certain professions, organizations can obtain employees who are pre-indoctrinated into some norms (Noble 1979), but will still need to teach the specific history, mission, and goals of the organization (Selznick 1957).

So how does learned information become knowledge, especially within organizations? The field of knowledge systems examines this question. Knowledge systems are defined as “the organizational practices and routines that make, validate, communicate, and apply knowledge” (C. A. Miller and Muñoz-Erickson 2018, 3). Cornell et al (2013) say that knowledge systems include the agents, practices, and institutions that form around the production, transfer, and use of knowledge. This is not necessarily a linear process, but can operate in any order as use of knowledge helps transfer and produce it (Lave 2012). Miller and Muñoz-Erickson (2018) divide knowledge systems into four aspects: the knowledge itself, the values involved with interpretation of the knowledge, the epistemologies used to create and interpret the knowledge, and the structures built to produce, circulate, and use the knowledge. Because values and interpretation are essential parts of knowledge systems, the concept of rationality is not universal, but is instead embedded in a large web of social agreements and values (Bloor 1991; Hacking 1999).

According to De Long & Fahey (2000, 116), "Cultures, and particularly subcultures . . . , heavily influence what is perceived as useful, important, or valid knowledge in an organization." Scholars have found that culture is the most significant determinant of how organizational learning is conducted, especially in respect to how values, beliefs, and work systems are established that can either facilitate or suppress knowledge creation (Alavi, Kayworth, and Leidner 2005). Organizations do not learn directly from history, but rather through how that history is framed and understood (Levitt and March 1988). Values and beliefs influence sensemaking of information within an organization, which is the way the members of the organization decide what is reality and how to interpret information in a way that explains what is happening (Choo 1996). As Choo (1996, 337) observes, "organizational life is not just about choice but also about interpretation and the process of decision making must embrace the process of sensemaking even as it examines the behaviors of choice-making." How to make sense of information and how to use knowledge can be either explicit or implicit within organizations, depending on their culture (Choo 1996; C. A. Miller and Muñoz-Erickson 2018). Miller and Muñoz-Erickson (2018, 24) point out how organizational culture influences their knowledge systems and how knowledge systems influence the organizational culture,

> How an organization uses information to construct meaning, create knowledge, and make decisions is all part of the way that the organization creates an identity, establishes a shared (internal and

external) context for action, makes sense of its environment, and anticipates and adapts to changing conditions.

In organizations, people can come from different professional backgrounds, each of which has their own professional knowledge system, which scholars have pointed out has both advantages and disadvantages for the organization (Orasanu and Connolly 1993; Andrews 2002; Kasperson 2013; C. A. Miller and Muñoz-Erickson 2018). Professionals in an organization may have competing loyalties between operating under organizational norms and staying true to the norms of their profession (Andrews 2002). But scholars have also found that having a diversity of knowledge and skills helps to maintain a healthy skepticism around the knowledge that is being created. This helps reduce the chance that an organization will overly privilege one way of thinking, which can lead to blind spots (Andrews 2002; Berkes et al. 2006). Diversity of knowledge within an organization can create richer, more creative decision processes, but at the cost of disagreement and uncertainty among members (King and Anderson 1995; West 2002; C. A. Miller and Muñoz-Erickson 2018).

Knowledge Systems in the Water Sector

Within the water sector, as outlined in Chapter 2, traditionally an engineering-based knowledge system predominated. Engineers have been considered to be the main experts to listen to and make decisions in the industry; other professionals common in the industry such as financial and communications specialists have generally deferred to engineers or engineering decision processes for major decisions (Gandy

2003; Karvonen 2011; Finewood 2016; Cousins 2017; Finewood, Matsler, and Zivkovich 2019). With the introduction of green infrastructure, new professionals were brought into some organizations in the industry. A group of employees trained in ecology, environmental science, planning, and other professions were hired because of their expertise in vegetation and design (Karvonen 2011). Understanding how these two knowledge systems, engineering, and ecology/environmental science, differ is important in understanding what is happening in the water sector, and will become important in later chapters of this dissertation.

Both ecology/environmental science and engineering are based in a scientific mindset, so a basic outline of scholarship on the scientific method is necessary for understanding their knowledge systems. This section will start with an outline of what scholars have found are the essential elements of science, then move on to discussions of ecologists/environmental scientists and engineers. This will start with a discussion about how science is a social phenomenon.

As outlined by Shapin and Schaffer (1989), prior to the 17^{th} century facts were usually established purely through philosophical debate based in logic and geometry. They show how the experimental method was highly controversial when it was first introduced, and its acceptance was aided by the political and social context of the day. The controversy rested on who had the right to determine the truth: God, as represented by the state, or personal experience and interpretation of observations via the newly proposed scientific method (Shapin and Schaffer 1989). For many then, as well as now, the suggestion that a fact could be based in social processes and interpretation rather than an unadulterated revelation of nature was equivalent to saying it is a lie (Shapin and Schaffer 1989; Latour 1993). The acceptance of the scientific process within European and American society at that time was not because suddenly people acknowledged the inherent value of using observation and experimentation, but because the political environment and scholarly discourse at the time supported this way of thinking (Shapin and Schaffer 1989). Some scholars have pointed out that capitalism and science co-evolved to support each other (Noble 1979; Merchant 1980).

Conventional wisdom has long viewed science as a process for discovering pre-existing facts about nature and the world, which are then accepted by society based on their inherent truth (Latour and Woolgar 1979; Shapin 2010). When social scientists turn a critical eye on it, however, they see a very different process; one in which scientific facts are socially constructed. Kuhn's seminal book *The Structure of Scientific Revolutions* (1962) popularized the idea that interpretation of scientific observations does not occur in isolation from scientists' pre-existing theories about the world, something Kuhn called a "paradigm". Latour and Woolgar (1979, 54) define a paradigm within a scientific field as "a complex mixture of beliefs, habits, systematized knowledge, exemplary achievements, experimental practices, oral traditions, and craft skills." While scientists are always trying to discover new things and challenge existing assumptions, they are incentivized to do this within the existing paradigm. It is much less risky to operate in accordance with existing theories than to challenge, and thereby invalidate, what others in the field are doing (Bourdieu 1975). Nobody wants their conclusions to later be viewed as errors or as "unscientific" because they no longer fit in with a new paradigm; therefore, people who have achieved success in a particular scientific field will resist radically new ideas (Bourdieu 1975; Kuhn 1962).

This discussion of paradigms influencing how data is interpreted and what scientists believe to be true is known as social constructivism. Shapin and Schaffer (1989, 225) provide a good summary of the social constructivist view of science: they assert that,

> any institutionalized method for producing knowledge has its foundations in social conventions: conventions concerning how the knowledge is to be produced, about what may be questioned and what may not, about what is normally expected and what counts as an anomaly, about what is to be regarded as evidence and proof.

Extending this line of thinking, scholars of Science and Technology Studies (STS) outline a process where scientists design experiments and interpret them based in the existing paradigm under which that are operating. To do this, the physical world is manipulated in a laboratory to produce data. That data is then interpreted within the context of the paradigm of the interpreters to yield incrementally new knowledge. Importantly, if the data produces results that are not consistent with their paradigm, they may ignore or dismiss it as anomalous instead of questioning the paradigm. This accretion of new knowledge does not happen in a vacuum. Facts are only established with the acceptance of a community of scholars agreeing to the interpretation put forward by the proponent, a community that is operating under the same paradigm (Latour 1987; Latour and Woolgar 1979). This is done through the publication of scientific papers (or inscriptions, in Latour and Woolgar's terminology) which must be read, discussed, and referenced by others in order to be accepted. No matter how interesting, provocative, or well-fitted to the observations in a laboratory, if no other scholars engage with, and reference, a paper, the idea presented there will be lost to science and will never achieve the status of "fact" (Latour 1987). Power and status often determine whose papers are published in the most prestigious journals and read by the largest number of people (Bourdieu 1975; Latour and Woolgar 1979). And, importantly, scientists who operate under a different paradigm will see the data differently and may not agree on the interpretation or consider the idea to be a fact.

So, how are paradigms overturned? According to Kuhn (1962) this only happens when the accumulated anomalies that cannot be fit into the existing paradigm become too numerous to ignore; but even then, a new paradigm is often not accepted until the older adherents retire and a new cohort of scientists, trained in the new paradigm, take over. Latour and Woolgar (1979) agree that outsiders, or those peripheral to the field, are often the initiators of new ways of thinking. As Collins and Pinch (1998, 42) point out "the meaning of an experimental result does not, then, depend only upon the care with which it is designed and carried out, it depends upon what people are ready to believe." Sometimes a new idea is generated and published and ignored for a significant period of time, only to be "discovered" later when the scientific community is ready to think differently (Kuhn 1962).

Science has been able to operate without overturning the general understanding that scientific facts "speak for themselves" because once a fact is accepted by the scientific community, the social process behind that acceptance is disconnected from the fact and erased from history (Latour 1993; Latour and Woolgar 1979). In this way, western society continues to believe that nature is defining what is a fact, while STS scholars argue that the opposite is actually the case: that socially-constructed facts define nature (Latour 1987).

The idea that scientific understandings about the natural world are socially constructed is a controversial one because some think it asserts that scientific facts are "made up" or invalid. This was one of the main controversies in the "science wars" of the 1990s, the result of which was a more nuanced view of the relationship between social construction and reality (Bocking 2004; Hacking 1999). Since then, many STS scholars (and others) reject extreme views of constructivist science that suggest science has no basis in reality, or that any reality exists outside of human culture, and instead have settled on a view that social construction is valid, but that, as Dietz (2013, 33) put it, "strong norms of science favor accepting ideas that seem to match empirical observations and that are theoretically coherent." Scientists still need to fit their ideas to the empirical evidence, but social construction is a valuable intellectual frame in that it highlights that social processes are involved with the selection of research questions, interpretation of data, and coming to consensus that an assertion is a fact (Hacking 1999). Jasanoff (2004), in critique of a pure social constructivist perspective, points out that it is more useful to think about scientific processes as co-production, where scientific information is neither a pure reflection of objective reality nor purely socially produced, but is rather an interaction of the two. An important point in this discussion is that our current scientific view of nature as being a separate category from society is not inevitable, nor the only "scientific" way to view nature.

Another way that scholars have thought about limits to purely social construction in science is through the attribution of agency to non-human, and even non-living, objects. As Latour (1993, 6), the most prominent proponent of this way of thinking writes,

> Yes, the scientific facts are indeed constructed, but they cannot be reduced to the social dimension because this dimension is populated by objects mobilized to construct it. Yes, those objects are real but they look so much like social actors that they cannot be reduced to the reality "out there" invented by the philosophers of science.

Here we see not only a modification of social construction theory to include objects, but also a rejection of the human-nature split at the heart of scientific thinking. In this framing, non-human objects are actors that have agency to change outcomes, define (along with the human actors) what becomes a fact, and how nature is understood by scientists.

Removal of objects of study from their environment is at the core of the scientific method; some even view any endeavor that occurs outside of a laboratory environment, in the “real” world, as being outside of the realm of science (Gieryn 1999; Latour 1983; Latour and Woolgar 1979). This process is known as reductionism, the purpose of which is to gain universal and objective knowledge which will be true regardless of time and place, or social context (Shapin and Schaffer 1989; T. M. Porter 1996; Knorr Cetina 1999; Latour 1999; Sarewitz 2010). Reductionism and classification go hand-in-hand in science. Within science (and other human endeavors), elements of the natural world are intellectually pulled apart and put into “classes” for study. From the very beginning of modern science, the classification of natural objects was done from a mechanistic standpoint where living beings could be treated like machines, disconnected from their surroundings and without feeling (Worster 1977). Machines, unlike organisms, can have their parts separated, examined, and reassembled without destroying the functions (Merchant 1980; Noble 1979). They are devoid of feelings, so there are no moral consequences to treating them as objects; this line of thinking allows scientists to think about the parts of organisms and ecosystems separate from their context – and to classify them according to their parts (Merchant 1980; Noble 1979; Worster 1977).

People like to classify things since that makes it easier to examine, judge, and generalize about objects in the world (Bowker and Star 2000; Hacking 1999; Kitcher 2003). Many believe that nature has an inherent structure that science is trying to "discover," but STS scholars show that people devise classification to suit our own purposes (Kitcher 2003). These classifications change over time, not because we find that the old classifications do not fit reality, but rather because the social environment changes, which causes people to rethink the classifications that are being used (Bowker and Star 2000; Kitcher 2003). Bowker and Star (2000) argue that classifications are really about precision, not validity; that is, we construct classifications because of their usefulness to us, not because they reflect an underlying reality in the world.

While scientists see classification as simply a logical way to study the world and draw conclusions that are valid beyond one individual study, there are consequences to classification. Classifications can change moral views of the self and others, placing judgements about good or bad onto objects when the classification is seen as being real or inevitable (Bowker and Star 2000; Hacking 1999; Kitcher 2003). One consequence of classification can be seen in how elements of nature are valued. The ideal of objectivity in science means that practitioners assume that values are derived from scientific information, not the other way around (Bocking 2004). But, social scientists have found the exact opposite – that society's preexisting values determine how science is performed (Bocking 2004; Dupré 1995; Jasanoff 2004). Thus, the western views of the value of nature at the time the scientific method first came into being has determined classification schemes, and therefore values placed on natural elements through science at other times and in other locations.

As science establishes new facts, it paradoxically inevitably creates awareness of more unknowns than it resolves, so that there is an increasing amount of uncertainty (Gross 2007). But not all uncertainty is the same. Scholars have different definitions of uncertainty. One that has become useful for examining natural resource issues was proposed by Brugnach and collaborators (2008). This definition proposes three types of uncertainty: epistemic uncertainty, ontological uncertainty, and ambiguity. Epistemic uncertainty is defined as incomplete knowledge, or something this is not yet known but can be known, although sometimes this may be probabilistic knowledge (such as a probability of coin landing on heads). Ontological uncertainty, on the other hand, applies to knowledge about systems that are so non-linear and erratic in their behavior that they are unpredictable; in other words, it refers to knowledge that cannot be known because of its unpredictability (Brugnach et al. 2008; Ounanian et al. 2018). The third type of uncertainty, ambiguity, is the result of multiple frames of reference among those who are defining a problem or issue. This is the type of uncertainty that exists both because social values and preferences change over time and because how a problem is defined needs to be negotiated among different people who have different frames of reference and knowledge systems (Brugnach et al. 2008; Brugnach and

Ingram 2012; Ounanian et al. 2018). Scientific research generally focuses on reducing epistemic uncertainty, and some knowledge systems are more comfortable working with ontological uncertainty and ambiguity than others, as will be explored more in the subsequent sections of this chapter (Tempels and Hartmann 2014; Ounanian et al. 2018).

The question of valuing nature is important for this study. Sometimes scientific findings are used to justify quantifying the "value" of natural elements, in most cases today this is equivalent to the economic use value to humans. Where this type of valuation is used, there is rarely acknowledgement that this type of valuation is actually imposed by social processes, rather than objective truths (Sunstein 2005). In addition, using monetary cost-benefit analysis for making decisions about nature further upholds the split between nature and humanity – only those natural processes that can be quantifiably proven to benefit humanity are included (Sunstein 2005). Quantification is seen in society as being rational and objective, hiding the fact that societal values are embedded in any system of quantification (T. M. Porter 1994; 1996). When scientists measure things, as when they categorize things, they decide what is valuable based on the underlying values of the culture; by quantifying things in monetary terms, people are not objectively measuring the true value of nature, but are rather revealing the capitalist basis of today's society (Moore 2015). Critical scholars point out that this is not the only way of valuing nature, that nature can be seen as having a value that is entirely separate from human interests. This is known as existence value (Agar 2001; Bocking 2004; Moore 2015; Winner 2010).

Applied Ecologists & Environmental Scientists

The term “Oecologie” was coined in 1866 by Ernst Haeckel who purposely used a word similar to economy because he believed that “living organisms of the earth constitute a single economic unit resembling a household or family dwelling intimately together, in conflict as well as mutual aid” (Worster 1977, 192). The idea that nature acts together in a dynamic balance is, however, much older, going back at least to the time of Plato in Europe and time immemorial among indigenous peoples around the world (Egerton 1977; Smythe and Peele 2021). What Haeckel, and others of that time, did was to bring the concept into the scientific realm. They were expanding on the work of naturalists such as Linneaus and Leeuwenhoek from the 1700s, and von Humboldt from the early 1800s whose work was mostly descriptive rather than explanatory (Egerton 1977; 1983; Bocking 2012).

Haeckel defined what we now call ecology as the study of the interrelatedness of life in the “struggle for existence” that Darwin’s theory of species evolution outlined (Worster 1977). According to scholars, ecologists are interested in connections and interactions, and so they approach their work from many different angles, including the history of the area, the evolution of the individual species present, population dynamics and demographics, biological and landscape processes, flows of energy and matter, and disturbances in the landscape (Nelkin 1977; Johnson et al. 2002; Bocking 2012). Ecology is not a single approach, but a collection of different ways of exploring connections and processes in nature, and is by its very definition interdisciplinary (Worster 1977; Bocking 1997; Kingsland 2005). Ecology changed significantly after World War II when the turn from descriptive methods to more causal analysis gained momentum (Bocking 2012). But, unlike other scientific disciplines, ecology has focused more on the integrated nature of processes and landscapes.

As explained above, the understanding of nature as being separate from humanity is an essential part of the scientific mindset. Although there was a lively debate among early ecologists about whether or not to include humans in the study of nature, ecology, out of all the scientific disciplines, has been the strongest in challenging the division between nature and humanity (Worster 1977; Bocking 2004; Kingsland 2005; Lachmund 2013). According to Worster (1977), ecology has always been both a scientific discipline and a point of view which privileges a holistic approach to the world, where all things, including humans, are connected. This holistic approach operates in two directions: it includes humans as a part of the natural world, and it also extends at least some of the rights and privileges of humanity to nature (Worster 1977; Bocking 2012). Because people and nature are not separate to many ecologists, ecological theories need to include human influences in the landscape to understand what is happening (Bocking 2012).

This holistic view also challenges the reductionism inherent in the scientific processes. Ecologists are often pulled between these two competing principles, the scientific method that isolates pieces of the environment in order to study them, and the holistic principle of only gaining understanding by studying the whole. This tension between holism and reductionism exists throughout the literature on ecology. At its beginning in the late 1800s reductionism prevailed, as ecology tried to pattern itself after the "hard sciences" such as physics by adopting mechanistic models of nature (Worster 1994; Bocking 1997; Li 2000; Kingsland 2005). And while reductionism has never been completely abandoned, around the middle of the 20th century some ecologists started asking what reductionism misses (Li 2000; Bocking 2012). British ecologist Arthur Tansley coined the term "ecosystem" in 1935 as a holistic and integrative concept (Li 2000; Bocking 2012). Although some have tried to understand ecosystems by studying the pieces in isolation, ecologists as a whole tend to believe that "the ecology of plants could not be understood in isolation from soil, climate and animals" (Bocking 2012, 266). In the United States, this integrated approach took greater hold in the 1970s after passage of the National Environmental Policy Act (NEPA) required an examination of how ecosystems react and recover from disturbances (Risser 1985). The split of ecologists into two camps can be seen in the different emphasis between those who want to avoid politics, use reductive scientific methods, and tend to favor laboratory work, and those who want to apply their science to real-world problems and engage in the political process (Nelkin 1977). According to Bocking (1997) some who more directly engage in influencing regulations and policy took on a new name, environmental scientist, to distinguish themselves from more theoretically-oriented ecologists.

There is also controversy in ecology over the question of how, and whether, to quantify the value of nature in monetary terms. And, like holism versus reductionism, ecologists over the years have not agreed on this topic. There is a tradition within ecology of putting a human use value on nature (Merchant 1980; Egerton 1985). This comes to ecology in the US through the conservation movement, which was focused on managing nature for the benefit of "man" (Worster 1977; Kingsland 2005; Bocking 2012). Alongside that view in ecology, however, has been a tradition of rejecting a narrow valuing of nature only for economic or utilitarian reasons (Bocking 2012). For some ecologists, aesthetic, spiritual and existence values are also important, and the appropriateness of quantifying the value of nature, as though it was a market good that could be replaced, is often questioned from a moral standpoint (Bocking 2004; 2012).

Ecologists are oriented toward understanding dynamic and complex systems of nature. While much ecological research is aimed at reducing epistemic uncertainty, which as explained above is the type of uncertainty that comes from incomplete knowledge, ecologists and environmental scientists are also comfortable with acknowledging that some things cannot be known (ontological uncertainty) (Kingsland 2005; Evans 2011). Within the ecological restoration field there is a growing recognition that unpredictability is inherent in ecosystems (Tempels and Hartmann 2014; Ounanian et al. 2018).

More recently, the origins and knowledge systems that are used in ecology have been questioned by ecologists themselves. This is rooted in the realization that traditional science excludes local and traditional knowledge (Bocking 2004; Smythe and Peele 2021). Local knowledge is often tacit knowledge that is hard to explain, and so does not easily fit into the scientific method of acquiring and validating knowledge (Bocking 2004). In addition, local knowledge tends to be true only in the place where it is generated, making it less repeatable and unable to be universally applied; a problem that ecologists have long wrestled with since the history of a particular place has always been important to ecologists (Bocking 1997). Ecologists with a focus on connectiveness and holism have started to look toward Traditional Ecological Knowledge to develop a deeper understanding of nature (Smythe and Peele 2021).

Finally, an examination of ecologists would not be complete without acknowledging that a common view among the general public is that ecology is a part of the environmental movement; that ecologists are politically-oriented actors working to save nature from humanity (Egerton 1977; Bocking 2004). But, as was pointed out in the discussions of holism and quantification, ecologists are not monolithic in this regard. While some scholars acknowledge that ecology has always been both a point of view as well as a scientific discipline (Worster 1977), others argue that ecologists are scientists, and while they, like all other scientists, will have political opinions, the discipline itself does not (Nelkin 1977; Kaiser 2000; Bocking 2012). Some ecologists recognize that advocacy in the political realm can diminish their scientific credibility and that ecological findings can be used to support either side of any environmental debate (Kaiser 2000; Bocking 2004). Others believe that ecologists have an ethical duty to advocate for the environment in the face of ongoing and irreversible destruction of ecosystems (Bocking 1997; Kaiser 2000). Even among those who believe that advocacy for environmental values is an essential part of being an ecologist, there is disagreement on whether it is best to do that within the existing system, or by fighting the system from the outside (Nelkin 1977).

Engineers

Engineers are the primary implementers of intentional big, physical, anthropogenic changes in the world. Scholars agree that the engineering profession is based in the idea that nature can and should be controlled and improved to benefit people (Worster 1977; Melosi 2008; Schneider 2011). Engineering, as a distinct profession, has only existed for about 200 years (Benjamin 2002; Gandy 2003). But, of course, much of the work done now by engineers was being done in a less formal way for millennia. The 1828 charter of the (British) Institution of Civil Engineers defines engineering as, “the art of directing the great sources of power in nature for the use and convenience of man” (Ferguson 1992, 1); similarly the American Engineering Council defined engineering as “the science of controlling the forces and utilizing the materials of nature” (as quoted by Noble 1979, 311). Vincenti (1990) argues that engineers who work with built infrastructure that supplements or mimics processes of nature, such as sewage treatment and water supply, see themselves as solving social and environmental problems brought about by civilization. With roots in the sanitation movement, scholars assert that engineers see themselves as improving health through human ingenuity, rather than by trusting that nature or God will take care of it for us (Melosi 2008).

The idea that engineers could exert dominion over nature is sometimes seen as an essential element of the profession (Espeland 1998; Mitchell 2002; Teisch 2011). As society now questions the human ability to fully control nature, engineers will generally say that with enough money and time they can still do it (Espeland 1998; Ferguson 1992; Funtowicz and Ravetz 1993). And, in an interesting twist, engineers now assert that they are also essential for protecting nature from man through technologies such as sewage treatment (Schneider 2011).

An important element of engineering work is the presence of constraints. Constraints are essential for any design process; without them too many choices would be available and the design would not progress (Bucciarelli 1994). These can come from outside (for example, physical properties of materials) or inside (for example, a project budget) the design process, and can be formal (for example, federal standards) or informal (for example, the usual time it should take to design a specific part) (Bucciarelli

1994; Madhavan 2016). While constraints limit an engineering design process in some ways, scholars say they also spur innovation and creativity because they force a designer to think about how to solve a problem within a specific context (Madhavan 2016). Noble (1979) outlines how the engineering profession was established in the 1800s in conjunction with capitalism. The capitalist focus on reducing costs is built into engineering work, making financial constraints one of the essential considerations in the profession's knowledge system (Noble 1979; Madhavan 2016).

Vincenti (1990) found that engineers value certainty and believe decreasing uncertainty over time is inevitable. In this characterization, he was referring to epistemic uncertainty, the kind of uncertainty that can be reduced over time through acquisition of new knowledge. Others have found that engineers value predictability, or the absence of ontological uncertainty (Ounanian et al. 2018). This is linked to the desire to control nature and provide robust services since a design engineer must choose a particular set of conditions to design for, even if that number is based in probabilities (Tempels and Hartmann 2014; Ounanian et al. 2018).

Much of engineering work involves negotiating the tradeoffs and conflicts between differing constraints; other than the "laws of nature" as described by science, all other constraints are, in theory, negotiable by the designer (Bucciarelli 1994; Vincenti 1990). One of these constraints is incomplete or uncertain understanding of elements of a problem or potential solution (Vincenti 1990). Scholars have found that engineers are satisfied when the answer is good enough to proceed with the design, and will not object to standards and knowledge derived empirically without a solid, underlying theoretical foundation (Ferguson 1992; Vincenti 1990). As long as there is certainty about the design working as intended, knowing the reason why is not essential. Ferguson (1992, 9) says of engineering knowledge,

> The formal knowledge that engineering designers use is not science, although a substantial part of it is derived from science. It includes as well knowledge based on experimental evidence and on empirical observations of materials and systems.

According to Vincenti (1990), for an engineer, knowledge is valuable because it is useful, it cannot be separated from its practical application.

Engineering work cannot be performed solely in a laboratory, removed from the wider world. Engineers must interact with the environment as they produce physical things that will themselves interact with the environment. This requires engineers to have something in addition to explicit knowledge about the world, it requires tacit or intuitive knowledge of the objects, materials, and processes involved with design (Ferguson 1992; Madhavan 2016; Mukerji 2015; Vincenti 1990). This type of knowledge cannot be written down or formally passed on from one person to another, but is built up over time through experience, and is the reason why some say engineering is more an art than a science (Barry 2013; Ferguson 1992; Madhavan 2016; Vincenti 1990).

There is usually no one “right” answer to a real-life engineering design problem because multiple solutions could solve the problem within the constraints given;

instead, the engineer is looking for the "best" solution to the problem that can be found within a reasonable time and cost (Ferguson 1992; Vincenti 1990). This is one area where tacit knowledge comes into the process. According to scholars, an engineer needs to have a feel for the limitations of the materials that are being used and how they might react in concert in the design; the best solution cannot be found in a book when a new object is being designed, instead "engineering judgement" is used (Ferguson 1992). Another way that tacit knowledge comes into the engineering process is due to the visual nature of engineering work. Engineers produce drawings that others translate into the actual physical object; an engineer without a good feel for how the object in the drawing will exist in the world will not be able to make a correct and complete drawing (Ferguson 1992).

Despite recognizing the importance of engineering judgement, scholars have found that engineers prefer to quantify things. This extends to qualitative information as engineers will try, if possible, to create a scale and quantify feelings and sensations (Vincenti 1990). For example, Vincenti (1990) explains how early aeronautical engineers made pilots put their feelings about the ease of flying a plane or how the plane felt in the air into numeric scales. One reason proposed by scholars for this is that engineers always want to reduce uncertainty, and are convinced that over time uncertainty will decrease (Vincenti 1990; Madhavan 2016). As explained above, this is referring to epistemic uncertainty and is connected to a need for predictability. Engineers place so much emphasis on certainty that they are known for adding safety factors to multiple elements in a design; the robustness of the design is extremely important (Anderies, Janssen, and Ostrom 2004; Bucciarelli 1994; Madhavan 2016; Vincenti 1990).

For engineers, quantification of risks is important. These can be risks to the public from infrastructure failure or the natural environment, risks to the organization that stop it from fulfilling its mission, or risks that a project will go over budget or fail to meet its goals. This quantification is generally monetized so that the risks can be compared to the costs involved with ameliorating that risk (T. M. Porter 1996). As discussed in Chapter 2, engineers often use a Benefit Cost Analysis for this. For engineers, placing a dollar value on risks is unproblematic; money is thought of as a neutral metric that is used to compare things that are otherwise hard compare (Dorfman 1978; Weaver 1980; Sunstein 2005). To an engineer, it does not matter if non-market goods are being discussed, money is a good way to determine if the problem is "worth" solving.

One thing about engineers that scholars have noticed is that they tend to take their engineering training and thinking into other areas. One area that has notably been influenced by engineering training is management (Noble 1979). The founder of scientific management, Frederick Taylor, was an engineer – his system of using science (later found to be overstated) to analyze the workplace had a large impact on management theory in the late 1800's (Noble 1979). Madhavan (2016) outlines how an engineering education, and way of thinking through problems, can be useful in many other areas of life. But countering this is the engineers' (and scientists') desire to never be wrong or be seen to apply their expertise outside of their own profession. Within many organizations that build, manage, and maintain infrastructure, engineering culture permeates the entire organization.

Comparing Engineering and Ecological Knowledge Systems

The knowledge systems of both engineers and ecologists are based in a scientific way of seeing the world. Both professions have long histories, and both changed as the scientific method evolved over the last few centuries. There are, however, some major differences in the ecological and engineering knowledge systems and the mindsets of those who practice them.

The first difference is one of definition – who is a professional ecologist or engineer? In engineering that is fairly straightforward, as there exists a formal certification process. There are, of course, sub-disciplines, some of which do not have a certification process, such as computer engineers, but for the engineers involved with built public infrastructure, such as civil engineers, standards and certification do exist. Not all engineers become certified Professional Engineers (PE), but for most public infrastructure engineering work, a PE needs to put their stamp on a design for it to be considered complete (National Society of Professional Engineers n.d.). This is seen as a way to ensure that infrastructure projects are built cost-effectively and to ensure public safely. According to the National Society for Professional Engineers in the U.S., "by combining their specialized skills with their high standards for ethics and quality assurance, PEs help make us healthier, keep us safer and allow all of us to live better lives than ever before" (National Society of Professional Engineers n.d.). Beyond just certification, scholars assert that all engineering work is based on the assumption that engineers can improve the physical environment and control nature to benefit humanity (Worster 1977; Melosi 2008; Schneider 2011).

For ecologists and environmental scientists, there is no similar official certification process. One of the distinguishing features of ecology is that the work pulls together the knowledge and skills from many specialties (Worster 1977; Bocking 1997; Kingsland 2005). An attempt was made in the 1970s to "professionalize" ecology with a certification process, but it was resisted by many ecologists who preferred greater autonomy and freedom to change and grow (Nelkin 1977). As discussed above, there are many disagreements within ecology about the basis of the profession; ecologists disagree about reductionism versus holism, focusing on plant and animal species versus focusing on flows of energy and materials, quantification versus not, and being active environmental advocates versus being objective experts who stay out of political controversies.

There is a common orientation within ecology that shows a clear difference from engineers. In most modern ecology there is no philosophical separation between humans and nature (Worster 1977; Bocking 2004; Lachmund 2013). Engineering, on the other hand, is based in the idea that people are separate from nature (Noble 1979; Ferguson 1992). This means that the two also have a different focus. Engineers focus on the physical objects used to control nature to benefit people – building things to promote public health and prosperity are the heart of engineering (Melosi 2008). Ecology was also founded with an orientation toward human health, but ecologists connect that to the health of plants, animals, and processes within ecosystems (Kaiser 2000; Bocking 2012). For engineers the focus is on people versus nature, for ecologists it is on people with nature.

Engineering relies on quantification; scholars have found that knowledge is not useful to engineers unless it can be put in numeric terms and used in formulas; and as stated above, engineers will try to put even feelings and preferences into a numeric scale (Vincenti 1990). Ecologists have a more complicated relationship with quantification. Society has privileged the "hard" sciences, and ecologists have long tried to gain prestige by focusing on what could be quantified (Bocking 1997; Kingsland 2005). But, running through the profession has always been the feeling that some things that are very valuable cannot, and should not, be quantified, especially not in monetary terms (Egerton 1983; Bocking 1997; 2012; Matsler 2017).

Another difference between ecologists and engineers has to do with their relationship to certainty. For an ecologist, the natural world is full of dynamic processes that are relatively stable over time, but always changing and shifting; this is not a problem for the ecologists, for understanding the underlying processes is the aim, what state it is in at any one time is not as important, and unpredictability is an essential part of nature (Nelkin 1977; Anderies, Janssen, and Ostrom 2004; Bocking 2004). To engineers, predictability is vital; a design must be robust in the sense that it must be able to remain unchanged as long as the conditions designed for are maintained (Vincenti 1990). Ecologists are comfortable with the concept that there are things in the world that are unknowable, while engineers believe that all things can be known, and eventually be controlled once all the relevant variables are known (Ferguson 1992; Funtowicz and Ravetz 1993).

Engineers and ecologists do have some things in common. The most important is that both engineering and ecology share the trait of needing to be fully situated in the physical world. Because much scientific experimentation is performed in a laboratory separated from the world, many scientists can believe their work does not have an impact on the environment (Jasanoff 2004). This is not true for ecologists, who must always connect any work in the laboratory with what that means for the ecosystem as a whole (Bocking 1997; 2012). Similarly, engineers must always take the knowledge they have and apply it to an actual physical object that will need to exist in the world. Engineers and ecologists both need to take the knowledge they have gained from reductive investigations and put it back together to see how it interacts with other things. Both are oriented toward what actually happens when ideas are tested out in the real world.

Summary

There is not only one way of knowing and understanding the world. One way scholars talk about how knowledge is created, shared, and used is through the concept of knowledge systems, which includes professional knowledge systems. The two that are most important for the water industry, ecology/environmental science, and engineering, were discussed in this chapter. The major differences in the two knowledge systems are their internal consistency, views of the relationship between nature and humanity, the appropriateness of quantifying the value of nature, and the need for predictability. They are similar, however, in their need to practice their professions in the physical world. These differences and similarities between ecologists/environmental scientists and engineers will be important in this dissertation. Before presenting the results, the methodology used for the research is outlined in the next chapter.

Chapter 5 - METHODOLOGY

This research used a qualitative case study design using two cases. This chapter discusses why that research methodology was chosen and how the two cases were selected. It also outlines how the data was collected and analyzed.

Qualitative Case Studies

This research relies on a combination of document review and semi-structured interviews of two case studies. I used qualitative case study methods for this study because, as Maxwell (1994) explains, qualitative methods are good for understanding processes and causal explanations within particular contexts. Yin (2013) outlines that case studies generally focus around a decision or set of decisions. In this study, the decisions to be studied were adoption of green infrastructure in BES and implementation of asset management at both BES and the Water Bureau. The case study method is useful for examining the decision in its real-world (i.e. not experimental) context and when the boundaries between what is “inside” and “outside” the decision context may be blurry (Yin 2013). Both of those conditions apply to the cases that were examined in this study, In addition, the “how” research questions are particularly well suited to case study research because a strength of this form of research is in understanding complex social situations and events (Yin 2013).

Context and Case Selection

As explained in Chapter 2, the water industry consists of three main lines of business: drinking water provision, wastewater collection and treatment, and stormwater management. How responsibilities for these three are combined or split amongst utilities within a community varies; in Portland, Oregon the Bureau of Environmental Services (BES) is the city bureau responsible for wastewater and stormwater management and the Portland Water Bureau (PWB) is responsible for drinking water provision. Both of these organizations exist within Portland's unusual Commission form of government. In Portland, the City Council members hold legislative powers similar to elected officials in other cities, but they also individually administratively oversee bureaus that are assigned to them by the Mayor (Lansing 2003; Office of the City Auditor n.d.). Over the years, BES and PWB have sometimes been assigned to the same Commissioner but have usually been overseen by separate Commissioners. The basic demographics and professional identity of employees at the two bureaus historically has been quite similar, though not necessarily in the same proportions (for example, there is now a higher proportion of biologists and ecologists at BES than at the Water Bureau, as will be explained in Chapter 6) with anecdotal evidence of some employees moving between the two over the course of their careers. In addition, the two bureaus exist within the same external culture of Portland, Oregon and are serving the same community, which makes many of their local political pressures the same. While they are sister bureaus, each is run semi-autonomously.

There are interactions between the two bureaus at the leadership level with regular meetings of the Directors and Deputy Directors of the various city bureaus. In addition, there are informal interactions at other levels of the two organizations due to professional and personal relationships among employees, some formal processes for interaction (for example, customer billing is done through PWB, with BES employees interacting as a stakeholder in any changes to the billing process and appeals), and semi-formal interactions on rule and code changes and development review, to name a few specific instances. And, connecting to the innovation literature, both organizations have similar size, complexity, interconnectedness, slack, centralization, and formality. The remaining variable from the literature that may differ is their orientations toward innovation.

One of the cases I chose for this research is the Portland Bureau of Environmental Services (BES). The site was chosen because it is a water sector workplace where ecologists/environmental scientists and engineers work together in an organization that is recognized nationally and internationally as being innovative in the implementation of green infrastructure (Brown, Ashley, and Farrelly 2011). Also, I was employed there starting in May 2011 and had access to the field site. I had worked at other water utilities as a chemist, engineer, and water policy advisor, but my role at BES was as a policy analyst and employee support program lead, which involved working with all organizational units as a type of internal consultant, housed within the Strategy

Group. While I had not been employed as an engineer at BES, I was a registered civil engineer. In addition, I worked in planning, design, and construction of both grey and green infrastructure prior to joining BES, making me very much an insider in the industry.

Until the early 2000's, insider research, where the researcher is a member of the organization or culture being studied, was discouraged (Brannick and Coghlan 2007). But, in view of the current emphasis on collaborations between researchers and practitioners, this is no longer the case. Some of the unique issues to consider with insider research are: obtaining secondary access, ethical considerations, and power and supervisory issues (Coghlan and Brannick 2005; Yin 2015). Secondary access differs from primary access in that primary access is getting into the research site as a whole (which is easy as an employee) while secondary access refers to obtaining access to all sites and parts of the organization that are necessary for the research (Brannick and Coghlan 2007). As an internal consultant my typical job duties involved meeting and coordinating with employees throughout BES, granting me wide access within the organization. Access was also facilitated by my work history as a chemist, civil engineer, and policy analyst. I had experience working as, and could speak the language of, scientists and engineers. I did not supervise any staff and had the support of my supervisor and the rest of the bureau's leadership team for this research, so supervisory issues did not arise. Ethical issues were a concern, mainly because of Oregon's public records laws. I did not perform this research as part of my job, and clearly distinguished when I was acting as an employee and when I was acting as a researcher; keeping all of my jottings, notes, and recordings completely separate so as to make sure they would not be public records.

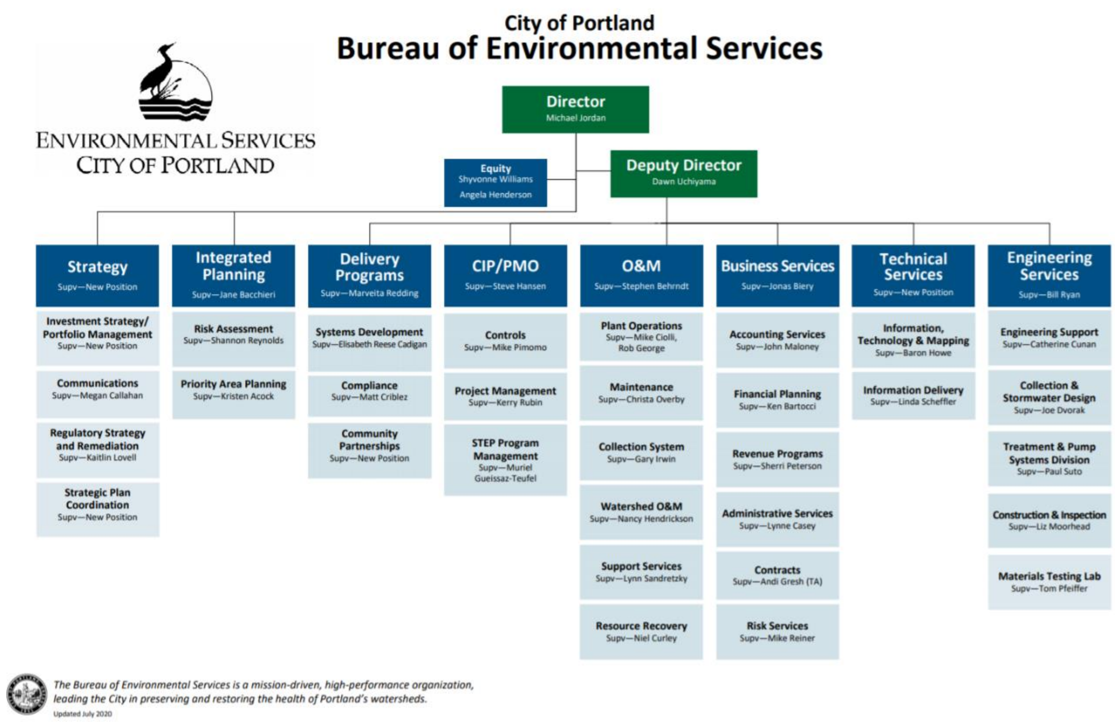

Figure 3: BES Organizational Chart

BES underwent a reorganization while this research study was being prepared, before formal interviews for Phase 2 began (see below for an explanation of the two phases of data collection.) Part of the purpose of this reorganization was to change the decision-making processes within the bureau. An organizational chart of the structure at the time of the Phase 2 interviews is shown in Figure 3. There are a few key places in the organization where decisions were made about the types of challenges to solve and what technologies or programs to use to solve them, and the interviews for this project focused primarily, but not entirely, on employees within those areas. These were Strategy, Integrated Planning, and Engineering Services.

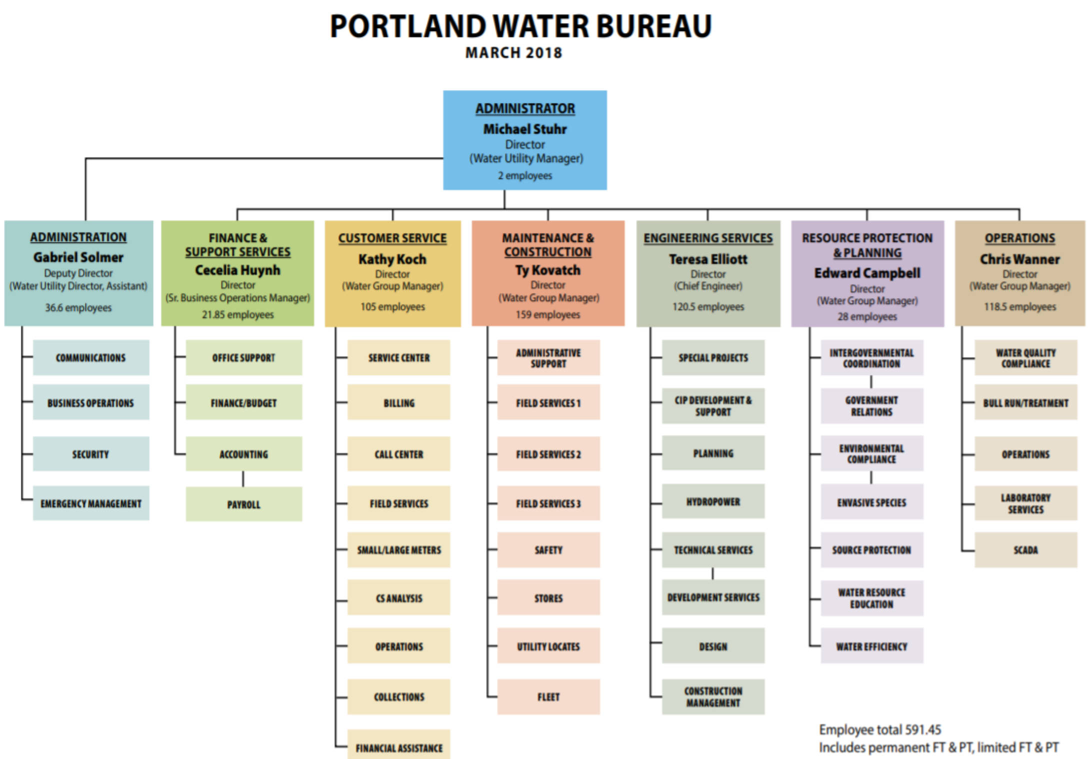

Figure 4: PWB Organizational Chart

The second case is the Portland Water Bureau. This organization was chosen because it is a sister bureau of BES and is also known among other water organizations for innovating, especially in implementation of an asset management program. Prior to joining BES, I worked at PWB as a planning engineer from September 2008 until May 2011. I maintained professional and personal connections with some employees at PWB. Before data collection began, I met with leadership at PWB and gained permission to interview employees and collect documents. The organizational structure of PWB at the time of the research shown in Figure 4. The key organizational units for infrastructure decision making were in Resource Protection & Planning, Engineering Services, Administration, and Finance & Support Services.

Data Collection and Analysis Methods

Data collection was conducted in two stages. The first stage occurred from January 2018 to February 2020 as a research project sponsored by BES to help the organization better understand the organizational culture in anticipation of the structural reorganization that occurred in March 2020. That research was done under approval from Portland State University's Institutional Review Board (Protocol #174403) under the direction of Dr. Charles Klein in the Anthropology Department. The data collection consisted of three interrelated activities: participant observation, interviews, and document review. Only the interview data was used for the current study. Forty-four interviews of BES employees were conducted in this first phase, distributed throughout the bureau's work groups that existed at that time, prior to the reorganization. For employees who worked in an office setting, each interview lasted

	Question:
1.	What group are you with? What is the mission/purpose of your group?
2.	When you first applied here, what reasons did you have for wanting to work here? Do you still feel that way? What motivates you about your work? Do you think the other members of your group share those values and experiences?
3.	How does your group work? What is your decision-making process?
4.	Can you give me an example of a process or incident within your work group where things went really well? What would you attribute success to? (How do you define success?) How about one that didn't work so well? What do you think could have been done differently? Would you say this was innovative? Why/why not?
5.	(Follow-up on statements made during meetings) What did you/does your group mean by risk? Why do you believe that ____ would be the best approach?
6.	When and how do you work with other groups at the Bureau? Which groups do you work with, how often, and in what context? Do you work in teams that are made up of employees from multiple work groups? What types of groups are they and who (by work group) participates?
7.	How do you think your relationship is with members of that group? How do you view their decision-making processes?
8.	Can you give me an example of a process or incident where things went really well working with that group? What would you attribute success to? How about one that didn't work so well? What do you think could have been done differently?
9.	Do you feel like members of the other work groups respect the work that you do?
10.	How do you feel about their work? What are the strengths/weaknesses of interactions between your groups?

Table 1: Phase 1 Data Collection Interview Questions

approximately one hour. For field staff, a less formal technique called "ethnographic interviewing" was used. For that, I accompanied employees while they carried out their normal job duties talking with them and asking questions in a more informal manner. Topics included those from the formal interviews as well as other things that came up in regular conversation.

From the Fall of 2020 through Summer 2021, a second phase of data collection occurred for both cases in this study. During that time, the City's physical archives were closed due to the COVID-19 pandemic and associated restrictions. Document collection was therefore limited to what I could obtain from the City's electronic records system and what could be provided by individual employees at both bureaus. Fortunately, employees in the two bureaus had kept copies of many documents stored electronically in accessible locations even after they had been officially transferred to the archives.

From prior knowledge of the water industry and the history of the two bureaus, I was initially interested in decisions around the adoption of green infrastructure (GI). Initial document review confirmed that the transition to using GI at BES was transformational for the organization. New types of experts were brought in and new organizational units were established (see Chapter 6). The Portland Water Bureau, on the other hand, has relied on the Bull Run Watershed's natural processes since 1895 (Short 2011). While the views on the value of the watershed and its performance as "infrastructure" have evolved over time, there had not been a sudden influx of new expertise into PWB or a transformational event around GI. Therefore, focusing exclusively on adoption of GI would not provide a productive comparison, but was more useful to examine as an important antecedent for the study. The initial document review uncovered another transition to focus on: the adoption of a common framework within both organizations that could be examined and compared to reveal differences in cultural orientations toward expertise – the establishment of asset management (AM) programs. After the initial document review, I decided to use the green infrastructure transition as background to the study, focusing the research on the decision both bureaus made to adopt AM programs and how implementation of those programs has occurred at the two bureaus. The timeframes being examined in the research are shown in Figure 5, which is a graphic representation of the temporal relationship of the adoption of GI and AM.

	1980s - - - 1990s - - - 2000s - - - 2010s - - - today
BES	"Before" Green Inf. begins Asset Mgmt begins
PWB	"Before" Asset Mgmt begins

Figure 5: Research Timeframe

As can be seen in Figure 5, an important element of the research is to establish the "before" culture of both organizations. To do this, I reviewed documents produced before 1990 relating to the missions and decisions of BES and PWB. In addition, I interviewed employees and former employees who worked at each bureau before 1990, asking about what the culture and decisions processes were like.

According to Schensul and LeCompte (2013, 3:172), semi-structured interviews are good to “find patterns within cases . . . and themes.” The interviews in the second phase of data collection lasted approximately one hour each using Zoom. They were recorded with transcripts generated by Zoom; I reviewed the transcripts for accuracy and made corrections where necessary to correct typos and the incorrect transcriptions made by the Zoom algorithm. I then used the corrected written transcripts as data for the study. The questions outlined in Table 3 were used as a starting point to structure the interviews, with follow-up questions based on the flow of the interview. Participants were initially selected based on my knowledge of the organizations to represent the various work teams, locations, and professional orientations that interfaced with the establishment and use of asset management within each bureau, and adoption of green infrastructure in BES. This included long-serving employees who had direct experience in the historical changes I examined, people who have left city employment, and relatively new employees in each bureau. Toward the end of each interview, I asked who else I should speak with to get more information on the questions I had asked, making interviewee selection partially based on snowball sampling techniques. In total, 34 interviews were conducted; two of those interviewees had worked at both BES and PWB and are included in both the PWB and BES columns in Table 2. The number of interviewees was determined by how much variation there was in the perspectives of the interviewees based on their backgrounds and position within the organizations (Schensul and LeCompte 2013). This meant that I stopped requesting interviews once I had interviewed people with the above-outlined selection criteria with knowledge of green infrastructure (in BES) and asset management (in both bureaus), and the answers from new interviewees was mainly repeated from what I had already heard. BES and PWB are large organizations with over 600 employees each. The number of interviewees represented only a small fraction of the employees within each bureau but included the majority of employees who were recommended by interviewees as having the background and knowledge about the topic of the study. There were only three potential interviewees who did not respond to my request for an interview.

	PWB	BES
Interviewees employed at each bureau	17	19
Engineers interviewed	11	10
Non-engineers interviewed	6	9
Number of interviewees at the bureau during initial establishment of asset management	10	10
Number of interviewees at BES during initial establishment of green infrastructure	NA	6
Number of interviewees at the bureau before 1990	4	7
No response to interview request	1	2

Table 2: Phase 2 Interviewee Characteristics

As noted above, initial document review occurred prior to the second phase of interview data collection. As Miles et al (2014) point out, in qualitative research it is important to iteratively analyze data during the collection phase in order to refine data collection techniques. I continued to analyze data as the interviews progressed in order to better refine follow-up questions and to know when interview information was

Question:	Who to Ask
1. Why do/did you work at BES/PWB? What is special about BES/PWB? How is BES/PWB unique?	All
2: How are decisions made about what gets funded and built? Who makes the decision and what data/information is used? Do you think the right people/information is currently used in decision making? Why or why not? Do you think BES/PWB strikes the right balance in putting resources toward different types of infrastructure?	Current employees
3. What types of water infrastructure do you think will be needed in the future? What do you think will be different from now, and what do you think should stay the same? How should the organization decide? Who should be involved in those decisions?	All
4. Do you believe BES/PWB is innovative? Do you want it to be? What are some recent innovations? What changes have you made that you are most proud of?	Current employees
5. Who pushes for changes here? Who pushes back to maintain the status quo? What types of changes are frequently discussed? What types of changes are most likely to be implemented? Who are the internal change agents/external influences?	Current employees
6. How do you find out about new technologies and trends in the industry? How do you find out about new issues that may become relevant to your work? Internal and external experts they rely on? Anyone they don't consider an "expert," but still rely on?	Current employees
7. How was the decision to start implementing asset management made? How did implementation of asset management change how decisions were made about what infrastructure is funded and built? Who was involved in the decisions?	All
8. How did you find out about asset management? Where did you look to understand it better and start designing a program here?	All
9. What are/have been the biggest challenges in implementing asset management?	All
10. What influenced the decision to look at green infrastructure solutions in the 1990s? Ask about external influences like regulations, community groups, lawsuits, professional associations. Ask about internal influences like leadership, younger employees, what their background/profession was.	Employed at BES in the 1990s
11. When you first came to BES/PWB, how would you describe the culture? What was most noticeable to you? Ask if any particular profession or work group had greater influence on decisions in the organization than others.	Employed at bureau during or before the 1990s

Table 3: Phase 2 Data Collection Interview Questions

mostly repeating what had already been expressed by others. Post-data collection analysis consisted of both qualitative content analysis and thematic analysis.

Content analysis is a systemic, theory-guided analysis of text (Kohlbacher 2006). In practice it involves assigning categories, called codes, to portions of text in a way that facilitates understanding and interpretation of meaning (Maxwell 1994; Kohlbacher 2006; Schreier 2012). Interpretation is necessary because data cannot speak for itself; in qualitative content analysis the research questions and theoretical framework structure how the data is interpreted (Saldaña 2009; Schreier 2012). According to Saldaña (2009, 3) a code is “most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data.” During the first pass of coding, I started with deductive codes based in the literature and my research questions. For example, when interviewees discussed the purpose of asset management, I had codes derived from the literature on asset management, namely I looked for answers that focused on risk, cost, services, or assets. In addition, inductive codes were added based on what I was seeing in the data. Using this same example, I added a code about asset management being a communication tool.

The second pass of coding was done along two separate pathways. The first path was aimed at understanding what happened. This is called descriptive coding, where the goal is to identify what the data is saying happened, but not why (Saldaña 2009; Braun and Clarke 2012). These codes were useful primarily for Chapters 6 and 7 where I describe the events that occurred during the time period studied and present how interviewees themselves described the cultures of the two cases. In this analysis, the codes from the first pass were adjusted and refined. This adjustment is seen as essential to this form of data analysis as the first pass of coding is meant to be exploratory and refined as the analysis progresses (Kohlbacher 2006; Saldaña 2009; Miles, Huberman, and Saldaña 2014). In addition, the information was organized chronologically to assist in telling the story of how the two cases changed over time.

The second path of data analysis used a thematic analysis method with conceptual and interpretive coding. This form of analysis was primarily useful for Chapters 8 and 9 where I analyze what the data mean and why the information presented in Chapter 6 and 7 occurred as they did. Thematic analysis is defined as "systematically identifying, organizing, and offering insight into patterns of meaning (themes) across a data set" (Braun and Clarke 2012, 57). This analysis also involved adjusting and refining codes in an iterative manner as codes were sorted into themes and different themes were linked together to reveal meaning (Miles, Huberman, and Saldaña 2014; Willig 2014). After coding, the data was examined first within each case to help describe, understand and explain what was happening at each case site (Miles, Huberman, and Saldaña 2014). Then, a cross-case analysis using a replication strategy was used. Miles et al (2014, 20) define this as using a theoretical framework "to study one case in depth, and then successive cases are examined to see whether the pattern found matches that in previous cases." As can be seen in Chapter 8, the engineering and ecology knowledge systems framework was used to analyze events at BES and then the Water Bureau was used as a negative case to refine and explore the findings.

The final step in the analysis process was to present the preliminary findings to the leadership at both bureaus to obtain their reactions and opinions on the conclusions of the study. Discussing and negotiating findings with those who are being researched is known as communicative validation (Kohlbacher 2006), and while I did not attempt to reach full consensus with leadership of the two bureaus, listening to their reactions helped refine and validate the results.

Summary

The research for this paper was done using a comparative case study design, looking at two organizations, the Portland Bureau of Environmental Services and the Portland Water Bureau. These two cases were chosen because they are sister bureaus in the same city, because I had easy access to the research sites since I have worked for both organizations, because they are both known within the water industry as innovators, and because they differed in the proportion of engineers and ecologists/environmental scientists in the organizations. Data collection occurred over two phases. Interview data from the first phase was used as background to phase 2, which consisted of document review and interviews. The data was then analyzed using both qualitative content analysis and thematic analysis. The next two chapters are primarily descriptive, outlining what happened at the two bureaus during the period examined in this research.

Chapter 6 – BACKGROUND OF PORTLAND'S WATER UTILITIES

The purpose of this chapter is to provide background knowledge about the evolution and organizational cultures of the two case study organizations prior to the time period being examined in the current research. This should be read in the context of Chapter 2, which covered the history and evolution of the water sector as a whole in the United States. For the two water organizations being studied, both that global/national context (provided in Chapter 2) and the local context are important. Water organizations across the United States share many things in common and are connected through national organizations as well as personal relationships between employees who have met along the course of their careers. The two organizations being examined in this study are likely not radically different from other water organizations, but the local context is important in understanding some of the external pressures for innovation. This chapter begins with the local context, situating the two organizations in Portland, Oregon before going on to outline the histories of the two cases and how adoption of green infrastructure in the water sector influenced their organizational cultures. This is all background knowledge to the time period in which asset management was first introduced into the two organizations, which will be the focus of Chapter 7.

The Setting: Portland, Oregon

The City of Portland is known for having an environmental ethos. The self-identity of residents is connected to its natural environment and having access to nature (Orloff 2004). Early American settlers in Portland, however, struggled against their natural environment, fighting flooding, mud, and bad water quality for the first 150 years of the city's history (Lansing 2003). Through the 1950s Portland was considered to be conservative and growth-oriented, very unlike its reputation today as a liberal and open city (Mayer and Provo 2004). Parks were viewed favorably, but mainly for their amenity value and contribution to quality of life for residents. This started to change in the 1960s and 1970s with the rise of environmentalism nationwide. In Portland, seminal events brought about by community advocacy and activism in the 1970s exemplify this turn toward nature: the defeat of the Mt. Hood freeway, the removal of Harbor Drive on the west bank of the Willamette River near downtown, and the adoption of the Willamette River Greenway Plan (Lansing 2003; Mayer and Provo 2004; Orloff 2004). This is when Portland started to be seen as a leader in protecting and enhancing natural resources inside the city (Ozawa and Yeakley 2004).

In the 1990s Portland transitioned away from being an economy based in resource extraction into a knowledge economy, emerging as a "green" city (Mayer and Provo 2004; Stephenson 2021). There is now a thriving community of professionals and community advocates, supported by voters, who work to promote open space, natural resources, and nature-based solutions to environmental problems (Ozawa and Yeakley 2004; Stephenson 2021). During the 1990s Portland became known as a leader in green infrastructure for multiple different purposes, including for water management (Brown, Ashley, and Farrelly 2011; Matsler 2019). Water management is implemented at the city level by the Portland Water Bureau and the Bureau of Environmental Services, the two cases studied in this research.

One of the background questions of this research is: does the movement toward green infrastructure change the culture and decision making within water organizations? To look at this question, we turn to our case studies. What were the cultures of the Portland Water Bureau and Bureau of Environmental Services prior to the turn toward green infrastructure in Portland, and how much did the bureaus change because of that turn?

Portland Water Bureau

The Portland Water Bureau (PWB) has existed almost as long as the City of Portland. The City's second charter in 1853 allowed for the establishment of waterworks under a committee that was both part of the municipal government and somewhat autonomous from it (Lansing 2003; Short 2011). The original driver was to find a cheaper water supply that didn't draw from, or necessitate cleaning up, the polluted Willamette River (Lansing 2003; Short 2011). Even back then, the removal of tree cover in the city was linked to water supply and water quality; the Water Committee decided to look for a new water supply that was unspoiled, using the natural forest to guarantee the purity of the water (Short 2011). The Bull Run, located east of Portland near Mt. Hood, was chosen because of its “good, pure and wholesome water” (Lansing 2003, 185).

In a book commissioned by the City about the history of Portland’s water system, Casey Short (2011) portrays the engineer in charge of the original Bull Run water system as the father of the Water Bureau and an engineering genius. According to Short, the engineering work “still inspires respect for his talent among modern-day engineers” (2011, 35). From the very beginning of the organization, the Water Bureau was rooted in an engineering knowledge system, with a culture that valued engineering know-how. When asked about their experiences in the Water Bureau and how decisions were made prior to the 1990s, the interviewees agreed. They talked about the Water Bureau having an engineering identity and culture. Interviewees also talked about engineers having more decision-making power than others.

Identity and how employees describe the work are important elements of an organization’s culture (Alvesson 2012; Martin 2002). The Water Bureau’s foundational story about Colonel Smith being an engineering genius is part of that identity. The 1984-85 City budget describes the mission of the bureau being “To ensure that a reliable and adequate water system is available to provide sufficient quantities of high quality water at standard pressures” (D. of F. and A. City of Portland 1984, 252) As discussed in the earlier section of this study about the water industry, those two goals highlighted in the budget document, reliability and quality, are the main priorities for traditional, engineering-based water organizations (Lemos 2008). As one PWB interviewee who is an engineer said, “utilities are infrastructure, and those are engineering functions.” To this employee, engineering and utility operations were inextricably linked, and a utility could not function without engineers having an outsized role in the organizational identity and decisions. Another employee who is not an engineer said the organization “came from that very traditional engineering approach.”

How decisions are made and the people who have most influence over decisions about infrastructure can also reveal important information about the culture and predominant knowledge system (Argyris and Schon 1978; Orasanu and Connolly 1993). In the past, engineers had more decision-making power than many others: for example, from 1955 to 1971 the Chief Engineer reported directly to the elected Commissioner (Short 2011). Interviewees from the Water Bureau described decisions around infrastructure as a process where decisions were being made by the engineering section with other employees having a chance to “weigh in”, provide input, or rubber stamp it at the end of the process. As one non-engineer said, “frankly, decisions about infrastructure are largely made out of our engineering section.” The “users” of the infrastructure, such as operations personnel, were subordinated to the engineering section in decision making. Another long-term employee stated that “the water bureau has been a very engineering-centric bureau in the past. Decisions were made by engineering."

Being a traditional water organization with an engineering knowledge system does not mean the Water Bureau was resistant to environmental concerns or the green turn in Portland. A popular slogan for many years has been "From Forest to Faucet", as seen in Figure 6. As far back as 1892 there is evidence that bureau water managers valued the forested watershed and prioritized its protection (Short 2011). Keeping the watershed pristine and untouched was a major theme of Casey Short's book on the water system, with attention brought to several battles between federal forest managers and the city. The Water Bureau identity is not only tied to engineering, but from the beginning has also been tied to having a protected watershed as the source of "clean, clear, cold, and constant" water (Portland Water Bureau 2018).

Figure 6: Portland Water Bureau logo
https://portlandalliance.com/news/2020-07-13/portlands-small-business-program-for-utility-relief-spu.html

Events since the 1970s have challenged the bureau's stance toward keeping the watershed, and the water, untouched. Drinking water regulations and water industry practices require some intervention in the water system to remove impurities and provide health benefits. Portland activists have resisted this: "A mythology has developed around Bull Run water, one of the last surface water systems in the country to flow through the tap without need of filtration" (Short 2011, 217). The Water Bureau has been pulled between regulations and public opinion on several issues because of this, most notably in relation to the Long-Term 2 Enhanced Surface Water Treatment Rule adopted by the Environmental Protection Agency in 2006 which provided pressure on Portland to cover the water storage reservoirs and build a water filtration plant. Portland lost a lawsuit where they attempted to force an exemption from the rule. They then applied for and received a variance to that rule, but at the time of the research were under order to build a filtration plant after not meeting the conditions of the variance (Portland Water Bureau n.d.). Portlanders fought against filtering the Bull Run water, not only because of the cost, but also because it went against their vision of the water being perfect, pure, and natural (Merritt and Barnett (ed.) 2009). In addition, the bureau was no longer allowed to use open-air water storage reservoirs in town because of regulations and despite activism to the contrary by the local community (Theen 2014).

The Water Bureau does not manage stormwater, except in the Bull Run Watershed. The watershed itself is closed to the public, and has only a few small developed areas where stormwater management is a consideration. Therefore, the movement toward using green infrastructure for stormwater management has not impacted operations at the PWB. Besides the water quality regulations discussed in the previous section, the main impacts the environmental movement has had on the PWB come through climate change and endangered species protections (Short 2011). According to interviewees, those issues are both seen as tying the hands of the bureau rather than offering opportunities. The impact is viewed as negative.

PWB has not remained static throughout this time; as the country's thinking evolved on several issues, the Water Bureau has had to evolve their thinking as well. Some of the interviewees who were engineers expressed that they no longer felt that the bureau was as engineering oriented as it used to be. They highlighted the work being done with equity and climate change as altering decision processes in the bureau, as well as the increase in the number of bureau employees who are not engineers. This has created some backlash among the more traditional engineers, as they have felt that their power was begin taken away. One interviewee who is not an engineer said that there was a controversy during the recent strategic planning process,

> in the strategic plan that was identified as one of the risks of, like, I don't know how it was framed, it was like something like: the risk of the water bureau being this engineering, I think it said dominant or engineering

> focused culture. Oh, people, like, people did not like that. And I can understand how it might make some people sensitive, but I think there's a lot of truth to where that was coming from.

The non-engineers in the bureau, and even some engineers, stated that engineering culture and engineering decision processes were still privileged over others in the bureau. They felt that environmental and equity issues were being brought into the pre-existing engineering decisions processes as just another variable and that engineering considerations still ruled the organization. The organizational unit that is responsible for managing responses to climate and endangered species, Resource Protection, and their different knowledge system is seen as peripheral to the organization and its mission. One employee who is an engineer even described it as being an “us versus them” situation where the Resource Protection group is seen as being in opposition to the culture and priorities of the rest of the Water Bureau. Another engineer interviewee at the Water Bureau said, “In water the project manager is the engineer. Engineers are cradle to grave on capital projects. Not the same person, but it's still an engineer. They’re in engineering with an engineering mindset.” This person went on to say that other infrastructure organizations they were familiar with did not have this singular mindset throughout their processes, “It's not just about technologies, but it's mindset innovation. I don't think we have that at the water bureau. I think people would mistrust that, frankly, because we say, well, they don't think like us." With only a few exceptions, employees perceive the Water Bureau as still being rooted in an engineering knowledge system today.

Bureau of Environmental Services

Public sewers were on the Portland agenda from the very beginning, considered a core service for a community (Lansing 2003). For many years, sewers, stormwater drains, and streets were all managed by a public works organizational unit. In 1983 those public works functions were split into two separate bureaus, one handling transportation and streets: the Bureau of Transportation, and the other handling sewage and stormwater infrastructure, and waste collection: the Bureau of Environmental Services (BES)[5]. According to documents and interviewees, at the time of its' creation, BES was a traditional wastewater organization dominated by the sanitary engineering knowledge system. The 1983/84 City budget document describes the role of BES, "To provide for efficient self-supporting sewerage and solid waste systems which meet the needs of Portland area residents and businesses and which complies with Federal, State and local requirements" (D. of F. and A. City of Portland 1984, 207). Interviewees who were around at the time talked about the identity of BES being tied to being a "pipe bureau" with the focus on "pumps, plants, and permits." One interviewee, who is not an engineer, explained that a colleague described BES as "the Corps of

[5] Waste collection was soon removed from BES's portfolio, leaving the organization to focus on wastewater and stormwater.

Engineers for the City of Portland" that focused on built infrastructure and engineering expertise. Interviewees who were around in the 1980s, both engineers and non-engineers alike, agreed that the culture was oriented toward engineering.

This was seen in the decision processes and power structures at BES. Interviewees described the decision processes being engineering-oriented and focusing on human health. They mentioned that the engineers had all the power in the bureau, the leadership being dominated by people with professional engineering credentials, and engineers holding strongly to their positional and decision-making power in BES. However, other interviewees talked about some of the engineers being open to other ways of looking at problems, and flexible enough in their thinking to recognize the value of other knowledge systems. Like Water Bureau engineers, they were part of the Portland orientation toward nature. A non-engineer at BES who was interviewed said, "I think there were people in engineering services that were wanting to be innovative and wanted to find different ways of solving problems."

There was public concern over the polluted state of the Willamette River, which runs through Portland, at least as early as 1885, but wastewater treatment was seen as an expensive luxury (Lansing 2003). Because of this perception, nothing was done until the late 1940's/early 1950's when the City built interceptor sewers and a wastewater treatment plant to capture and treat runoff up to three times the dry weather flow (Environmental Quality Commission of the State of Oregon 1991; City of Portland

Bureau of Environmental Services 2001; Lansing 2003). However, when the public sewers were first being built in Portland, combined sewers (where rainfall and sewage were carried in the same pipes) were common. These combined sewers were built in Portland. Rainfall often exceeded the capacity of the interceptor sewers and raw sewage discharged into the Willamette up to 150 times a year (City of Portland Bureau of Environmental Services 2001; Melosi 2008). A 1964 documentary by then-future Oregon Governor Tom McCall called "Pollution in Paradise" called for cleanup of the Willamette, but the City continued to drag its feet (Lansing 2003; Orloff 2004).

After passage of the Federal Water Pollution Control Act amendments in 1972, commonly known as the Clean Water Act, Portland made changes to the sewer system so more flow was conveyed to the treatment plant and less to the river (City of Portland Bureau of Environmental Services 2001). Afterwards, there were still approximately 50 overflow events, called CSOs, short for Combined Sewer Overflows, per year and many entities, including regulators at the Oregon Department of Environmental Quality and members of environmental advocacy organizations, viewed this work as barely meeting the minimum requirements of the Clean Water Act, supporting the reputation the City had of doing the least amount of work possible to remain in compliance with the law (N. Bell 1991; C. Clark 2000).

With the passage of additional Clean Water Act amendments in 1987, a scheduled periodic permit renewal, and a lawsuit against the City by a local advocacy organization all coming together in the late 1980's and early 1990's, Federal and State regulators started pushing for Portland to do more to clean up the river (Environmental Quality Commission of the State of Oregon 1991; City of Portland and Northwest Environmental Advocates 1998). After several rounds of negotiations and the settling of the lawsuit, the City and State signed an agreement known as the "Amended Stipulation and Final Order" in 1994 (Environmental Quality Commission of the State of Oregon 1994). To solve this problem, City engineers started to generate cost estimates in the hundreds of millions of dollars for CSO control (Adderley 2007). In addition, there were several other significant events around this same time: The Clean Water Act amendments of 1987 included provisions for municipal stormwater discharge permits, in April 1994 a Federal CSO policy was adopted, in 1998 the Columbia River Steelhead Trout was listed under the Endangered Species Act (the first listing of a local species, with more to follow), also in 1998 sections of the Willamette River in Portland were listed as impaired because of the presence of various pollutants, in 2000 Portland Harbor was placed on the Federal Superfund list, and the Environmental Protection Agency started paying more attention to stormwater's impact on groundwater quality (City of Portland Bureau of Environmental Services 2001). All of these problems were coming together to push for change.

New difficult problems alone are not enough to spur an organization to initiate change. Decision makers in that organization must decide to put the issue on the “agenda” first (Kingdon 2010). Bureau and City leadership understood that innovation was necessary. Green infrastructure was an existing idea that was then being discussed and experimented with both at a small scale in Portland and elsewhere in the country, and was supported by an active environmental movement and advocates that were pushing for more green space and ecological solutions to environmental problems (Houck 1989; Ozawa and Yeakley 2004; Stephenson 2021). BES’s political and administrative leadership made the decision to begin using green infrastructure for stormwater management, one of the earliest utilities in the United States to do so (Brown, Ashley, and Farrelly 2011; McPhillips and Matsler 2018; Matsler 2019).

To implement green infrastructure, new employees were needed with different types of expertise than engineering. The engineering knowledge system was still needed, but it needed to be supplemented with an ecological knowledge system (Matsler 2019). New employees were brought into BES who had training in fields such as environmental planning, landscape architecture, biology, ecology, and public involvement. Some employees within BES started to think about stormwater as a resource that could be managed as close to where it falls as possible and also started to think about balancing the needs of people with the needs of fish and other wildlife. One interviewee who is not an engineer described this as “the curse and the blessing of BES is that, because of our watershed interest, it brings us into different disciplines. And so our portfolio requires a broader range of expertise.”

At first, there was resistance to green infrastructure from regulatory agencies. Even though changing regulations were a large part of the reason BES started looking toward green infrastructure solutions, interviewees noted that the regulators still wanted traditional, engineered solutions. One interviewee who is an engineer said,

> within regulatory bodies those people care deeply about the resource, but they also care deeply about strict compliance with every comma and period within every regulation. The regulation was not drafted with this sort of thing (green infrastructure) in mind. You're asking them to, kind of, go out on a limb and to flex in areas where they're nervous because they can get sued by someone who said, you didn't follow every point within the regulatory framework.

Regulators did not want to block the use of green infrastructure, but rather they would not allow BES to significantly reduce the amount of water handled by the pipe system or allow more time for implementation in exchange for installation of green solutions; as one engineer who worked at BES at the time put it, “The EPA in their infinite wisdom said, yeah that is really cool stuff, we like it and we'd like you to do both. Still meet the 2011 deadline and do all this (green infrastructure), so we're not letting you off the hook.”

There was also resistance to using green infrastructure to solve stormwater-related problems in Portland from some BES engineers, and the wider engineering community; one non-engineer interviewee said there was some opposition to putting resources into green infrastructure from “the engineering community who had really found a way to do things right . . . and then to throw in this new idea about trying to integrate green infrastructure" was resisted. Engineering resistance stemmed from the belief that green infrastructure was too new and unproven, as one non-engineer interviewee said, many engineers in BES seemed to think, "well, just, we've always done it this way (using pipes, pumps, and treatment plants) I don't understand your making us go out and look at that (green infrastructure)." Among some of the engineers, there was a cultural path dependency and belief that things should not change. The new green infrastructure advocates noticed the resistance and felt the need to push for more ecological approaches. The work group within BES where most of the stormwater and habitat restoration planning occurred gained a reputation for being zealots and advocates for green solutions.

Green infrastructure work at BES started with small experiments, such as test plots and parking lot swales, according to employees who were around at that time. The organizational unit, known first as the Planning group, and later Watershed Services, was also small and separate from the rest of the bureau. This is known in the literature as a niche. Niches are formed when there is a new problem that cannot be solved using current technologies and knowledge systems, a situation in which BES found itself (Kemp, Schot, and Hoogma 1998). Niches are protected spaces where experimentation can occur and the predominant assumptions and general rules of the organization can be ignored (Geels 2004; Hodson and Marvin 2006; Farrelly and Brown 2011). A niche is focused on learning and experimentation; one interviewee who was not an engineer described the BES Planning group as a “skunk works” within the bureau where “wacky” ideas were proposed and tried at a small scale. Besides being experimental spaces, another essential feature of a niche is that it is separated from the main culture. This was the case in BES, with interviewees describing the different areas of the organization begin “siloed” from each other, and the Planning/Watershed group as being insular and in a separate box from the Engineering group. One interviewee who is an engineer put it this way, “it feels like at BES there's, definitely, an infrastructure side, and then there's the, like, the environmental side. And it does feel like there's a bit of a split there in the workforce.” Another interviewee talked about decisions being made entirely separately, each group using their own criteria and decision processes.

There was a feeling among interviewees that early green infrastructure work did not change the culture of the bureau in a significant way. There was a reduction in the size of the “Big Pipe” that was the heart of the work BES did for CSO control, but only because it met the engineering criteria that existed in the bureau. The interviewees who were bureau engineers at the time of the CSO work said they grew to appreciate green infrastructure, but only because it reduced the volume of water entering the bureau’s pipes. All of the other benefits were seen as “nice to have,” but were not appropriate considerations for decisions about infrastructure. This is reflected in the CSO design reports from that time (City of Portland Bureau of Environmental Services 1994; 2001). This supports the assertion that the green infrastructure work was in a niche. The experiments and new ideas from those working in green infrastructure did not change the overall culture or decision processes at the bureau while green infrastructure work was contained within the niche.

The watershed work being in a niche did not prevent it from implementing some significant projects and programs in the community that were very different from traditional water infrastructure organization activities. A couple of note include the Foster floodplain work and Community Watershed Stewardship Program (CWSP). In the Foster floodplain BES collaborated with local community organizations in restoration of floodplain land and a willing seller program for residents. This work involved removing engineered infrastructure that had straightened and rock-lined a portion of a creek in Portland and instead using "nature as a partner – to recreate and mimic more natural floodplain functions" (Walkiewicz 2015, 222). The CWSP is a collaborative program between BES and Portland State University built to support community-led water quality improvement projects (T. Miller et al. 2015). Rather than focusing on infrastructure, the program is designed around community engagement and education for achieving both watershed and equity goals. Both of these programs were initiated when green infrastructure was within a niche in BES and influenced the reputation of BES as being a green organization. The reputation for being green was also enhanced by the BES logo showing a great blue heron (Figure 7).

ENVIRONMENTAL SERVICES
CITY OF PORTLAND
working for clean rivers

Figure 7: Bureau of Environmental Services logo
https://eastportlandchamberofcommerce.com/page-18127/5320906

Niches are seen as important for innovation, but in order for real change to occur, the niche must grow and spur change in the wider organization and industry (Kemp, Schot, and Hoogma 1998; Brown and Clarke 2007). According to the literature this is a difficult process, and few niches succeed at scaling up and transforming the organizations and industries in which they exist (Kemp, Schot, and Hoogma 1998; Berkhout 2002; Farrelly and Brown 2011). Much of the difficulty lies in resistance from the existing entrenched knowledge systems, which will be explored in detail in Chapter 8 in the context of asset management implementation at BES. Interviewees talked about two approaches that were used to try to scale up the green infrastructure work at BES. Both approaches were used simultaneously by different employees, depending on their individual style and outlook; according to interviewees this has been going on for the last three decades.

The first approach was to fit green infrastructure into the existing engineering decision process and knowledge system. Interviewees describe this as the Planning/Watershed employees learning to "speak engineering," "learn their world," and "apply engineering tools." One non-engineer said, "part of the deal was, you had to bring those engineering principles with you, and then this was viewed as a bridge to the relationship, and improving the relationship between engineering and watersheds." Another non-engineer said, in reference to green stormwater swales, that watershed employees "knew the engineers were not going to buy the idea just because it was a nice touchy-feely idea. They're going to want to see the numbers. That the thing actually filters water." An example of where this approach was used at BES is in the "Big Pipe" project design where small-scale, semi-green, local projects such as disconnecting residential downspouts from the combined collection system and building stormwater infiltration facilities, were implemented only when they could be proven to reduce costs (City of Portland Bureau of Environmental Services 1994; 2001). Implementation of these projects allowed BES to modestly reduce the size of the piped infrastructure, but only if the projects met engineering criteria for reducing flow.

The second approach was to challenge the existing knowledge system. The Planning/Watershed employees were seen by some other employees as "true believers" who were politically oriented and zealously advocating for green infrastructure and environmental solutions. One non-engineer interviewee described it as "a political fight.

And they wanted people to protect the environment at all costs, and it was just always, again, us versus them." Within the Planning/Watershed group this was characterized as being progressive, pushing for change, trying to advance the science on green infrastructure. The CWSP program, mentioned above, is an example of this. It evolved to be less engineering-centered and more community-based over time.

Summary

Both PWB and BES were engineering-based organizations in the past. Interviewees expressed that PWB still is. On the other hand, most BES interviewees felt like the siloing and separation of green and grey infrastructure decisions was a thing of the past in BES, or at least it was less common than it used to be. People talked about the traditional engineering and green infrastructure knowledge systems being compatible or complementary, and the process being collaborative. Interviewees described the culture as being more open, and that the bureau uses both, as one non-engineer put it, "natural assets and built assets to provide services to our community." Does this mean that BES no longer can be characterized as being an engineering-centric organization that relies on the traditional water industry engineering knowledge system for decisions? To answer those questions, this study examined another innovation, asset management, that was initiated in the 2000s at both BES and the Water Bureau. In Chapters 7 and 8, I will examine how the language about, and perceptions of, asset management can reveal the underlying knowledge systems present at the two bureaus.

Chapter 7 - ASSET MANAGEMENT AND PORTLAND'S WATER INFRASTRUCTURE

This chapter is an outline of the introduction and implementation of asset management programs at both the Portland Water Bureau (PWB) and the Bureau of Environmental Services (BES). The material presented below is primarily descriptive, describing what happened at the two organizations from the perspective of the employees who worked there. Analysis of these events will follow in Chapters 8 and 9. Asset management implementation was chosen as the focus of this study because it was an innovation that was initiated at both bureaus at around the same time. Importantly, implementation began after BES had added employees with a more ecological orientation. Therefore, in following asset management implementation, we are able to see the influence ecologists and environmental scientists have had on BES and compare that to what happened at PWB, which did not have that influx of new types of professionals.

The basic concepts of asset management (AM) were familiar to water managers before they had ever heard the term. As outlined in Chapter 2, AM is a system that aids in infrastructure decision making using a risk-based framework (Marlow, Beale, and Burn 2010; Alegre and Coelho 2013). Looking at the condition of an agency's assets and deciding when to perform preventative maintenance, when to repair, and when to replace were all common practice in the industry. The main difference was that asset management introduced new language and new ways of looking at different maintenance and replacement strategies all together under a common framework (Grigg 2012). Asset management was an innovation for the industry, but it falls closer to the incremental end of the innovation continuum than the radical departure side because of this familiarity of the concepts involved, and asset management's compatibility with the primarily engineering knowledge system of the water industry. This does not mean that implementation of asset management programs at water organizations has been easy.

Asset management came to the attention of the two bureaus at approximately the same time. In the 1990s engineers and maintenance personnel at both bureaus began hearing about the concept at conferences, from colleagues at other water utilities, and from industry journals. Up until that point, maintenance activities were relatively reactive in both organizations. The late 1990s were a turning point, where the bureaus recognized that maintenance and replacement of existing assets was going to be more important than they had been previously. Because of the age of the city, up until that point there had been mostly a focus on building new assets. This was because the "useful life" of most water and wastewater pipes was estimated to be approximately 100 years. There was also the recognition that elected officials and ratepayers wanted more justification for how the bureaus spent their money. Asset management was seen as having a benefit both for internal decision making and for communicating and justifying decisions outside the organizations.

The introduction of asset management into BES and the Water Bureau was partially internally driven, as will be discussed below. But implementation was also influenced by activities at the city level. The City has long had a policy to "maintain assets in good working order to protect capital investments and to minimize future costs of maintaining and replacing them, especially to avoid costly deferred maintenance" (Office of the City Auditor 2012, 6). Decisions about asset management needed to be consistent with this, and there is a multi-bureau committee, the Citywide Asset Managers Group, that coordinates among bureaus (City Asset Managers Group 2016; Matsler 2017). According to interviewees, each bureau, however, makes decisions about their own programs in a mostly autonomous way.

Portland Water Bureau

Water Bureau employees trace the origins of their official asset management program to the mid-2000s. There is a recognition that elements of AM had been part of PWB's operations for a long time (Portland Water Bureau Management Team 2007), but when asked, the interviewees tied the beginning of the program to two events that happened in 2003/2004: the hiring of a new Chief Engineer and the reorganization of the Engineering Services group. The reorganization included the creation of an Asset Management work group within Engineering Services, after which an Asset Manager was hired (Parametrix, Inc. 2004; Portland Water Bureau 2013). Employees credited both the Chief Engineer and the Asset Manager with being champions within the bureau who drove the adoption and development of the program. Employees placed importance on the fact that the program was implemented from both a top-down perspective, with the Asset Management Steering Committee including all senior leadership at the bureau, and from the bottom-up perspective, with lower and mid-level managers driving the work forward. As one interviewee who is an engineer said, “it had to be top-down bottom-up. Both directions. It's got to be done at the bottom because that's who knows the most about the assets, but nothing happens if the bosses don't support it.”

The charge for the new AM work group was for it to “be a place to improve investment decisions for prolonging the life of PWB assets and help prioritize preventative activities of the maintenance group” (Parametrix, Inc. 2004, 51). There was the general feeling among interviewees that the AM work group was part of Engineering Services because that was where the idea originated; if the new Chief Engineer had not been hired or the reorganization had not happened, asset management would not have come into PWB at that time. Interviewees also expressed that, while asset management did not need to be in the Engineering Services group, it made sense to have it there since AM work was data-heavy, technical work that required analytical skills and knowledge of the bureau’s assets, skills that interviewees felt were best found in Engineering Services. In addition, as one non-engineer said,

> the power of the organization both then, more so then and still so now, you know, comes out of the Engineering Services group. So, if it was

> going to happen and be taken seriously and actually impact the way that the CIP[6] was gonna, you know, be built . . . it needed to be in their world, inside their walls.

According to interviewees, to make changes to how major decisions are made in PWB, the new AM work group needed to be in Engineering Services.

Development of the AM program started out small, with a conscious attempt to get some early, small “wins” to prove the usefulness of the methodology. The Asset Manager decided to start with a business case analysis of fire hydrant repair and replacement. The team’s goal was to show the maintenance manager “what’s in it for you,” and how following AM methodologies could both help with scheduling the work and for justifying the budget requests for the hydrant program. According to one interviewee, this resulted in more support among upper leadership. In their words, the work “showed the value to doing asset management.” At the same time, the AM work group started outlining the overarching processes and principles that were essential to have a fully functional asset management system. Looking at a timeline of the development of the program, the bureau started doing business cases, pulled together a steering committee, completed its first Asset Management Plan, and started work on Level of Service goals in those first years (Office of the City Auditor 2012). By 2010 most of the major elements of a well-developed asset management program were in place,

[6] CIP is the Capital Improvement Program. It is the term used in BES and PWB to refer to the planning, design, and construction of built infrastructure.

according to an interviewee with a background in asset management practices. Initial implementation occurred simultaneously both at the detailed level with one specific asset and at the strategic level.

Another focus from the beginning was a recognition that asset management needed to be adopted in all areas of the organization for the program to be fully effective. Interviewees said one of the biggest challenges with implementing AM at the Water Bureau was getting buy-in from throughout the organization and making it part of the bureau's culture. Many of the interviewees said that PWB has been fairly successful in this. One example of the concept's acceptance throughout the organization is that the latest Strategic Plan, completed in 2019, focused on risks to the bureau (Portland Water Bureau 2019); interviewees said this risk focus came from an asset management approach to the work. One interviewee, who is not an engineer, said this risk focus was chosen because "a lot of people already bought into that framework, they understand what it means." The bureau is continuing to implement asset management in new areas; besides the Strategic Plan, interviewees also talked about asset management plans recently being used to inform budgeting and financial planning for the first time. There was also a feeling, however, among other interviewees that many employees do not fully buy in, or even understand, the asset management approach. But even those employees feel they need to outwardly support it, that they cannot be perceived as being against asset management at PWB. If you want to be accepted into the dominant culture of PWB as “one of us,” you need to support asset management.

Another challenge that was highlighted by interviewees, both engineers and non-engineers, was the challenge of adequately including newer issues that the water sector had not traditionally considered in the asset management framework. Interviewees felt that there was still a lot of work to be done to include climate change, natural resources, earthquake resilience, and equity into the program. There have been some recent attempts to include these considerations and asset types into asset management; interviewees felt that trying to fit these types of non-traditional considerations into asset management was the way forward with getting the issues taken seriously in the Water Bureau and were working in creative ways to fit them into the existing program by setting goals and talking about them as risks. They talked about struggling with this because they felt that asset management was a fairly rigid, regimented program without a lot of flexibility, that the bureau followed best practices that were built around traditional infrastructure needs, and there was there was no movement, or even acknowledgement that it was possible or desirable, to change the AM system to adequately handle non-traditional considerations.

Despite these struggles, the Portland Water Bureau is very proud of its asset management program. Several of the interviewees stated that PWB was a national leader in asset management, and until recently the “About Us” section of the public website said PWB "is recognized as a national leader in pioneering its model of asset management in the water utility industry" (Portland Water Bureau n.d.). Overall, employees pointed to the bureau's asset management program as proof that the water bureau could be innovative. It is seen at the water bureau as a valuable tool that needs to continue and expand throughout the work of the organization to assist in making all kinds of organizational decisions.

Bureau of Environmental Services

There is no consistent narrative among BES staff about the origins of asset management at the bureau. Some interviewees rooted asset management in the 1980s maintenance management and condition assessment work of the bureau; it was not called asset management then, but some employees retroactively consider that to be the start. Some others consider the start to be 1990, when a maintenance management software program was purchased. Still others talk about the late 1990s being the start, when engineers in the bureau started hearing about it at conference and brought the language of asset management to BES. Some talk about it not starting until the mid-2000s when the bureau participated in a benchmarking exercise and a few employees made a trip to an asset management conference in Australia. That was the time when the term "asset management" first came into the bureau. Similarly, there is disagreement about where in the organization the concept first developed and who "owned" asset management at the beginning: the Engineering Services Group or the

Wastewater Group[7]. One interviewee said that it was a "maintenance initiative" without engineering involvement, while another interviewee said that after engineering started adopting asset management principles, they needed to "drag (the Wastewater Group) into it."

These disagreements are partially because early asset management adoption at BES was primarily driven by mid-level staff rather than leadership. The leadership of Engineering Services and Wastewater supported it early, but the rest of the bureau's leadership were not involved in its adoption or implementation until after much early development work had already been done. With no official decision by leadership to start implementing asset management during the early stages, there is no one instance everyone can point to. Another reason is that there is not widespread agreement in BES about what it means to be "doing" asset management. Because there is no overall agreed-upon framework, interviewees did not agree on the key elements; for example, some thought having an asset inventory and condition assessment meant the bureau was implementing asset management, others believed that modeling risks and expressing risk in dollars was necessary in order to be doing asset management, while others said having levels of service that were accepted by the community were necessary before asset management could really start.

[7] The Wastewater Group was renamed the Operations & Maintenance Group during the reorganization in 2020.

According to a 2013 document, BES officially launched an AM program in 2010 to "bring asset management principles into practice at the bureau in a consistent manner, addressing the bureau's most pressing needs" (City of Portland Bureau of Environmental Services 2013a, 7). It was around this same time that an Asset Systems Management (ASM) work group was formed within the Engineering Services Group at BES. There is disagreement among interviewees whether ASM was given the authority to lead the implementation of asset management throughout the organization. Some people refer instead to an AM "core team" that included employees from several of the bureau's work groups. Most of the interviewees did see ASM employees, and Engineering Services, as being in the lead on implementation. The ASM team facilitated the core team meetings, arranged trainings about AM for bureau employees, and organized a larger asset management steering committee, which was made up of approximately 30 to 40 employees from throughout the bureau who were interested in asset management. As one interviewee said, people saw ASM as "the group that made the decisions, or that they have expertise for asset management . . . they had the last say in decisions."

Asset management was considered to be an engineering concept by many in the bureau, though that view was contested by some engineers. The view that it was an engineering concept comes from the language and structure of asset management being brought to BES by engineers, because a work group within Engineering Services was the lead in implementation, and because asset management concepts were compatible with an engineering knowledge system. As on interviewee put it, "engineering held tight to it and didn't expand it. And even when we expanded it to stormwater, we hired engineers to do it. So we reinforce this notion that it is an engineering concept." From the beginning there was pushback against this. Interviewees who were engineers said they believed asset management was not an "engineering thing." However, many ecologically oriented Watershed Services employees did see it as an engineering concept. And, in their view, even if AM is not inherently based in engineering, they believed that how it was being implemented at BES privileged engineering considerations above others.

Part of this disagreement was because of how asset management practice evolved in BES. The new ASM group focused on one of BES's systems – the sanitary and combined sewer collection system. This was a system that was entirely composed of highly engineered, non-vegetated infrastructure; the green infrastructure elements of BES's work were not included in early AM efforts. There are a few reasons given for this by interviewees; the first is that the people who first learned about AM and decided to start experimenting with it were people who worked on sanitary and combined sewer system planning. Also, Engineering Services leadership was supportive of AM, and decisions around rehabilitation and construction of that system were all made in Engineering, while other of the bureau's systems would have needed support from a broader collection of leaders in the bureau, support which AM did not have at that time. Another reason is that there was the belief that because BES could run computer models of the functioning of the sanitary and combined sewer system, they could more easily determine risks of asset failure in that system. This last reason highlights how AM practice evolved in BES, the initial work was to perform highly technical and detailed engineering modeling for one of BES's systems. All of the tools and processes for doing AM at BES were initially developed for this one highly engineered type of infrastructure and were developed to a level that interviewees thought was more rigorous and mature than anywhere else in the country. BES started by going deep into implementing AM for one system well before any agreements were reached for a strategic big-picture framework that could apply to all of BES's work.

There were continual attempts over the years to expand AM to the wastewater treatment and stormwater systems, and to come up with an overall AM framework that could work bureauwide. BES documents from the last 20 years continually committed the bureau to fully incorporating AM into all aspects of the bureau's work. Interviewees expressed that this had not yet happened, that instead each of the bureau's systems had attempted to implement some aspects of an AM program on their own, without any common framework. This is demonstrated by how different parts of the bureau talk about the "Levels of Service" (LOS), a key concept in asset management. Those interviewees working on the sanitary and combined sewer system point to adoption of

LOS in 2012, and while they agree that the LOS should be updated and improved, they use the 2012 LOS for their work. Interviewees working on the wastewater treatment system point to permit requirements as their LOS and ignore the 2012 effort. Interviewees working on the stormwater system state that the 2012 LOS were never adopted by leadership because the proposed levels did not make any sense from a green infrastructure/stormwater perspective and that, instead, BES needs to begin a public-oriented process for determining what the first bureauwide levels of service should be. There is no agreement in BES on whether the 2012 LOS were ever adopted by leadership, let alone agreement on whether the bureau should be making decisions based on those levels of service. This demonstrates that BES does not have a consistent AM framework in place.

All BES interviewees agreed that implementation of AM in the bureau has been variable and siloed. The reason for this siloing has to do with perceptions of the usefulness and compatibility of the asset management system with BES’s work. Some believe that the fundamental tools of asset management are compatible with concepts that were not traditionally considered by water infrastructure organizations such as equity, resilience, and green infrastructure. These interviewees expressed that the computer models for the stormwater system need to be improved, and that bureau needs to determine what value in dollars should be put on green infrastructure assets and community and ecological risks in order for asset management of the stormwater system to proceed. For them, stormwater system planning is not yet mature enough for asset management. As one interviewee, who is not an engineer, said “for certain asset classes we haven’t applied it at all because it’s either been very difficult, we don’t know how for other assets and/or we don’t have the information.” For this interviewee, the failure to implement asset management to the stormwater system is due to a lack of information and knowledge. Others argue that the concepts and tools of asset management need to be fundamentally redesigned to work for BES’s green infrastructure, equity, and resilience work. They talk about adapting the asset management concepts, language, and tools; they see asset management, as it exists in the water sector today, as immature and lacking the sophistication needed for this newer type of work. One interviewee, who is not an engineer, said, “we want to build asset management for the future, not make it perfect by the measures of the past. So that means we need to adapt it.” A large part of this conversation is focused on moving from a focus on the assets to focusing on the services that are desired by the community. Other pieces include redefining what is meant by the word “asset” for the stormwater system since much of what makes the system work is not owned by the bureau, coming up with new procedures for prioritizing that do not rely on valuing in dollars, talking about both risks and opportunities instead of just risks, and expanding benefits of a project to include elements that are not directly related to the bureau’s mission.

There has been work in implementing asset management at BES for over 30 years, depending on when you consider the “start” to be. But there still is not agreement throughout the organization that AM is compatible with the bureau’s work, or a desirable program to implement. Official bureau documents continue to support the development of an asset management program (City of Portland Bureau of Environmental Services 2018; 2019a), but the bureau still lacks agreement on the fundamental elements of a program, or what actions need to be taken to move it forward.

Summary

The most obvious difference between the evolution of asset management in the two bureaus is the cohesiveness of the program at PWB as compared to BES. PWB interviewees all provided a similar origin story for asset management at the organization, BES interviewees did not. PWB interviewees all agreed that the bureau had a comprehensive asset management system, BES interviewees did not. PWB interviewees acknowledged struggles with including newer more complex considerations into the AM system, but felt that the path forward involved, for the most part, fitting their needs into the existing AM structure. At BES there was still a fundamental disagreement that AM was an appropriate system for including these newer considerations, and there was a movement among some employees to change some of the foundational concepts and practices of asset management.

Interviewees at both bureaus expressed that there was still much work to be done to realize the full benefits of a comprehensive asset management program and are continuing to work on implementation. The main difference is that at PWB this is seen as a logical, if slow, progression of program expansion over time, while at BES the path forward is still unclear and contested. The obvious question is: why the difference? There is likely more than one reason, as any two organizations will have different challenges and implementation stories. One major one, however, is that the Water Bureau has an engineering knowledge system as an overall framework to hold the organization together, a knowledge system that is compatible with asset management. Things are more complicated and contested at BES. That will be the focus of the next chapter.

Chapter 8 – ASSET MANAGEMENT AND BES'S KNOWLEDGE SYSTEMS

As outlined in Chapter 6, the Bureau of Environmental Services was originally a traditional engineering-based water organization. Through a combination of regulatory changes, cost pressures, and a leadership orientation toward trying more environmentally-beneficial technologies, BES started implementing green infrastructure for stormwater management in the 1990s (Brown, Ashley, and Farrelly 2011; McPhillips and Matsler 2018; Matsler 2019). To do this work, new professionals were hired into BES with a more ecological knowledge system. This set up a situation where the two knowledge systems outlined in Chapter 4, engineering and ecology/environmental science, were both represented in the organization. This chapter will examine how these knowledge systems have interacted at BES in influencing the adoption of asset management starting in the mid-2000s. The main differences between the engineering and ecological knowledge systems that will be important for this examination are differences in the orientation toward predictability versus dynamic systems, the separation of nature and humanity, monetization of nature's value, the scale at which to define problems, and finally the cohesiveness of the engineering profession versus the multifaceted nature of the ecological/environmental science knowledge system.

For this analysis there is an important point that must be kept in mind: People are not stereotypes. No individual can be characterized as having a fully engineering or ecological knowledge system. People belong to multiple social groups at the same time which all influence their thinking and the knowledge systems that they use (Bijker 1995). In the discussion below, I talk about people who have an engineering/traditional knowledge system or an ecological/environmental knowledge system based on their statements, their position at BES, and their professional background. As with all models, the categories are chosen because they can be useful, not because they are absolutely or objectively true (T. M. Porter 1996; Hacking 1999). I have used them because they help in understanding the social dynamics present at BES and reveal important aspects of how and why developing an asset management program at BES has been more complex and contested than at the Water Bureau.

Levels of Service: Predictability vs. Dynamic System Orientation

The first area where there was a clear difference in the orientation of BES's engineers and ecologically oriented employees was in their comfort with either predictability or dynamism. This was most evident in the ongoing struggle in BES to adopt clear goals for the work. In the asset management context, having defined "Levels of Service" are how organizational goals are defined and agreed upon. How various people in BES discussed attempts to produce and agree upon Levels of Service reveal differences in this orientation toward certainty within the organization.

Engineers, and traditional water managers, value predictability in their design work (Vincenti 1990; Bucciarelli 1994; Ajami, Thompson Jr, and Victor 2014; Tempels and Hartmann 2014; Ounanian et al. 2018). It is very important that infrastructure does what it is designed to do. An engineer can only know that the goals of a design have been achieved if those goals are clear. As outlined in Chapter 7, whether or not BES adopted Levels of Service (LOS) in 2012 is contested. Levels of Service are considered to be one of the foundational concepts of asset management (Amadi-Echendu et al. 2010; Marlow et al. 2013; Alegre and Coelho 2013; Grigg 2012; Pathirana, Heijer, and Sayers 2021). LOS is defined as "a statement of outputs or objectives that an organization or activity intends to deliver to customers and stakeholders" (American Water Works Association 2018, 23). The value of having clearly defined LOS was apparent and obvious to the engineers and traditionalists interviewed at BES. As one said in defining asset management, ". . . We need to figure out what level of service we want to have, and how to develop the tactics to get there, and how much it's going to cost, and then get the resources to do it." For people in the engineering knowledge system, simplifying the bureau's work into clear numeric Levels of Service and figuring out how to meet them was a logical way to approach the work. If the bureau could do that there would be predictability and certainty about success as an organization. In addition, those LOS should be numeric so that it was easy to determine if they had been met.

Individuals who have a more ecological knowledge system are more comfortable with the idea that goals could constantly shift, and that each activity is an experiment, to be used to refine those goals on a continuous basis (Nelkin 1977; Anderies, Janssen, and Ostrom 2004; Bocking 2004). For them, setting goals is a more dynamic, holistic, and iterative process, and deciding on a set of specific goals is more problematic unless they can change over time as the system shifts and as more is learned. People who had adopted a more ecological/environmental knowledge system were not as bought in to the idea of having simple numeric Levels of Service and predictability of risks and outcomes. The interviewees said that the LOS proposed for green infrastructure in 2012 did not make any sense and that they were problems with scale. Instead of using specific numbers for LOS, the environmental scientists in the bureau were using a watershed health index, which included four goals that were each multifaceted and rated on a sliding scale that included ranges for interpretations of quality (see Figure 8). The overall rating system could stay consistent while allowing for specific numeric targets for the various components of the metric to be adjusted. This is more consistent with an ecological knowledge system, where certainty of outcomes is not the goal. For them, the goals should adjust and change over time as more knowledge is gained and as conditions change. Working to achieve one simple, specific number (such as one concentration of a chemical in the water across all streams and rivers) does not make sense outside of the context of everything else happening in that water body. In addition, each location may have different needs based on the aquatic species using that water body and the environmental conditions of the area. The goals for individual projects were not to meet a single specific numeric target, but rather to advance over time along the scale toward the “properly functioning” end of the range. They expressed resentment and “PTSD” over the 2012 LOS effort, feeling like the engineers ignored their objections and tried to push through something that did not fit with the way they did their work. In addition, the people with an ecologically-based knowledge system objected to developing LOS without community input.

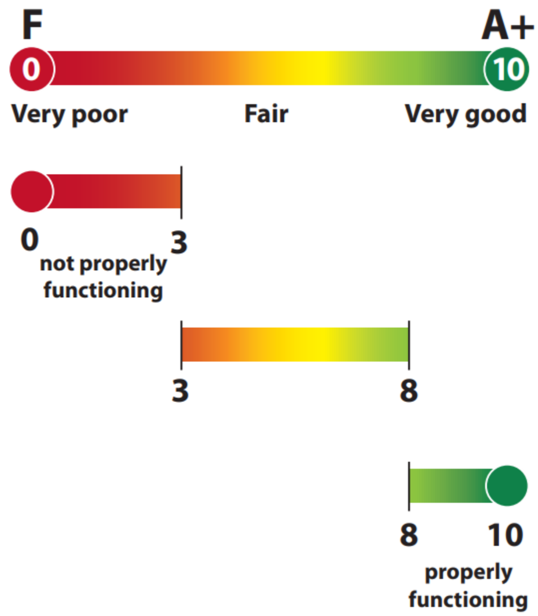

Figure 8: Watershed Health Index Rating Scales
(City of Portland Bureau of Environmental Services 2019b, 6)

For the interviewees with an engineering knowledge system orientation, the inability to fully embrace clear and numeric LOS did not make any sense. They recognized that it was more difficult to determine clear goals for green infrastructure, but having a specific defined goal was ingrained in their way of thinking about work. When talking about the difficulty of establishing clear goals for green infrastructure work one said, "what is required for us to do? What does our charter say we have to do? And it's very vague, we do watershed management, I think that, okay well what's good enough? What's good, what's not good? What's the level of service?" The engineering knowledge system is oriented toward predictability, and people oriented toward that system saw LOS as a way to gain certainty of success in intended outcomes.

The abandonment of the 2012 LOS effort shows that the engineering knowledge system was being challenged at BES. Some with an engineering knowledge system insisted that the LOS had been adopted, but the bureau as a whole did not use them outside a few isolated applications. However, bureau documents, including recent ones, consistently state that adopting Levels of Service is a necessary part of asset management. This shows that the ecologically-based knowledge system has not taken over in BES either. This difference in knowledge systems is still being negotiated and contested.

The Bureau's Mission: Humans Separate vs. Part of Nature

There is another element of the Level of Service discussion where there is disagreement in BES. That disagreement is about how broadly to look at the goals of the organization. As explained in Chapter 4, engineering is based in the idea that humans are separate from nature and controlling nature for the benefit of humanity is a core underlying function of engineering work (Noble 1979; Ferguson 1992). Ecology, while also founded to benefit humans, has an orientation that is more holistic, seeing nature and human health as being interlinked (Worster 1977; Bocking 2004; Kingsland 2005). In

BES this difference is not discussed explicitly. It is, however, an underlying factor in a disagreement about the ultimate purpose of the work the bureau performs.

For traditionalists at BES, and many with an engineering knowledge system, goals must align very closely with the narrow mission of the organization; they must tie directly to wastewater collection and treatment and stormwater management. Other benefits, such as saving fish species from extinction, are peripheral and outside the mission of the bureau. The focus for these employees is on specific services that are outlined in BES's charter, whether or not the community prioritizes those specific services. Any other community priorities, such as cleaner air or reduced summer temperatures from trees or an increase in livability of a neighborhood from the aesthetic benefits of green infrastructure, are outside the mission of the organization and should not be considered when planning projects or determining success. Some of the interviewees who were engineers felt BES had gone off track recently saying, "I actually looked at the strategic plan that was developed last year, and it seemed almost, I didn't see anything that says anything about public health, it kept talking about fish and then I just didn't see the people." For this employee, doing work to benefit fish was the opposite of doing work to benefit people.

Others, particularly those with an ecological or environmental science background, take a more expansive and holistic view of the purpose of BES. For these employees, environmental improvements are at the heart of BES's work. They talked about risks to endangered species and watershed health as being risks to BES fulfilling its mission to the community. Others talked about community needs being paramount, and wastewater and stormwater management being important only because they improve community livability. As one non-engineer said, “as we move into the future, we always see all of our infrastructure in service to the community and the community that we all want to live in.” They also talked about community input, and the community’s knowledge about, and relationship to, natural areas needing to be at the heart of the bureau’s prioritization processes. For ecologically oriented employees nature and people were inextricably linked, and therefore the bureau’s work and community priorities needed to be closely linked as well.

Interestingly, while there was a clear difference between the engineers and ecologically-oriented employees at BES overall, some of the engineers interviewed, people who otherwise expressed thoughts that were consistent with an engineering knowledge system, also talked about the importance of considering the wider community benefits of BES’s work. These employees were trying to determine how to reconcile the engineering focus on specific, mission-oriented LOS with how to bring community benefits, such as greater equity and a more resilient community, into decision processes. In this area a synergy has developed where elements of the engineering and ecological knowledge systems are coming together to create something new. However, it is unclear how much of this comes from the influence of the wider community in Portland, including City Council, that is focusing more effort on community priorities like equity, resilience, and livability. This will be discussed more in the section below focused on the Water Bureau.

Risk in Dollars: Monetization vs. Existence Value

Quantification is at the heart of an engineering knowledge system, and as outlined in Chapter 3, engineers will try to quantify even qualitative things such as feelings and impressions (Vincenti 1990). Quantification of the value of things in dollar terms, or monetization, is a part of this. Engineers view money as a neutral metric by which to measure and compare things (Dorfman 1978; T. M. Porter 1996; Sunstein 2005). Ecologists, on the other hand, have a more variable relationship with quantification, and a much more negative view of monetization of the value of nature. Some people operating under and ecological knowledge system work to quantify the values of nature, while others have argued against quantification of nature on moral and ethical grounds (Merchant 1980; Egerton 1985; Bocking 1997; 2004). It should come as no surprise, then, that quantification of the risks to BES and values of assets has been a point of contention at BES. Interviewees talked about this in the context of determining "risk in dollars" for BES's various assets and services.

More traditional water industry-oriented members of BES who have an engineering knowledge system view quantification of risk in dollars as essential to implementing an asset management program at the bureau. One interviewee said, "I believe that that's really the proper way to do asset management, to quantify your risk in dollars, for a lot of different reasons." Bureau documents also highlight that a mature asset management program puts risk into dollar terms so that different risks can be compared and ranked across the organization (City of Portland Bureau of Environmental Services 2013a; 2013b; 2021).

Some BES employees with an ecological knowledge system objected to quantifying risks to green infrastructure, watershed goals and community needs in dollars. As one non-engineer said, “There are purists who are concerned about following the rules . . . I don’t think you always had to have dollars . . . the framework is always just a reflection of your values, and you’re in charge.” There was also discussion in BES of asset management not valuing things in the right way, or in a way that made sense. Employees with an ecological knowledge system objected to the idea that dollars were a neutral metric with which to compare things.

At the time of the research, the bureau had a goal of quantifying all risks in dollars, but with a recognition that some types of values and services may never be adequately represented in dollar terms. Planning efforts during the 2000s and 2010s used other types of decision frameworks that did not rely on quantification, but they were always qualified to explain why dollars were not used for comparison, usually saying that it could not be done “yet.” However, a draft document from 2021 outlining the bureau’s asset management framework acknowledged some of the limitations and disadvantages to quantifying risks using dollars and explained that other ways to making planning decisions were also valid and could be useful to the bureau (City of Portland Bureau of Environmental Services 2021).

The conversations at BES around quantification of risk in dollars is a demonstration of an area where the engineering knowledge system still predominates. The bureau consistently says that the goal is to compare all risks in dollars. Other decision support tools are seen as inferior interim methods or substitutes for the more mature risk-in-dollar framework. There is some contestation of the quantification system in the bureau among ecologically-oriented employees on moral and ethical grounds, but at the time of this research that view was subordinated to those who valued quantification in dollar terms.

Focus on Assets and Asset Ownership: Boundaries vs. Holistic Watershed View

Another major topic that has been contested at BES is the question of whether the bureau should focus on assets that the bureau owns or on the services the bureau provides to the community. This is a question of the scale. Focusing on assets is consistent with an engineering knowledge system that sets clear boundaries around design process. All activities are concentrated on managing and controlling assets, everything else is considered an “input” from “outside” the system boundaries. Focusing on technology is a key aspect of the engineering knowledge system (Gandy 2003; Andersen 2018). The ecological knowledge system places more emphasis on looking holistically at how the non-human world interacts with human needs and activities (Bocking 2004). Focusing first on community priorities and then extrapolating how BES's work can help advance those priorities is more consistent with an ecological knowledge system than an engineering one. Ecology is less focused on setting boundaries.

The literature is not as clear about this being a significant difference between engineers and ecologists. Some scholars have noted that engineers, especially when engaged in a design process, need to draw clear boundaries around the work (Ferguson 1992; Bucciarelli 1994). But, needing to fit that design into the whole, making sure what you've designed within those boundaries fit into the real world around it, is also very important in engineering (Ferguson 1992; Madhavan 2016; Mukerji 2015; Vincenti 1990). Ecologists also work in both the larger scale and the smaller; the ecosystem scale is the primary focus, but much ecological work is performed in laboratories (Worster 1994; Bocking 1997; Li 2000; Kingsland 2005). The difference between engineers and ecologists is more subtle in the literature, but was clear in the interactions at BES. For example, one interviewee said, "and so this notion of restricting how you view things versus opening up how you view things, like that culture shift is still very much" a tension at BES between engineers and environmental scientists.

One theme among employees with an engineering orientation was a focus on the bureau's assets, particularly asset condition and what investments were needed to keep them functioning properly. These employees talked about the bureau's purpose as being stewards of the assets needed to fulfill the organization's mission. As one interviewee who is an engineer said about asset management, "it has a lot of emphasis on asset inventory and asset condition, and I think those are, kind of like, the groundwork of any asset management program." This is also why some interviewees, as mentioned in Chapter 7, considered the start of asset management in BES to be in the 1980s. As one interviewee said,

> if we are keeping track of what we have, and what it does, and what outcomes each asset produces, and how they work together in a system, and how much they're worth, and what kind of maintenance needs to be done to optimize performance and life expectancy, then you're engaging in asset management. You're managing assets and trying to lower your risk of failure and non-compliance.

And, as another interviewee said, "What are we doing that's specific and tangible within an asset management framework? How are we treating this as an asset and getting the outcomes we need?" For them, the title "asset management" means what the words literally say – managing assets.

Others in the bureau, those with an ecological orientation, begin with a focus on services. They see asset management as a program that might have started with a focus on assets, but that it is evolving to orient toward community needs. One interviewee stated that BES "made a pivot. Instead of looking at the assets per se, we've made a pivot towards saying, let's look at the services that BES, instead, offers and figure out do we fail in that service, rather than looking at the assets themselves." For these employees all potential solutions, even ones that do not involves assets at all, should be looked at in a holistic manner to determine what actions will be most effective in providing the services the community desires. In addition, it opens up the conversation to prioritizing BES's work to fulfil the more pressing community concerns, even if that does not align with the largest risks to wastewater collection and treatment and stormwater management, BES's specific mission. It also opens up the possibility of investments in non-asset solutions such as educational programs.

There is another asset-related controversy at BES around what can be defined as an "asset." One of the main challenges some engineers see in the bureau's stormwater management mission is that the bureau does not own all of the infrastructure needed to properly manage stormwater. This relates to the discussion above about scale and engineers setting boundaries while ecologists and environmental scientists look at watersheds more holistically. This ownership question is also connected to accounting standards and financial management, two professional orientations that have co-existed within engineering-dominated water organizations for a long time. Matsler (2019) outlines the difficulties of accounting for green infrastructure in asset management in Portland, noting that the issue of using utility funds for non-owned assets from an accounting and regulatory aspect have mostly been resolved as of 2010. I found, however, that the question of ownership, and the appropriateness of prioritizing work focused on things the bureau does not own, was still an important issue at BES.

For engineers who focus on the bureau's assets, defining what counts as an asset is very important. For interviewees with an engineering orientation, the bureau can only invest resources in something that is defined as an asset, and it is a big challenge to try to treat property that is owned by others as an asset. As one traditionally-oriented interviewee said, “I don't think we can worry about treating private assets as assets right now . . . I don't know why we would want to work so hard to tackle private assets, when we don't have a good asset inventory for the assets we do own.” While there was a temporal aspect to what this employee said, there was also an assertion that what the bureau owns was more important and needs to be a higher priority than what they didn’t own.

For ecologically-oriented employees, the system is the whole watershed, built and not, regardless of ownership. As explained in a 2019 BES report about the stormwater system,

> BES relies on thousands of private facilities within the stormwater network that are not owned or controlled by BES as formal assets. Further, Portland’s stormwater system depends on the management and expansion of the city’s tree canopy and natural areas that intercept rainfall, keeping it out of pipes and filtering it naturally. Finally, although they are not owned by the bureau, acres of wetlands and thousands of miles of natural streams and drainageways are a critical part of the stormwater conveyance network.

These employees see the landscape as a whole system that all needs to function together, and view BES’s mission as making sure the system works, regardless of ownership. They talk about where BES needs to invest resources to make the most impact. As one non-engineer said regarding how to overcome a definition of assets being only something the bureau owns, “by looking at services and community outcomes again, I think it breaks you out a little bit of some of those narrow definitions, because you kind of have to make it hold together and work. But we're kind of right at that point, right now, of exploration.” This employee was highlighting the ecological position that the whole system was more important than the ownership question, and that the bureau was still debating how to overcome this obstacle.

Questions around setting boundaries around the work versus holism is an area where contestation was continuing at the time of this research. Some interviewees talked about the bureau moving away from an asset focus toward services, but others kept the focus on the bureau’s assets. The question of how to define assets is still unresolved at BES, despite the official barriers being removed over ten years ago. This suggests these are cultural disagreements. In some cases people who are otherwise oriented toward an engineering point of view have been rethinking their assumptions about what to focus on in adopting asset management toward a more holistic approach, deemphasizing technology in a way that is moving toward an approach to the work that is more consistent with the ecological knowledge system. This highlights that the relationships between engineers and ecologically-oriented employees at BES are still changing, and that neither knowledge system is completely dominant.

Reinvention: Cohesiveness vs. Heterogeneity

In the discussion of the difference between the engineering and ecological knowledge systems in Chapter 4 one of the most striking aspects was the heterogeneity of ecology compared to engineering. From the beginning, contestation of the profession's basic assumptions has permeated the profession of ecology. Historians of ecology have described it as "a remarkably heterogeneous discipline" (Bocking 1997, 5) where the basic underlying assumptions and orientations have remained contested throughout its evolution as a profession (Bocking 1997; 2004; Kingsland 2005). Engineering, on the other hand, is based in some consistent underlying assumptions about the world. Engineering practice has changed and evolved over time, but it has not had a similar history of questioning its own basic underlying principles (Vincenti 1990; Bucciarelli 1994; Madhavan 2016). Thus, the continuing contestation of some of the basic foundational principles of asset management is perhaps the most significant indicator that BES no longer has a fully engineering-oriented knowledge system.

Some employees at BES who came from a more traditional water industry or engineering background expressed a desire to develop an asset management system that was consistent with industry standards and could be used consistently for all bureau work. Being able to compare across the bureau's categories of work was the goal of establishing an asset management system for these employees. Early asset management efforts used benchmarking against what was done at other water utilities to determine what BES needed to do. This was described as trying to increase the maturity of BES's asset management system. These employees talked about bringing green infrastructure "into asset management" and resisted altering language or practices to better fit the different attributes of green infrastructure, such as the ownership differences discussed above. This point of view was still common in BES during the time of the research, but it was being countered with a different narrative, one that acknowledged the value of moving away from what others had done.

The counter-narrative at BES endorsed a more heterogeneous way of looking at the work, arguing that the way asset management was done at other water utilities may not work for BES. Looking at different types of BES's work differently was also highlighted by some interviewees, such as one who said in talking about green infrastructure, "But you can't just apply the same measures that you did on the pipe side. You had to be able to look at it differently, and measure it differently, apply a different kind of matrix." In addition, there was a willingness to question the basic assumptions of asset management that had been developed at other water utilities. One non-engineer said,

> I think every discipline should also question its own, sort of, expertise and wisdom. I think asset management should do the same. That's why, when I speak about building an asset management of the future, we should always be willing to pause and say, like, I think equity is an important challenge that we need to use the tools and the approach of asset management, but be quick to identify the shortcomings and fix them, not persist them.

As discussed above, this orientation toward questioning the assumptions of one's profession is a theme that runs through the history of ecology, but not engineering.

Comparison to the Portland Water Bureau

The analysis in this chapter has concentrated on one of the case studies examined in this research. This is because, as discussed in Chapter 7, BES's asset management program development has been more contested than the Water Bureau's. Before getting more specifically into how AM was implemented at the Water Bureau in comparison to BES, it is important to recognize that the two bureaus did interact and, on some level, coordinate with each other and other city infrastructure bureaus on their asset management work. A group called the City-wide Asset Managers Group (CAMG) was formed in the 2000s for this coordination (City Asset Managers Group 2016; Matsler 2017). However, interviewees expressed that the CAMG mostly focused on putting together an asset inventory for the city and designing consistent communications to City Council. They did not feel that the existence of the CAMG created consistency in implementation of AM across the different bureaus. Rather, bureaus had a lot of autonomy in how their AM programs evolved.

As outlined in Chapter 6, the organizational culture of the Water Bureau is based in an engineering-oriented knowledge system and is therefore more aligned with a traditional water industry orientation. Having a more consistent knowledge system dominating an organization does not mean implementing new programs is easy. The Water Bureau has also had challenges in implementing asset management. This section will outline PWB's development of asset management using the lens of the five sections discussed above. This comparison helps support the main argument of this chapter, that BES no longer has an engineering-dominated knowledge system, by showing the differences in implementation that happened at PWB, which is still engineering dominated.

The Water Bureau's Levels of Service (called "Key Service Indicators") were adopted in 2008, soon after the asset management program was chartered in the bureau. Interviewees described their adoption as a fairly straightforward process where the bureau looked at what was begin done at other water utilities, discussed them internally, adjusted them to meet PWB's needs, and adopted them. Interviewees noted that the Levels of Service needed to be re-examined, new considerations such as equity and climate included, and adjustments made to make them more useful. But there was no contestation of the appropriateness of having specific numeric goals with which to judge the success of the organization. Rather, the conversations focused on whether the goals were set at the appropriate level and included all the appropriate types of goals. The orientation to predictability was not contested at PWB.

The Water Bureau is also having conversations about community benefits and how to include them in the work of the bureau. As mentioned above, Portland government as a whole has placed increased focus on issues such as equity, resilience, and livability over the last several years. One example of this is the creation of the Office of Equity and Human Rights in 2011 (O. of E. and H. R. City of Portland n.d.). The non-engineers who were hired to lead the work in these areas, however, expressed that they felt that engineers in the Water Bureau were struggling with trying to find very clear connections between the bureau's mission and community benefits. They felt a clear connection was needed in order to work on them. The engineers wanted to fit things like equity and climate change into the existing engineering-based decision systems. However, this is changing. As one engineer said, "until a year or two ago I don't think we really saw people as the outcome, we only saw clean water as the outcome." This shows that the political environment in Portland is at least part of the reason why both BES and the Water Bureau are having conversations about taking community benefits, beyond the missions of the bureaus, into account.

Conversations around quantification of risk at the Water Bureau provides an interesting contrast to what happened at BES. PWB uses a matrix to determine risks to the bureau or the bureau's assets (Figure 9). For many risks, there are dollar amounts

Likelihood	**Consequences**				
	1 Very low	**2 Low**	**3 Moderate**	**4 High**	**5 Very high**
Very low (1)	VL	VL	L	M	M
Low (2)	VL	VL	M	M	H
Moderate (3)	L	L	H	H	E
High (4)	L	M	H	E	E
Very high (5)	L	M	H	E	E

Key
E = extreme
H = high
M = medium
L = low
VL = very low

Figure 9: PWB's Consequence and Likelihood Risk Matrix
(Portland Water Bureau 2013, 10)

assigned to the consequence, but it is not necessary to have “risk in dollars” under PWB’s system. This was not highlighted as a problem by PWB interviewees. Employees talked about issues they had with the results of the risk analyses, especially about what they thought about the results and whether or not the correct risks were being addressed first, but there is no movement either toward or away from a more rigorous monetary-based approach to risk determination. If quantification is so important in an engineering knowledge system, why is PWB comfortable with less rigorous quantification? I believe this is because the Water Bureau came up with a system early on in their development of asset management that allowed the bureau to move forward. Because everyone is using the same engineering-based assumptions in determining which events have higher or lower consequences there is no need to strictly impose a neutral, objective quantitative system into the process. Theodore Porter (1996) explains that the need for explicit and quantitative decision processes does not arise within disciplines, but rather from the pressure from outsiders to justify decisions. He explains in the book *Trust in Numbers* that quantification is necessary when trust is absent, stating “reliance on numbers and quantitative manipulation minimizes the need for intimate knowledge and personal trust” (1996, ix). If this was true at PWB, why do BES’s engineering insist in quantification of risk in dollars? I interpret the focus of the engineers in BES on quantitative, monetized risk determinations as stemming from a lack of trust that is based on the different underlying assumptions from ecological and engineering knowledge systems.

Differences in underlying values and assumptions pushes BES toward more objective and measurable decision criteria, a situation that does not exist in PWB, which allows for acceptance of a risk analysis that involves more subjective judgment.

The Water Bureau's asset management program focuses chiefly on their assets, following the engineering knowledge system's focus on technology and clear boundaries. The bureau has put together twenty-two Asset Management Plans (AMPs), one for each type of asset. For example, there is an AMP for fire hydrants and another one for storage tanks. Interviewees stated that projects were prioritized within the bureau using the AMPs, and that the AMPs were one of the most advanced elements of PWB's asset management program. There were some interviewees in the bureau who expressed frustration with the focus on asset classes, as one said, "those twenty-two are individual siloes, there's nothing looking at all of them as a system." This was, however, pushing back against relying on separate AMPs, not on focusing on assets. Instead, the focus on assets was seen as a way to bring the major work groups of the bureau together around a common framework. One interviewee said,

> in 2017 they had over twenty asset management plans written. And that was another big thing that started to drive, started to link what happens in operations and maintenance and construction and engineering is all really knit together at the end of the day, because all of us have a part of the life cycle process that we have in our technical disciplines, but it's the AMP ties it all together

The only interviewees that expressed any dissatisfaction with the focus on assets were members of the more marginalized teams in the bureau who worked on newer issues such as climate change and equity. Those employees talked about how to bring more focus on people and community into the bureau, but there was a recognition that they would be more successful doing that if they worked with the current asset management system as it existed rather than trying to challenge the underlying assumptions and design of the system. This is another area where the dominance of PWB's engineering knowledge system was evident. In addition, there is no ongoing conversation about ownership of assets. The bureau focuses on asset it owns, without contestation.

Finally, PWB's asset management program was designed along standard industry practices. The contestations and challenges to the underlying assumptions to asset management did not arise in interviews with employees at the Water Bureau. They were proud to be a water industry leader in asset management, having a program that was in some ways more developed, but not different from other water organizations. Some of the interviewees talked about upcoming participation in another benchmarking study so that the bureau would know how they measured up to others in the water industry. When asked if they thought they had to change or adapt asset management to meet their needs, they said that adaptations were always necessary to a certain extent, but that asset management was fundamentally compatible with the bureau's work and building out the system was the priority. Asset management as it is practiced in the US today is compatible with an engineering knowledge system, so implementing it has been fairly straightforward, though not simple, for PWB, unlike for BES where it has been challenged and contested.

Interestingly, even non-engineer interviewees expressed that because the Water Bureau agreed to operate within the AM framework, some types of subsequent innovations were easier. This is consistent with Madhavan's (2016) finding that engineers are comfortable with trying new ideas within the context of the familiar, and that they innovate within the existing paradigm. One example that was highlighted was the recent work on PWB's Supply System Master Plan. For that plan, instead of using a traditional deterministic approach where specific system improvements were listed in the plan, they took a more flexible scenario-based approach. The plan includes "contingent solutions" that are discussed each year (Jacobs Engineering Group Inc. 2021). This is not a traditional engineering way of doing things, but interviewees felt that having agreement about using the engineering-based asset management framework allowed them to innovate around the edges to start pushing for more creative thinking.

Summary

The introduction of new types of professions into BES in the 1990s has resulted in contestations and conflict. Because of the timing of its introduction into the bureau approximately ten years after the introduction of green infrastructure, and at about the same time that the employees working on green infrastructure were starting to move out of a niche environment, the adoption and evolution of asset management in BES highlights this conflict. The main differences between the two knowledge systems used in this analysis can be seen in Table 4. This is not to say that BES should be looked at as a field of battle where two competing armies, engineers and ecologists, face off in opposition. While some in BES have felt there was an "us versus them" attitude among staff, others felt that everyone was working toward the same goals, and that conflict was due to misunderstandings and the difficulties inherent in change.

Engineering	**Applied Ecology/Environmental Science**
Predictability is very important; want certainty of goals	Dynamic system: changing conditions require changing goals
Separation of People & Nature: control of nature	Humans are part of nature, but history of working to benefit humanity
Quantify everything; monetization is unproblematic, helps compare things	Also value quantification, but allow exceptions. Nature has existence value: it is immoral to value nature in dollars.
Primarily Project and Asset Scale: then fit into larger world. Clear boundaries are important	Watershed/Ecosystem Scale: individual projects only make sense within a holistic framework
Consistent Knowledge System: PE certification	Heterogeneous Knowledge System: multitude of disciplines and orientations

Table 4: Highlighted Differences Between Engineering and Applied Ecology/Environmental Science Knowledge Systems

For some of the engineers in BES, asset management provided a framework for bringing the green infrastructure work up to proper (i.e., engineering) standards. For them, the challenges the bureau faced in implementing green infrastructure was mainly because the ecologically-oriented employees did not understand how to do things the "right" way, and needed help to get there. For these employees asset management was a tool that could be used to uphold the supremacy of the engineering knowledge system in BES. They tended to see asset management as a rigid system with rules that must be followed. One engineer said of green infrastructure work, "they need to be more part of our business stream, they need to be taken more seriously, all of those other categories of work, and brought up to the same level of maturity, frankly." This was not because they thought green infrastructure work was less important or incompatible with the bureau's other work, but rather that they believed bringing green infrastructure decisions into a more engineering-oriented asset management system would help the ecologists be successful at BES. They talked about asset management providing "common ground" and being "foundational" for decision making.

On the other hand, there were employees at BES who viewed asset management as a way to move away from strict engineering-based decision making. They talked about the flexibility of the asset management framework and insisted that it did not have to be based in engineering principles, but rather was agnostic in its knowledge system. For them, the different ideas and orientations of the engineers and ecologists in BES provided the opportunity to create something new, something better than a strictly engineering-based decision process. One engineer said,

> I do think that our diversity of assets and our diversity of professionals and subject matter experts to inform on the investment and management and value of those assets certainly has brought a more robust way of looking at asset management, hands down.

Another ecologically-oriented employee summed it up very nicely, describing how the contestations within BES between engineers and ecologists/environmental scientists around asset management are creating a new and innovative system that could be a model for the water industry,

> It's not an either-or thing. A bunch of us are very comfortable with the notion of integrating the two, recognizing that there are shortcomings in doing that, but Portland being Portland, we are in a perfect position to, kind of, change and evolve asset management from a natural infrastructure perspective or a watershed approach.

At the time of this research the bureau was slowly moving forward with creating a new, more heterogeneous asset management approach that combined elements of the engineering and ecological approaches, though key elements were still being contested.

In short, the continuing contestations at BES over concepts in asset management and how to implement and adapt them to BES's needs shows that the ecological knowledge system at BES is no longer contained within a niche. The engineering knowledge system has not been replaced, but rather is being supplemented. In some ways the two knowledge systems are competing for influence; but another way to look at is that the two complement each other, and in the process a new, more heterogenous knowledge system is being produced. The evolution of asset management highlights this.

Chapter 9 - CONCLUSION

This final chapter finally brings us back to the research questions asked in Chapter 1: R1. How does external pressure to innovate change an infrastructure organization's culture? R2. How does external pressure to innovate change what expertise is valued in an infrastructure organization? and R3. How do changes in an organization's culture and expertise interact to change the internal willingness to innovate? After engaging with these questions in the context of the two case studies, a discussion of what this means more broadly for understanding the interactions between innovation, organizational culture, and expertise is presented. Following this are a discussion of potential future research in this area, some thoughts about what organizations that want to innovate more can do, and what this all means for tackling the wicked problems highlighted at the beginning of Chapter 1.

Chapter 8 outlined how the two knowledge systems present in BES after the adoption of green infrastructure, ecology/environmental science and engineering, have been interacting and negotiating a new organizational culture and more heterogeneous knowledge system at the organization. In contrast, the Water Bureau has a relatively stable engineering knowledge system. That chapter explained, in short, that PWB's implementation of asset management was more straightforward because there were not the same contestations and negotiations that were necessary at BES. Below is a more specific discussion about what this means for our understanding of the interactions between innovation, culture, and expertise.

Research Questions 1 & 2: External Pressure, Expertise, and Culture

As discussed in Chapters 2 and 3, pressures in the water sector to innovate come from multiple different places. To explore the questions of how external pressures to innovate change what expertise is valued in organizations and how it changes an organization's culture, this section will step through the two innovations discussed in the case studies. The decision to initiate implementation of green infrastructure at BES was mostly due to external pressures from changing regulations and public attitudes toward nature in the city, as well as costs, as outlined in Chapters 2 and 6 (Lach, Rayner, and Ingram 2005; Brown and Farrelly 2009; Karvonen 2011; Lachmund 2013). Asset management, on the other hand, was initiated due to a combination of external and internal pressures at both BES and PWB, as outlined in Chapter 7.

At BES, in the 1990s the external pressures to change how stormwater was managed caused leaders to look for different solutions, and after green infrastructure was chosen, new experts were brought into the organization. Interviewees who were around at that time said that they welcomed this new expertise because they realized that they did not have the knowledge needed to design and manage vegetated facilities. In the case of BES, the external pressure to innovate made new types of knowledge necessary, and more diversity of professions followed the decision to innovate. That is the simple answer to the first research question. But it is not the whole story. While the technical knowledge about vegetation and ecosystems was welcomed, that did not mean that all the other less explicit aspects of the culture and knowledge systems of ecologists and environmental scientists were welcomed with open arms.

The more ecologically oriented interviewees who joined BES during the 1990s and early 2000s described the bureau as still being very engineering oriented. Interviewees also described an oppositional mentality at that time between some engineering and ecologically oriented employees. The ecological expertise was welcomed as long as it stayed in its niche and did not try to influence the engineering-dominated processes and decision structures at BES. This is not surprising, since niches exist as protected spaces (Rip and Kemp 1998). That protection can operate both ways, where the niche itself is protected from the expectations and limitations of the larger organization, and the larger organization is protected from the experimentation and changes occurring inside the niche. Scholars have found this resistance to change in the larger organization or regime to be the largest challenge to expanding beyond a niche environment (Kemp, Schot, and Hoogma 1998; Berkhout, Smith, and Stirling 2004). By the mid-2000s, BES employees valued varying types of expertise, but the dominant organizational culture had not appreciably changed; it was still dominated by the engineering view of the world. This was the situation when asset management first came into BES.

The drivers for introducing asset management into both BES and the Water Bureau were partially external and partially internal. Chapter 7 outlines the events surrounding the decision to start implementing asset management at both bureaus. The reasons are similar: both bureaus had heard about this system at conferences and from others in the water industry, and both were facing internal funding pressures that pushed them to more critically examine their operations. Asset management is interdisciplinary, but the disciplines involved, engineering, management, utility operations, and finance, already existed in both bureaus previously and were oriented around a dominant engineering knowledge system (Amadi-Echendu et al. 2010; Marlow, Beale, and Burn 2010; Grigg 2012). Thus, implementation of this innovation by itself did not change how expertise was valued at either bureau, if it had then the culture change would have been seen at both bureaus.

An analysis of how the implementation of asset management at BES revealed the changes in culture related to expertise and the engineering and ecological/environmental science knowledge systems is presented in Chapter 8. I argue in that chapter that the culture of BES has changed. The engineering knowledge system is no longer dominant. It is being replaced by a more heterogeneous knowledge system that blends engineering and ecological world views. This, however, leads to a "chicken and egg" question. Did the pre-existing presence of the two knowledge systems alter the culture and influence implementation of asset management at BES, or did the implementation of asset management provide the catalyst for the conversations and contestations necessary for culture change that would otherwise not have happened on the same timeline?

Figure 10 shows a rough visualization of what happened with BES's knowledge systems over time. Before the introduction of green infrastructure the engineering knowledge system was firmly in place in the bureau. Even then, this was not a solid, homogenous knowledge system, indicated by the blurry and not quite straight nature of the line in Figure 10. Once green infrastructure was introduced, the ecological/environmental science knowledge system appeared, but there were few linkages between the two. After asset management was introduced, and green infrastructure was no longer confined to a niche, the connections increased so that today there is a broader, more expansive knowledge system in the bureau that includes both the engineering and ecological/environmental science knowledge systems.

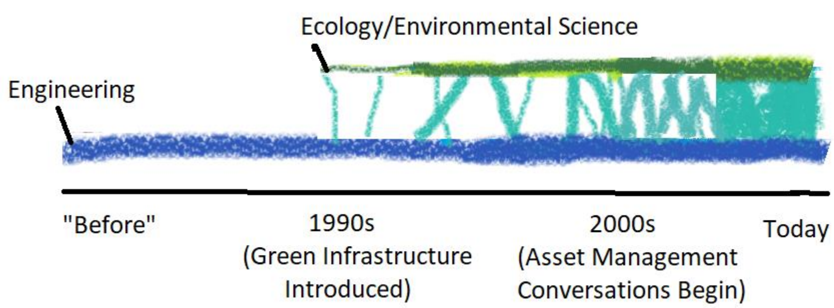

Figure 10: BES's Changing Knowledge System

Looking to implementation of asset management at the Water Bureau might help answer the question of whether asset management, and the questions it highlights, spurs cultural change. The Water Bureau has implemented asset management without moving away from their primarily engineering-based cultural orientation. Asset management alone, and the conversations and decisions necessary to implement it, are not by themselves a cause of culture change related to expertise. The culture change occurring at BES is certainly a function of the diversity of professions that have existed there since before asset management was introduced. This does not, however, fully answer the question of whether the culture changes would have happened at BES without asset management implementation activities helping structure conversations. We do not have a third case to use for comparison for this question. The data, however, does point to the specific questions and conversations that were necessary for asset management implementation influencing how the two knowledge systems have been interacting with each other over the last two decades.

The questions that must be asked to establish an asset management program intersect with the fundamental differences between ecologists and engineers. For example, to implement asset management an organization must ask itself what are the greatest risks faced by that organization, and what are the goals of the organization. These types of questions forced the bureau to have conversations about what was important to the organization, how the work should be valued, whether to focus on assets or the community, and what was the bureau's tolerance for inconsistency across various types of work. These were the values at the heart of disagreements about implementing an asset management program at BES. and how much adaptation was necessary for it to work for BES's needs. But, in this process at BES those fundamental differences in values were often not discussed openly. Asset management did not surface the fundamental disagreements between ecologists and engineers in a way that allowed those values to explicitly reveal themselves and be intentionally confronted. Implementation of asset management began twenty years before the time of this research, and many of these concepts were still being contested. On the other hand, BES has come a long way and is now answering these fundamental questions about the work in a different way than they would have before bringing in ecologists and environmental scientists.

Research Question 3: Willingness to Innovate

Both the Bureau of Environmental Services and the Portland Water Bureau were willing to adopt asset management and started implementation of asset management as a program at about the same time. This was a relatively straightforward, but still lengthy, process for the Water Bureau. As outlined in Chapter 7, after testing the asset management methodology on the fire hydrant program, the Water Bureau had most of the foundational pieces in place within the first five years. Work since then has focused on expanding the program into all of the bureau's twenty-two asset classes, refining and improving processes, and moving into new non-asset related areas, such as financial planning and equity. There are challenges with the program, and it has evolved over time, but it is still focused on building out elements, rather than challenging any of the fundamental assumptions of “engineering asset management,” as it is sometimes called in the literature.

Implementation at the Bureau of Environmental Services, as outlined in Chapters 7 and 8, has been more complicated. In a sense, BES’s multiple types of expertise made them less willing to adopt this particular innovation. Although the bureau consistently committed to implementing asset management, interviewees agreed that it was only actually being used at a few places within BES at the time of the research. The goal of the bureau, however, is still to implement asset management throughout the organization and a new Asset Manager was hired recently with the charge of putting the fundamental pieces in place within the next few years. Interestingly, this person is not an engineer, something that surprised interviewees who were familiar with asset management in the water sector.

Another question that is related to research question three is: How do changes in an organization’s culture and expertise interact to change the internal willingness to reinvent or adapt an innovation? As mentioned in Chapter 3, in innovation theory reinvention is a process by which innovations are changed as they are adopted by new actors (McLoughlin, Badham, and Couchman 2000; Rogers 2003). The more straightforward adoption of asset management at the Water Bureau can be attributed, at least in part, to the compatibility of the innovation with existing processes and expertise at the organization. Because BES no longer had a traditional engineering-based knowledge system, however, asset management was not as compatible with the organization's culture. This made adoption more problematic. The innovation literature indicates that this can be a barrier to, or slow down, adoption (Rogers 2003; Wisdom et al. 2014; de Vries, Bekkers, and Tummers 2016). The research into BES confirms that adoption is slowed by this lower compatibility of the innovation with the organization. It also shows that reinvention is facilitated by the presence of a diversity of expertise. Interviewee language about adapting AM highlights that BES is engaging in a process of reinvention.

Also raised by this research is a question about the relationship between process innovation and product/technology innovation. At BES, a technological innovation, green infrastructure, led to the hiring of employees with new types of expertise, which then facilitated organizational change. This impacted the adoption and adaptation of a process innovation, asset management. So far, there is no indication that the conversations and work that have gone into asset management at BES has caused further innovations in the physical infrastructure that is being built. One interviewee expressed frustration with the pace of technological innovation at BES in the last twenty years. When asked about innovation at BES they said,

> I think we think of ourselves as innovative in process. I think that has not yet translated into innovation on the ground. So, whereas before we weren't innovative on process, but we were innovative in solutions and on the ground stuff . . . the pendulum has swung and now, with this notion of asset management, expanding it . . . to incorporate watershed work, that is an innovative process piece. But we're not seeing any changes, and in fact we're seeing some pretty significant stepping back with our on the ground investments.

Other interviewees agreed that BES was more innovative and experimental with green infrastructure in the 1990s and early 2000s. This corresponds with the time green infrastructure was done in a niche at BES. Future research into whether BES's process innovations with asset management translates into technology innovation could help answer this question.

In summary, for the case studies examined in this research the relationships between organizational culture, innovation, and expertise are complex. Rather than being a relatively linear process, as suggested by the literature (see Figure 1) where diversity of expertise is a necessary precondition to innovation, this study shows a more dynamic process at work (Figure 11).

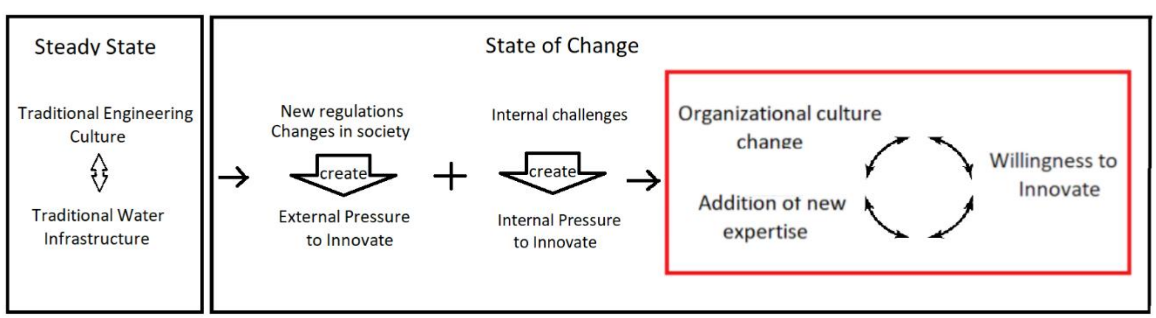

Figure 11: Revised Conceptual Model of Water Industry Innovation

A More Complex Understanding of Innovation, Organizational Culture, and Expertise

The sections above examine how innovation, organizational culture, and expertise interacted at the case study organizations. This section will explore what that means for our understanding of innovation, organizational culture, and expertise in general. To do this, we first go back to the summary of innovation and organizational culture literature in Chapter 3 which highlighted several aspects. First is an examination of the interactions between the characteristics of innovative organizations and the characteristics of the innovation. Next, is an exploration of how the degree of innovativeness and the organizational culture's orientation toward expertise interact.

In Rogers' Diffusion of Innovation theory more innovative organizations are decentralized, less formalized, more complex (including having many types of expertise), interconnected, have available resources, and are larger. Rogers (2003) acknowledged that these are tendencies and not absolute, and sometimes their influence on innovation changes as an innovation moves through the various phases from knowledge to confirmation. However, the theory does place organizations on a spectrum from least to most innovative without regard to the innovation in question. Rogers separately outlines attributes of an innovation that will increase its chances of adoption. As outlined in Chapter 3, these include its perceived advantage to the organization, trialability, observability, compatibility, and the complexity of the innovation. There is an acknowledgement that a particular innovation may be more easily adopted by some organizations than others, but there is not a similar recognition that an organization may be more or less innovative depending on the innovation in question. There is a lot of literature that talks about the innovativeness of organizations as though it is an essential characteristic of the organization regardless of the innovation itself. My research suggests that the question of whether an organization is innovative or not cannot be answered in general, but must be answered in the context of a particular innovation. This research could, at least partially, answer the question raised by Kiparsky et al (2016) that found water managers had a skewed perception of their own innovativeness. These managers may be expressing that their organization will innovate under the right conditions while ignoring that they are less willing to innovate under other conditions or regarding other types of innovations. That innovativeness is not a simple concept is not entirely novel, as the complexities of innovation in organizations has been acknowledged by others (Zaltman, Duncan, and Holbek 1973; Davis 2018), but most of the literature has either focused on what makes an organization innovative or what makes an innovation easy to adopt. There is relatively little on how the two interact and influence each other. This research shows that understanding those interactions is an important element of understanding innovation in organizations.

This research also found a complex interaction between the degrees of innovativeness and expertise. Innovation scholars have linked creativity and inventiveness with diversity of knowledge systems and skills (West 2002; Rogers 2003).

That was seen in this study as well, as BES's implementation of asset management involved more reinvention than at PWB. The push and pull of negotiating decisions and activities in an organization with multiple knowledge systems leading to more innovation is not surprising. But this study also found that having a less heterogeneous knowledge system can also facilitate innovativeness in some cases. With an agreed-upon decision making structure, an organization has less conflict and can sometimes take chances within that structure. For example, PWB's innovative Supply System Master Plan mentioned in Chapter 8 was highlighted by interviewees as an example of what could be done while operating within the engineering knowledge system's confines rather than rebelling against it. In some cases, organizations may be more willing to take chances within a familiar knowledge system and understanding where opportunities for innovation exist within that space. The question remains: can the wicked problems that society faces be solved if we stick to innovations that can be implemented within the traditional knowledge systems of infrastructure organizations? The fact that water and other infrastructure organizations are not currently solving these problems suggests that sticking to these relatively compatible innovations will not be enough.

This research has shown that bringing in new types of expertise to an organization can change the overall organizational culture, but that it can take a long time. Organizational cultures exist because they work for the people and for organizational goals (Schein 1984; Alvesson 2012), but organizational cultures can and do change for many reasons (DiMaggio and Powell 1983; Schein 1984; Gersick 1991; Alvesson 2012). Although adding new types of expertise will change the culture, it does not guarantee a change in the culture's innovativeness or acceptance of differences. Decision structures and, especially for infrastructure organizations, the physical assets being managed by the organization, can influence how much and how quickly the culture changes. For example, this research found that BES's overall orientation toward engineering knowledge systems did not change when the green infrastructure work was contained in a niche. What this suggests is that decision processes need to be critically examined, with participation by the new experts, in order for the overall culture to begin to change. It is not, however, a quick process.

Qualitative case study research is not suited to making broad generalizations (Maxwell 1994). However, this section did highlight some elements of the research findings that can likely be extended beyond the specific case studies examined. Theories about innovation in the water sector, and organizations more generally, has focused on trying to isolate important elements in order to understand what was happening. This is all part of the scientific process, discussed in Chapter 4 as reductionism. But it is equally important to put those pieces back together to understand the whole. This study has attempted to do that. The main lesson has been, therefore, that the interaction of these elements is complex. As noted above, determining the innovativeness of an organization should not be done while ignoring the specific innovation being discussed. The relationship between degree of innovation and types of expertise available in an organization is complex without a clear, universally-applicable answer. And, organizational change is not a single process, but a series of negotiations without a clear outcome. All of these show that in the study of organizational innovation there are no simple or universal answers.

Research Recommendations

There are several areas where more research could help shed light on the topics explored here. One is for there to be more empirical case studies looking into the interactions between organizational culture, innovation, and expertise. As outlined above, there is a complexity in the interactions of the three main variables. This study only looks at two organizations in the context of implementing asset management programs. Other organizations and other innovations could highlight different dynamics and lead to a richer understanding of how these interact. Research that looked at other process innovations that spur conversations about values and decision making could be particularly fruitful. Another area to look at in more depth is the different between compatible and more radical innovations and what that means for solving wicked problems in an industry.

The question of process innovation versus “on the ground” innovation was highlighted by some interviewees in this study. At BES they were seen by interviewees as being in some ways in opposition to each other. Tidd et al (2005) cite four types of innovations: product, process, position, or paradigm innovation. More research on how different types of innovations interact within organizations could be another interesting area of research. Do some types of innovation foster others? Do some types make others harder to implement? What are the implications of attempting to implement different types of innovations sequentially or simultaneously? A better understanding of the answers to these questions would be useful for organizations.

Finally, further research into how to more quickly integrate a new professional knowledge system into an existing organization could help move the water industry, and other organizations, forward. There are other types of diversity in organizations, looking at how the tools used for racial, gender, and other types of diversity could be applied to an organization with a diversity of professional knowledge systems could be a fruitful area for future research. Similarly, the concept of intellectual humility (Whitcomb et al. 2017; Krumrei-Mancuso et al. 2020) is a relative new area of research that is being mostly conducted in the educational field. Future research into the value of intellectual humility and how to foster it in organizations could help organizations with diverse types of expertise.

Recommendations for Water and Infrastructure Organizations

For organizations looking to be more innovative there is no simple formula to apply. Some organizations with a more singular and stable culture will be more likely to implement compatible innovations. Others may need to diversify their knowledge systems to be more receptive to innovations. What a specific organization should do will depend on their specific circumstances and the barriers they have to innovation. An important question for an organization to ask themselves is: are compatible innovations going to get your organization where you want to go? If not, you may need to diversify your expertise. For those whose knowledge systems are preventing them from innovating in the ways desired, establishing a niche within the organization may be a good first step. But, after that, what can organizations do to successful integrate new types of knowledge systems into their organizations?

As mentioned in the section above, looking to what organizations are doing in the field of diversity, equity, and inclusion may be helpful for organizations with professional diversity. My experience with these types of programs is that they help organizations question some of their basic assumptions about workplace culture and how employees are treated. In examining language that is used and the assumptions behind decision processes, as well as the results of decisions on the community, the underlying values can be revealed, and employees could establish a culture that is more welcoming and inclusive for all.

In more concrete terms, if an organization is finding that interactions between different types of professionals are contentious and unproductive, looking to negotiation theory may help. The main principle of this theory is to get the parties to focus on values rather than positions (Fisher, Ury, and Patton 1987). According to scholars, often the main problems when people of different cultures negotiate is a misunderstanding due to differences in how language is used (Diamond 2010). Diamond (2010) recommends using a cultural mediator to translate between the participants, if possible. Different professions use language in different ways, and the lack of a shared language not only increases misunderstandings but is also bad for innovation (Edmondson and Harvey 2018). Just assuming employees will figure it out on their own may not work, especially if the employees do not understand the differences in assumptions and approaches due to professional differences that may be at the heart of their disagreement. Having people within your organization who can act as facilitators and translators can be beneficial.

Water industry organizations with Engineers and Ecologists/Environmental Scientists should discuss the primary differences between the two knowledge systems, as outlined in Table 4. Each of those fundamental differences in the focus of people who have been trained in each of the knowledge systems is likely to cause friction in an organization trying to integrate the two. For example, the differences in understanding of the concept of certainty can cause ongoing disagreements in determining the goals of a project, and whether a completed project was successful. Because engineers are less comfortable with ontological uncertainty than ecologists, going back into a project site to make adjustments is indicative of failure to an engineer, but not to an ecologist.

Agreeing ahead of time about the acceptability, and desirability, of adaptive management may help the engineers feel more comfortable with the process. Discussing all the differences shown in Table 4 could also help members of the organization understand and appreciate the value each other brings to the organization, opening up new possibilities for collaboration and creativity.

I have observed leadership putting a lot of thought into what new technical skills are needed in the organization and making a business case for establishing a new position. But, I have yet to see a robust discussion of how the organization, and the organizational culture, may need to change to accommodate a new way of thinking and get the most out of increasing the diversity of professional backgrounds. The main advice I would give to organizations is to be intentional about discussing these aspects when bringing in employees with a different professional orientation than is the norm in your organization. Do you know what underlying assumptions and values are embedded in your organizational culture? Is your organization willing to change the decision processes and assumptions that go into your work? Are you willing to consider a different point of view and values on an equal footing with your traditional views and values? Do you have a culture that promotes productive disagreement and learning throughout the organization? If not, these would be good first steps to implement before hiring in new people. Otherwise, you may be unintentionally creating an environment that delays or prevents the changes you need to solve your most difficult problems.

Final Thoughts

One of the main messages of science and technology studies is that all scientific activities are embedded in the culture and social process of scientists (Latour and Woolgar 1979; Shapin and Schaffer 1989; Collins and Pinch 1998). This has been especially recognized in the social sciences, where research positionality is an important consideration in their work (Holmes 2020). With this in mind I have a few thoughts on conducting insider research based on my experience working for the City of Portland while researching two of its' bureaus. In doing this research I was what Adler and Adler (1987) would call a "complete member" at BES because I was working there during the study. In Chapter 5 I talked about access, ethical considerations, and power and supervisory issues not being a problem. Here I would like to address the issues of role conflict, objectivity, and repercussions and how I experienced these during the research.

Role conflict is when it is hard to distinguish between the dual roles as researcher and employee, or when these two roles cause conflict (Brannick and Coghlan 2007). This was not a large concern for me during the research. I think that is because my primary work role was mostly unrelated to the research topic. I never felt like my colleagues were reluctant to speak about issues related to my normal work duties, which included things such as analyzing proposed environmental legislation, facilitating technical policy discussions, and promoting a more person-centered management culture, because of my academic role. Therefore, I never felt that my identify as a researcher got in the way of performing my job. I also did not feel that my identity as an employee got in the way of my role as a researcher. I was very open with my colleagues about the topic and focus on my research; some of my colleagues approached me to talk about their experiences of organizational culture and professional identity. They would initiate these conversations because they wanted to help with my research, and they freely granted permission to use that information in my study. I had access and relationships that would have been extremely difficult to establish if I had not worked at the two bureaus. Overall, I think being an insider was beneficial for me and my research because I was able to observe many interactions and discussions that helped enrich my understanding of the organizational culture and dynamics without always having to schedule special “research” time to do it.

Another concern in the academic literature about insider research is the lack of objectivity on the part of the inside researcher (Coghlan and Brannick 2005; Brannick and Coghlan 2007). Luckily, the former privileging of objectivity in social science research is no longer as secure as it once was. Scholars now understand that objectivity is an illusory goal, especially in social science, and have been recognizing that all research is in some ways subjective (Bloor 1991; T. M. Porter 1994; Denzin 2017; Daston and Galison 2021). Instead, I fully embraced subjectivity by discussing my thoughts and preliminary findings along the way with a wide variety of my colleagues. Their and my combined subjective views of events and meanings are reflected in the analysis and conclusions in this study.

The final concern that I will address is that an inside researcher will be unable to produce high-quality or honest research because of their fear of the repercussions of the work on their career and their organization (Brannick and Coghlan 2007). I admit that this was a concern for me early in the research process. Would I be able to produce academically honest research without angering my colleagues and leadership at my organization? I felt from the beginning that it would be important to acknowledge tensions and frustrations that exist within my organization, and in some ways my findings could be read to be critical of the water industry and engineers. I could not downplay any of the tensions or shy away from criticism of the organizations if I wanted to understand what was happening. Instead, I tried to critically examine these tensions so that I could further explore what they meant. I began to see the actions of others with a more thoughtful eye because I knew them personally and, in some cases, had performed similar work as them in the past. This prevented me from improperly ascribing negative intentions to actions and prompted me to try to gain a deeper understanding of what was going on. I do not yet know if there will be personal or professional repercussions from this study but am confident that I did not let that get in the way of the research.

Having an organizational culture researcher on staff is a luxury few organizations could afford. However, gaining a better understanding of one's own culture and decision processes is important for any organization trying to implement changes or innovations. From the last several years in doing this research, I have been able to begin changing how I work and pointing out when and where I think there are misunderstandings and tension being created because of differences in professional knowledge systems. For the most part, when colleagues hear about these differences they are grateful to finally be talking about the actual underlying problem rather than continuing to talk around the issues. The biggest lessons I have learned that could be useful for infrastructure organizations are to become familiar with you own knowledge system, to question your own assumptions, to be curious about the knowledge systems and values of others, and to welcome and foster change.

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