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Science and Technology Studies in the Energy-Water Nexus:
A Naturalistic Inquiry of
Reclaimed Water Use in Thermoelectric Power Plants

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Science and Technology Studies in the Energy-Water Nexus: A Naturalistic Inquiry of Reclaimed Water Use in Thermoelectric Power Plants

by

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Dedication

I dedicate this dissertation to Dr. Robert Young, graduate advisor, life mentor, fierce supporter and co-Patrick Geddes defender. From those of us that were lucky enough to laugh, cry, and be changed through your passionate lens of the world—thank you, my friend. You are missed by all of us.

To Dr. Steven Moore, Dr. Katherine Lieberknecht, Dr. Bjorn Sletto, and Dr. Michael Webber, I am deeply grateful for your guidance in this dissertation and for your encouragement as we carried on this work that I hope Dr. Young would be proud of.

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- Electric Power & Research Institute (EPRI)
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- Emerald Point Marina
- Freedom Solar
- Just for Fun Watercraft Rental
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- Texas Bureau of Reclamation
- Texas Commission on Environmental Quality (TCEQ)
- Texas Municipal Utilities Association (TMUA)
- Texas Municipal League (TML)
- Texas Water Development Board (TWDB)
- University of Texas Energy Institute

Science and Technology Studies in the Energy-Water Nexus: A Naturalistic Inquiry of Reclaimed Water Use in Thermoelectric Power Plants

Kristina Lynn Tajchman, Ph.D.
The University of Texas at Austin, 2019

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Energy is necessary to transport, treat, pump, convey, cool, and heat water such that it is available at the appropriate time, place, temperature and salinity for an array of human uses. Water is required to produce and extract fuel sources such as oil and gas, and it is used in the cooling systems of power plant operations as they generate electricity. This dissertation examines the interrelationships between these resources, also known as the Energy-Water Nexus, and the associated actors, technologies, environments, and policies that affect them.

While there are many interrelated system boundaries to this relationship that are critical to society—such as food, sanitation, and carbon footprint—I focus on large-scale solutions that can make a significant difference in efficient use of energy and water. Specifically, this study is focused on the use of water in thermoelectric power plants and investigates which factors lead decision-makers toward using reclaimed water rather than the traditionally used freshwater. Important quantitative studies have addressed

feasibility, costs, logistics, and policy developments related to the use of reclaimed water for cooling, but these studies leave a substantial gap in qualitative understanding of the sociopolitical influences on this transition.

To support a growing understanding of using reclaimed water as an alternative, this research design is guided by methods developed in Science and Technology Studies (STS), a field of study that recognizes the complicated and continuously evolving nature of energy and water use. The research began with an Interactive Qualitative Analysis (IQA) of utility company relationships within the ecosociotechnical infrastructure in the state of Texas. This method was followed by and completed with Naturalistic Inquiry, which is well-suited for this research because of the complex and dynamic nature of the topic under study. This approach is especially important to the energy-water nexus as the units of analysis include not only policies, climates, and social pressures, but also the changing relationships between them. Where possible, diagrams have been created to visually aid interpretation and indicate connections between scenarios and solutions.

The goal of this research was to: (1) understand the variables that influence the decision-makers in the process of shifting to reclaimed water use, (2) understand how these variables relate to each other, and (3) use that understanding to articulate how to support a dynamic and adaptive framework for continual evaluation of electricity generation and water resource alternatives, and to identify the factors that influence both theory and practice in energy and water planning.

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Chapter 1: Introduction

Energy is required to extract, convey, and deliver water of desired quality and temperature for diverse human uses. The reverse is also true. Water is required in most phases of energy production and electricity generation. The use of *water for energy* and *energy for water* is a relationship known as the energy-water nexus and is broadly depicted in Figure 1.1.

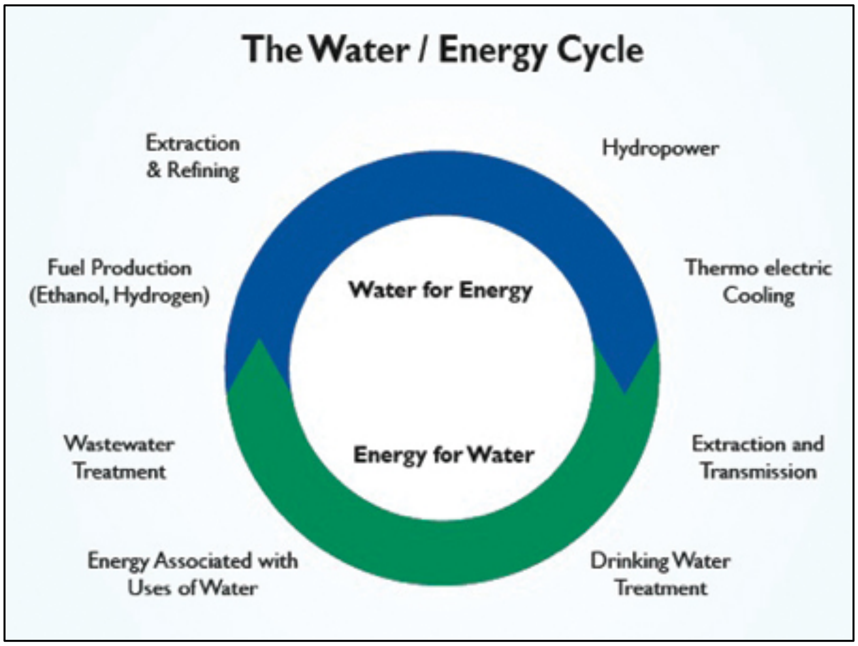

Figure 1.1: The Energy-Water Cycle (LeChevallier, 2012)

The importance of this relationship grows even stronger in cases where changes in energy production move towards more water-intensive practices, such as biofuels,[1] shale gas,[2] and increased use of carbon capture and storage (CCS)[3] technologies.

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[1] The water footprint of biomass can be greater than traditional thermoelectric sources depending on the

[2] Extraction of shale gas requires the injection of tens of millions of liters per well of high-pressure water underground to fracture low-permeability formations.

[3] Carbon capture and storage can significantly impact power plant water withdrawal and consumption; see “Carbon Considerations” in Chapter Two.

Alternatively, increased use of wind and solar photovoltaic panels[4] can reduce energy's water intensity, but these technologies trade reduced water use for operational and transmission constraints due to their intermittent nature. On the *energy for water* side, there are some cases in which changes in water procurement may require the use of increasing quantities of energy; examples include desalination[5] and long-haul water transfer.

As a result of the energy-water nexus, energy constraints can become water constraints and water constraints can become energy constraints (Webber, 2016, p. 112). A common yet more complex illustration of this mutually constraining energy-water flow is the Sankey diagram. The following example of a Sankey diagram provides a starting point to visually understand the interconnectedness of these resources. However, it does not capture the dynamic ways in which these flows are impacted by changes in policy, economics, or technologies (U.S. DOE, 2017, p. 5).

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[4] "Wind turbines and solar photovoltaic (PV) panels… require small volumes of water for cleaning, but otherwise use no water" (Carter, 2010, p 35).

[5] The process of removing salts and other chemicals to freshwater levels (Pennington, Karrie Lynn and Thomas V. Cech, 2010, pp 347).

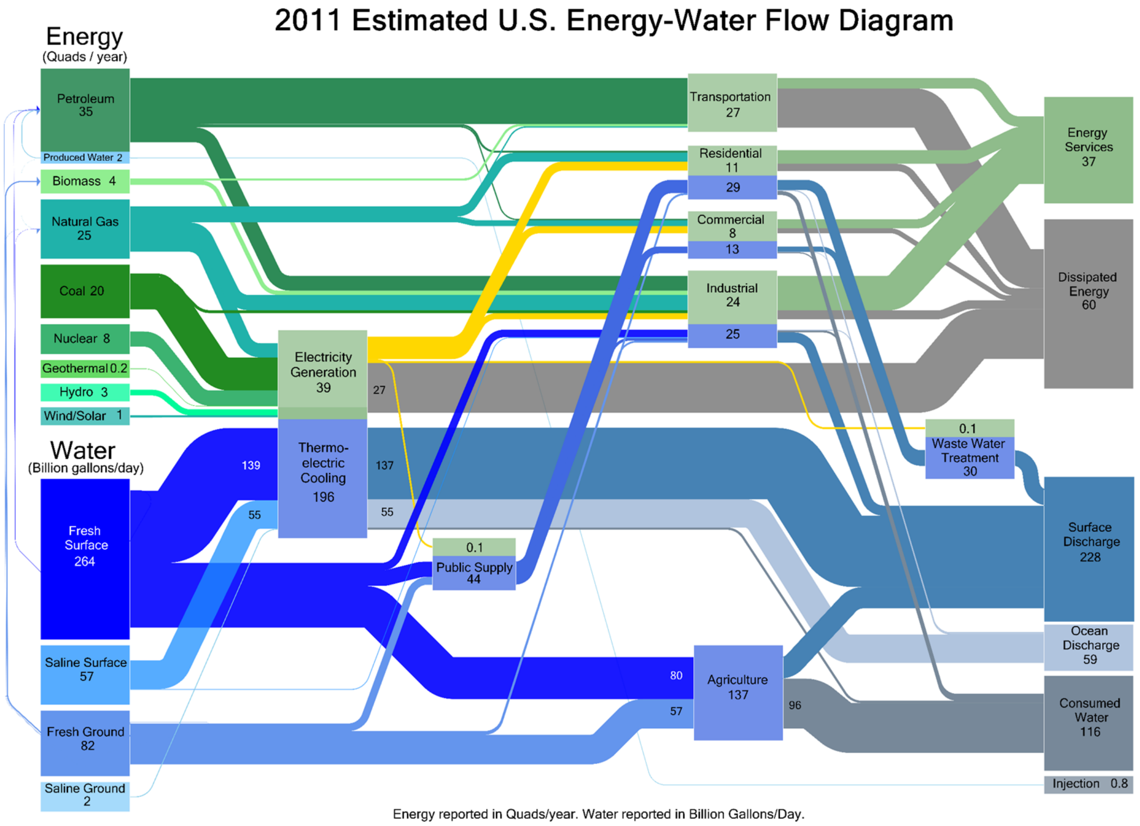

Figure 1.2: 2011 Estimated U.S. Energy-Water Flow Diagram[6] (U.S. DOE, 2017, p. 5)

The U.S. DOE identifies four current trends that they suggest increase the urgency of addressing this relationship in a proactive way. These trends include: (1) climate change affecting precipitation and temperature patterns,[7] (2) projected U.S. population growth and migration to arid areas, (3) new technologies that shift energy and water demand, and (4) changing policies and regulations that may introduce both incentives and challenges to addressing the relationship (U.S. Department of Energy, 2017, p. 13).

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[6] This diagram uses a unit of energy called quad which is considered a convenient unit for discussing world energy resources and is the equivalent of 1 quadrillion British Thermal Units (BTU).

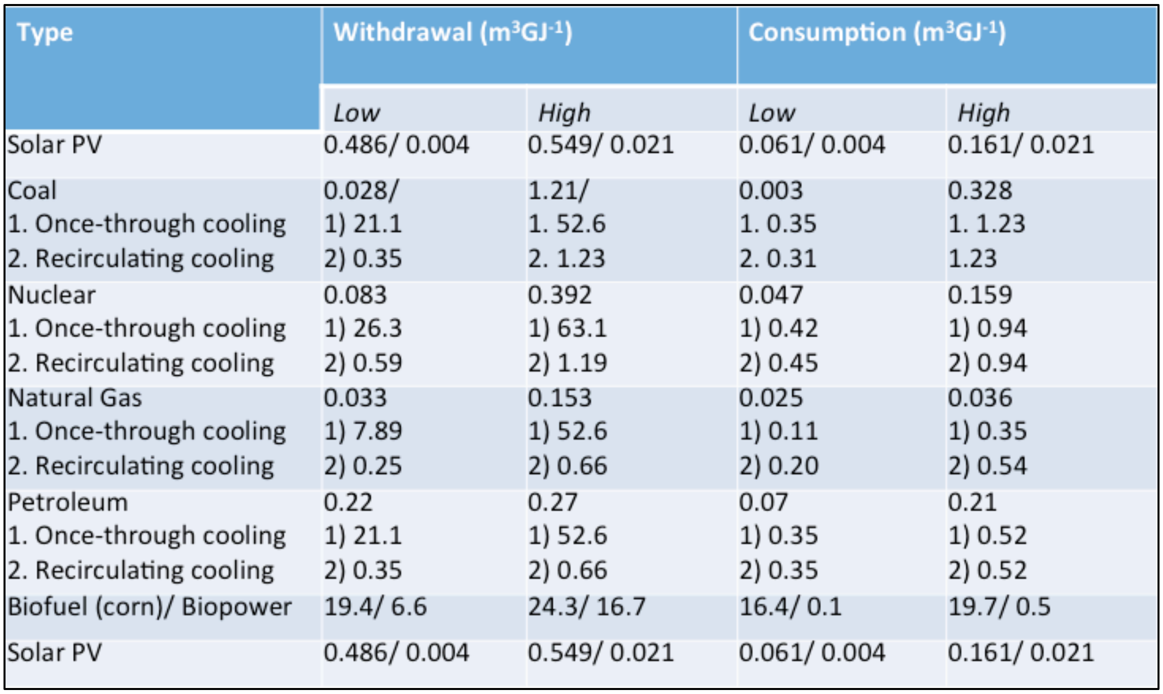
[7] "Shifts in precipitation and temperature patterns – including changes in snowmelt and timing – will likely lead to more regional variation in water availability for hydropower, thermoelectric generation and other energy needs. Higher temperatures also have the potential to decrease the efficiency of thermoelectric generation, which could increase water requirements for thermoelectric cooling when water demand for non-energy purposes is also high" (U.S. DOE, 2017, p. 15).

This research focuses on the *water required for energy* half of the relationship, which has received increasing national attention as severe drought in recent years has impacted both power plant operations and other energy production. Specifically, I focus on the thermoelectric power sector, which currently accounts for approximately 40% of U.S. freshwater withdrawal and 3% of freshwater consumption (Wolf, Goldstein, Maulbetsch, & McGowin, 2009, p. 30). Operational definitions are provided at the end of this chapter, and the differences between water withdrawal and water consumption are further discussed in the technical description of water use in power plants below.

It is important to distinguish between water withdrawal and water consumption when deciding between alternatives because the energy-water nexus is highly site-specific. A range of local and regional factors influence what type of energy and water applications are chosen, how effective they are in each location, and what impact they have on the human and non-human surroundings. The ecology of the area can lead to the economical use of hydropower near elevated water, the use of solar panels in sunny areas with little water, or the controversial use of nuclear energy in areas that have few natural resources of their own. Different choices need to be made for each situation depending on the energy, water, political, financial, and cultural makeup of the area. When comparing alternatives, it is important to determine which of these factors are included and which are left out of analysis. I refer to this choice as the system boundary.

The statistics reflecting each of these alternatives may vary tremendously depending on the system boundary included, and a range of sources exist in literature that indicate water consumption by fuel source and generation technology. For these reasons, I assert that it is critically important for planners, educators, policymakers, and other decision-makers to consider data sources that address water use throughout the life cycle and not just at production. The following table illustrates this point; it is extracted from research that examines not only water consumption for electricity generation, but also water consumption for material resource/ acquisition (McDonald, 2012, p. 4-7).

Table 1.1: Water Withdrawal and Consumption Intensity per Generation Type



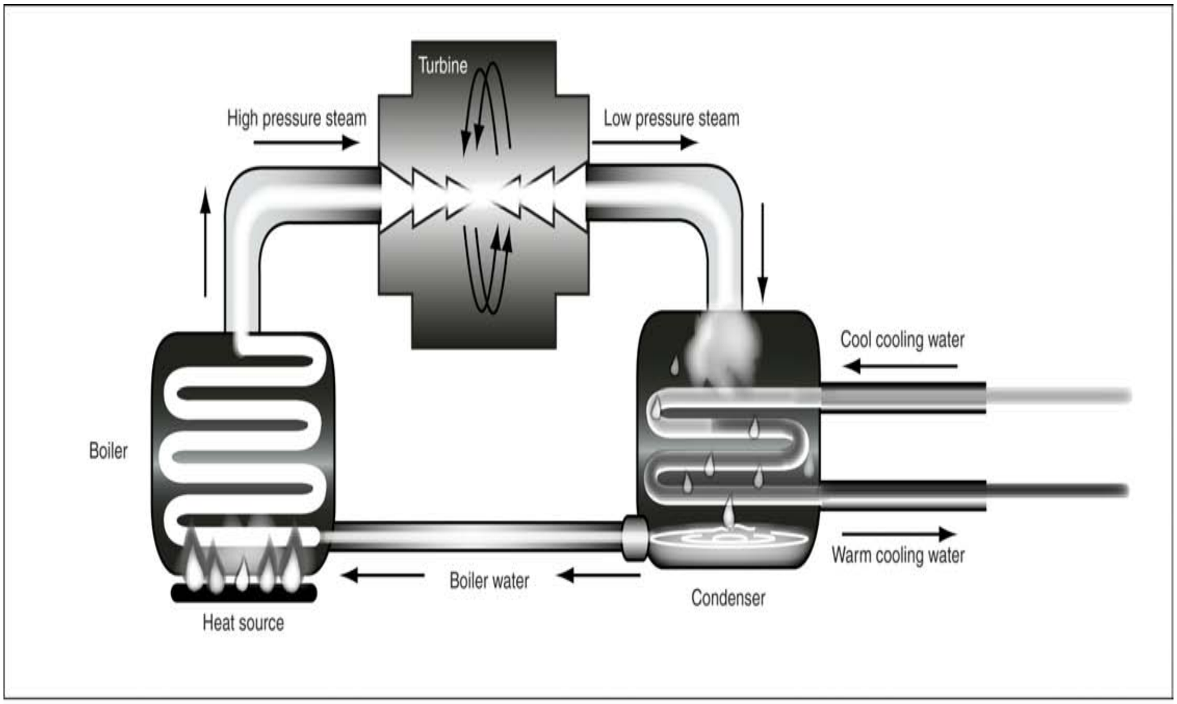
Type	Withdrawal (m^3GJ^{-1})		Consumption (m^3GJ^{-1})	
	Low	*High*	*Low*	*High*
Solar PV	0.486/ 0.004	0.549/ 0.021	0.061/ 0.004	0.161/ 0.021
Coal 1. Once-through cooling 2. Recirculating cooling	0.028/ 1) 21.1 2) 0.35	1.21/ 1. 52.6 2. 1.23	0.003 1. 0.35 2. 0.31	0.328 1. 1.23 1.23
Nuclear 1. Once-through cooling 2. Recirculating cooling	0.083 1) 26.3 2) 0.59	0.392 1) 63.1 2) 1.19	0.047 1) 0.42 2) 0.45	0.159 1) 0.94 2) 0.94
Natural Gas 1. Once-through cooling 2. Recirculating cooling	0.033 1) 7.89 2) 0.25	0.153 1) 52.6 2) 0.66	0.025 1) 0.11 2) 0.20	0.036 1) 0.35 2) 0.54
Petroleum 1. Once-through cooling 2. Recirculating cooling	0.22 1) 21.1 2) 0.35	0.27 1) 52.6 2) 0.66	0.07 1) 0.35 2) 0.35	0.21 1) 0.52 2) 0.52
Biofuel (corn)/ Biopower	19.4/ 6.6	24.3/ 16.7	16.4/ 0.1	19.7/ 0.5
Solar PV	0.486/ 0.004	0.549/ 0.021	0.061/ 0.004	0.161/ 0.021

While it is difficult to project how these numbers will change over time, analysts converge on the conclusion that future water availability depends heavily on the choices made with respect to energy sources and their cooling systems (Badr, Boardman, & Bigger, 2012, p. 256). As my colleagues at The University of Texas at Austin lightheartedly point out, with unlimited energy we could desalinate the ocean and transport water where needed, and with unlimited water we could build power plants in any location and extract oil and gas as needed (Sanders & Webber, 2013). Since this is not the case, it is important to understand the significance of water use in electricity generation.

The volume of water withdrawal required to generate power in the thermoelectric power sector is explained in the following extract from work conducted at The University of Texas at Austin Environmental Defense Fund:

> A number of primary energy sources such as coal, uranium, natural gas, biomass, sun, water, or wind, can be used to generate electricity, which distributes energy to domestic, commercial, and industrial customers. Using different process, energy within these fuel sources (chemical, kinetic, or radiant energy) is converted into electrical energy. However, the conversion processes are inherently inefficient, which generates waste heat that is typically dissipated by use of cooling water.
>
> The thermoelectric power plants use nuclear or fossil fuels to heat high purity water into steam, which then turns a turbine connected to a generator, producing electricity. The steam is then condensed back into water to continue the process again in a closed loop. This condensation requires cooling either by use of water, air, or both. The energy efficiency of the turbine in converting steam into electric energy depends in part on the effectiveness of the steam condensation process. That is, the efficiency of the power plant depends on its ability to cool its steam loop. The quantity of water required for cooling depends on the type of fuel, power generation technology, and cooling technology. (Stillwell, King, Webber, Duncan, & Hardberger, 2009, p. 5)

This process is illustrated in Figure 1.3, which shows steam returning to the condenser where cool water is used to turn the steam back into water and continue the cycle.



Source: GAO analysis of various national laboratory and industry sources.

Figure 1.3: Diagram of a Boiler Loop in a Power Plant (GAO, 2012, p. 5)

Typically, the cooling technologies include either: (1) a closed-loop cooling system (also known as wet-recirculating) that withdraws less water but consumes most of the water withdrawn, or (2) an open-loop cooling system (also known as once-through) that is designed to withdraw more water, but returns more to the source.

As an alternative to these systems, there are also hybrid and dry cooling methods, illustrated in Figure 1.4. Dry cooling is a cooling method in which steam is directly condensed in an air-cooled condenser (Zammit, 2012).

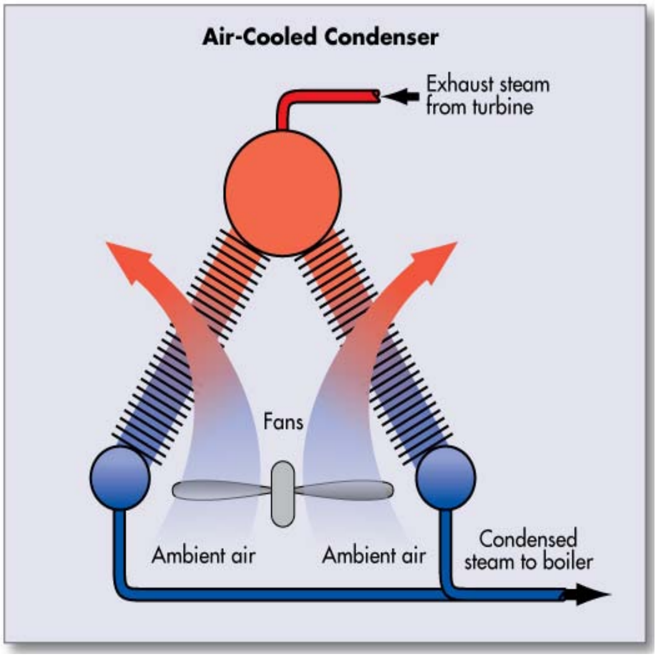


Figure 1.4: Air-Cooled Condenser (EPRI, 2008, p. 41)

While the dry-cooling system is a zero water solution, it comes with significant penalties in terms of cost, plant performance, and land use. Specifically, the consequences of dry cooling systems include: (1) increased capital cost (approximately 10% more expensive than wet cooling, as well as higher operational costs), (2) increased energy[8] required to operate circulation fans which reduce the efficiency of the plant by requiring more fuel to operate and also producing more air pollutants, and (3) increased land use and noise issues due to the significantly larger system (Zammit, 2012).

The main takeaway is that each of these methods involves various tradeoffs in terms of total consumption of water per megawatt hour of electricity produced. The range of designs are especially important to understand in relation to this work because new

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[8] "Higher temperature of the air used for cooling increases the back pressure on the generating turbine, reducing generation efficiency, particularly under high-temperature ambient conditions" (U.S. DOE, 2017, p. 25).

research indicates that various types of cooling systems lead to definitional and reporting differences that make a significant difference in the amount of reported water withdrawal. This issue is further discussed in Chapter Two.

Whether the cooling method is open-loop, closed-loop, or a hybrid, the dominance of the thermoelectric power sector among water users leads to questions of what alternatives exist and what technical, political, economic, social, and environmental advantages and disadvantages are associated with each alternative. Energy and water are natural resources with associated industries that have historically been developed, regulated, marketed, and managed independently. As presented in Figure 1.5, inputs (such as time, money, or infrastructure) and outputs (such as air, water, or ground pollution) exist for both of these resources. Some of these inputs and outputs have consequences on other systems; however, it is difficult to account for those consequences. Additionally, the preference towards a free market in neoliberal economics is more conducive to considering each industry as a system by itself.

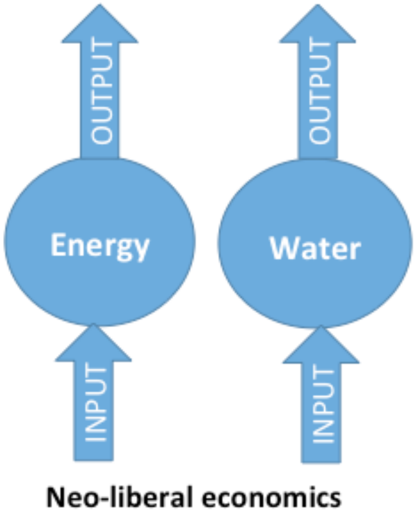

Figure 1.5: Independent System Boundaries (Source: Author)

Each system has unique variations depending on the source of energy (i.e. coal, natural gas, nuclear, solar, etc.) or source of water (i.e. freshwater and reclaimed water). However, these systems share some common boundaries in terms of their criticality to society. Some advocates of neoliberal economics recognize this commonality yet continue to treat the systems independently. I represent this better but still limited understanding in Figure 1.6, which illustrates neoliberal economics combined with an emerging recognition that each industry shares system boundaries.

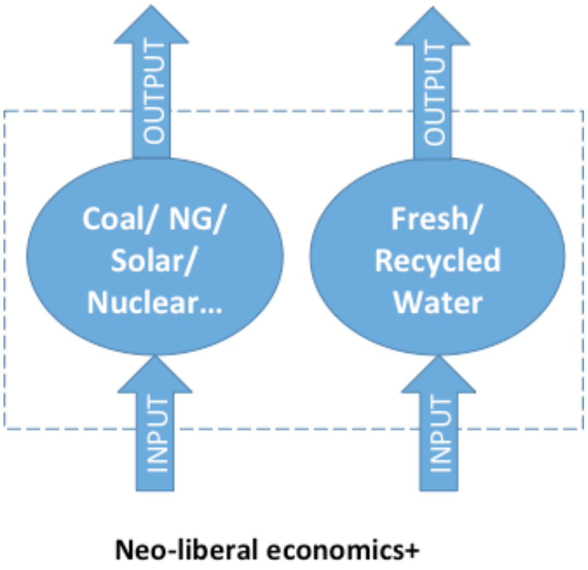

Figure 1.6: Independent System Boundaries for Each Energy/ Water Source (Source: Author)

As appreciation for the interrelationships in the energy-water nexus continues to grow, it becomes clear an approach that treats these systems as separate is insufficient; consequently, this approach no longer dominates mainstream dialogue. For example, when a new power plant is needed to keep up with a city's growth but the water necessary for the plant's operation is already over-allocated to other uses, it would not be effective to handle the power and water industries as if the two were independent of one another. Rather, they need to be considered together, so that supplying new energy needs does not come at the cost of creating new water strains or vice versa. As a start, we can apply the contributions of ecological economics, in which human economy is considered together with natural ecosystems (as shown in Figure 1.7). The perspective of ecological economics encourages a reconsideration of how these resources are used by industry, as well as the associated benefits and costs to the industry, the public, and nature. I further explore debates about definitional differences in ecological economics in Chapter Three.

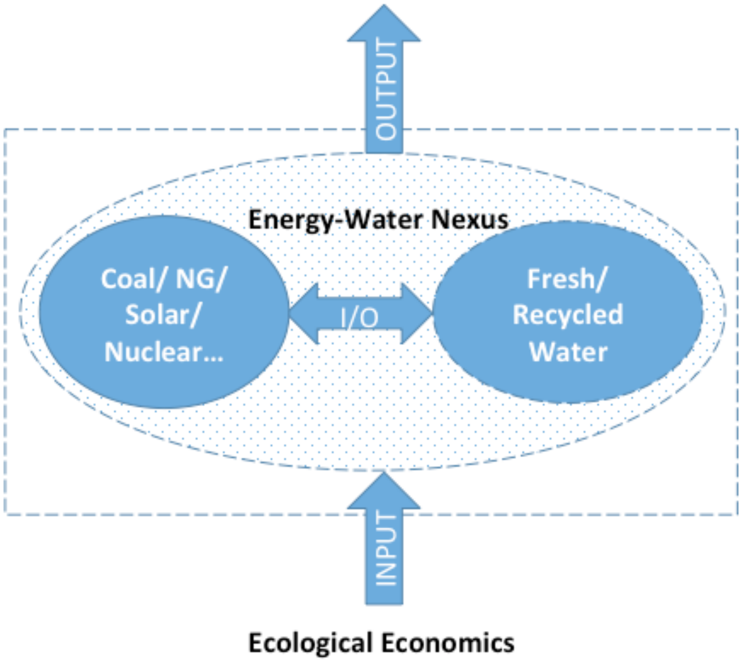

Figure 1.7: Integrating System Boundaries (Source: Author)

The use of a city's reclaimed water to run a power plant avoids adding to the already strained human and nonhuman freshwater supply. This idea was definitively applied in the 1960s when city managers of San Antonio pioneered the innovative use of reclaimed water in power production, making Braunig Lake the world's first large-scale attempt to use reclaimed water in cooling their generating plants (Eckhardt, 2018). Since this time, studies have been conducted to evaluate the viability of reclaimed water sources, such as assessing the distance and cost to pipe reclaimed water from existing wastewater treatment plants (WWTP) to existing power plants.

In fact, studies indicate that in the United States, nearly "50% of existing power plants could obtain sufficient amount of cooling water from publicly owned treatment works located within a 10 mi (16km) radius" (Li, Chien, Hsieh, Dzombak, & Vidic, 2011, p. C). Applying similar methods and narrowing in on the state of Texas as a test case, researchers found that "sufficient reclaimed water resources exist within 25 miles of 92 power plants" (Stillwell & Webber, 2014, p. 4588). A report by Argonne National Laboratory (ANL), however, revealed that only 57 out of approximately 1,500 U.S. generating units were using reclaimed water for cooling and, in some cases, for air pollution control equipment (Argonne National Laboratory, 2007, pp. 5, 7). Thus, despite the technical and spatial feasibility of using reclaimed water, and the relief it could provide in conserving freshwater for other users in the watershed, only a small ratio of power plants are actually using reclaimed water sources.

This study seeks to understand not only why this ratio is low, but also what could lead to making it higher. As I discuss further in Chapter Two, in recent years extended drought has resulted in power plant shutdowns due to a lack of freshwater for operations. When extreme boundaries like this are reached, decisions about ecological, social, and political trade-offs become more difficult. In the case of water used for thermoelectric power plants, these variables at a minimum may be broken down into categories of increasing competition for freshwater and reclaimed water and energy sources, politics, society, and the environment, as illustrated in Figure 1.8.

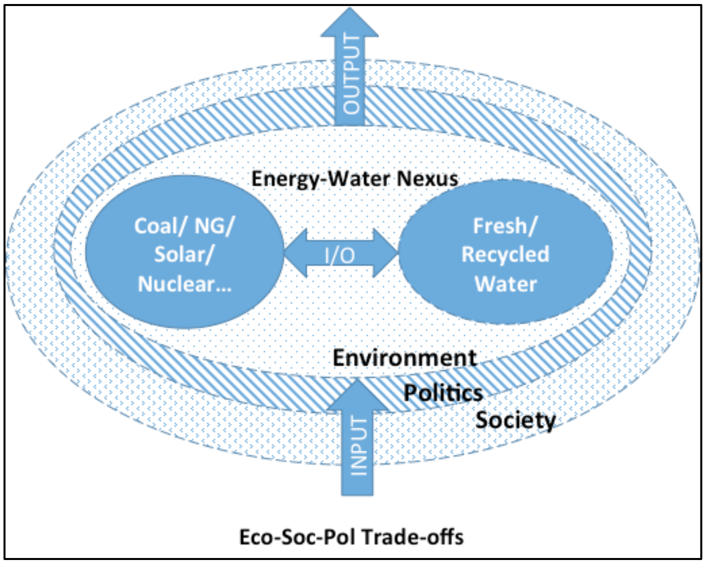

Figure 1.8: Expanding System Boundaries (Source: Author)

Each of these categories is often considered to have direct trade-offs with the other, such as the implementation of environmental restrictions that must come at the cost of economics or the assumption that new technology cannot be cost effective if it also protects the environment. This prevalent notion of trade-offs, however, ignores the many other variables that influence the outcome. As Feenberg points out,

> To claim that society must choose between industry and crafts is to concede that the existing industrial system is the only possible one, an essentially determinist position. It assumes there can be no reform of modern industrialism based on the invention of alternative technologies compatible with the health of the environment. (Feenberg in Moore, 2010, pp 269)

Due to the lack of information regarding all of the variables in the energy-water nexus, as well as the interaction between variables, I conducted this study to better understand the decision to use reclaimed wastewater in thermoelectric power plants. This research expands the existing knowledge boundary by observing how all of these systems interact within and among each other as they relate to reclaimed water use in thermoelectric power plants.

UNDERSTANDING THE DECISION TO USE OR NOT USE RECLAIMED WATER

To begin investigation of the key parameters of using reclaimed wastewater in thermoelectric power plants, I conducted three literature reviews on: (1) the energy-water nexus specific to water use in thermo-electric power plants, (2) water use in thermo-electric power plants in the state of Texas, and (3) Science & Technology Studies. These literature reviews are further described in Chapter Two. My research indicates that power plant executives and miscellaneous authorities are the primary decision-makers of whether or not a power plant transitions to, or is designed specifically for, the use of reclaimed water or freshwater. Thus, understanding the system in which that decision is made helps surrounding stakeholders understand how to affect that decision.

As a result of these literature reviews, I initially found general acknowledgement that using reclaimed water is technically feasible, more ecologically friendly than using freshwater, and may help avoid the potential risk of power plant shutdown in prolonged periods of drought. Additional research contends electricity producers could conserve more water than all of the U.S. residential water conservation methods combined if they modernized their cooling systems (Wilson et al., 2012, p. 5), which makes understanding this issue especially appealing. Based on my literature search, two of the key factors studied to date include the increasing population served by a power utility, the geographical location in a drought-prone area (Sovocal & Sovocal, 2009), and pipeline construction cost (Stillwell, 2013). This preliminary research implies economic, temporal, and spatial drivers to the transition decision.

Specific costs to those power plants using reclaimed water versus freshwater, for example, include further water treatment costs, water transportation costs, and additional capital costs for water monitoring and cooling water-contacted equipment. In cases where energy production is threatened by a lack of water, rates may be driven higher by the demand on both resources. Thus, there are dual socio-economic components involved in the allocation of these costs among energy and water users.

There is also a significant temporal component to the decision. In some cases, power plants are more likely to retire than to spend resources on retrofitting their equipment and permitting pipeline construction for reclaimed water use. Research indicates planning ahead can save 10-30% on these costs (Puckorius, 2013); however, power plants with existing water rights and adequate supplies have little to no financial incentive to decrease water use or seek more expensive water supply alternatives.

An important area of interest to me is how the decision to use reclaimed wastewater or to continue relying on freshwater supplies impacts people differently depending on their frame of reference, as well as how this impact changes as social groups and conditions shift over time. Through no fault of their own, many social groups remain largely unaware of the possibilities of reclaimed water use in thermoelectric power plants.

This lack of awareness is important because where water rights are grandfathered for the utility stakeholder, the needs of other stakeholders for over-allocated surface water supplies may have social impacts that have not been well-explored. One example of this impact may be found in low-income citizens who rely on surface water for other uses. Opportunities for low-cost recreational activities such as swimming and fishing, for example, may be impacted as competition for water supplies grows. This is not to say that swimming and fishing are more important than keeping a city's lights on, but to indicate that an end-to-end analysis should account for social impacts that have not yet been explored in the limited studies that currently exist.

My literature searches also revealed other studies of political considerations that influence the energy industry's ability to update power plant operations. Examples of these challenges may include governance boundaries that do not align with the physical boundary of energy and water resources, and a lack of knowledge and enforcement for resource capacity (King, Stillwell, Twomey, & Webber, 2013, p. 147). There are also environmental justice concerns to explore, such as the potential risk to communities living in close proximity to the power plant who would be exposed to mist coming off the cooling towers[9] as well as a possible environmental tradeoff of investing in older, less efficient power plants.

In summary*, the unit of analysis in my study is not a specific social group, policy, resource, or condition, but the interaction of these actors in the context of the policies, technologies, and environments that surround water use in thermo-electric power plants.*

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[9] "Power plant discharge regulated by NPDES permits applies to either freshwater or reclaimed water, however the plant water storage capacity may have an impact on the ability to comply in the event of an event at the WWTP that causes higher concentrations of pollutants" (Schmaus & Viciere, pp 1-12)

OVERVIEW OF CHAPTERS

Chapter One has introduced: (1) the energy-water nexus, (2) freshwater use in thermo-electric power generation including variance among fuel types and the distinctions between withdrawal and consumption, and (3) the reclaimed water alternative. This chapter also describes the sociopolitical-economic complexity surrounding the decision to use reclaimed water for power plant cooling systems, which has only been sparingly mentioned in existing literature. Operational definitions are provided at the end of this chapter to clarify the distinctions between closely related terms.

Chapter Two discusses three distinct literature reviews in support of this study and provides additional background information on water use in power plants. The first two literature searches revealed general recognition that using reclaimed wastewater[10] in thermoelectric power plants is: (1) technically feasible but expensive, due to the cost of retrofitting and running pipelines to existing power plants, (2) a complicated alternative for new power plants, and (3) in use by only a small subset of utility companies. This section also addresses Texas-specific considerations of reclaimed water use for power generation, such as the state's location in drought-prone area; regulatory, temporal, carbon capture, and economic considerations of the reclaimed water alternative; and special considerations for municipally owned utilities. The third literature review of Science & Technology Studies (STS) brought my attention to the prevalence of industry and engineering dominated research found in the first two literature reviews, as well as the associated concerns and potential consequences of this distinctive approach.

The theoretical framework and research methods are discussed in Chapter Three. In the first half, I begin with a discussion of the theoretical foundation and inspiration for

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[10] Reclaimed water is defined as municipal water treated for suitable use (TWDB, 2011, p. 5).

this study, which include: (1) sustainability and pragmatism in normative planning, (2) theoretical inspiration from a founding father of sustainability in planning, Patrick Geddes, and his influence in ecological economics, and (3) the need for qualitative research of this topic deriving from the communicative school of planning theory.

The second half of this chapter explains my initial research method of Interactive Qualitative Analysis (IQA) and provides condensed descriptions of the four phases of this method, including Research Design, Focus Group, Interview, and Report. This is followed by a brief discussion of why I abandoned this method for Naturalistic Inquiry as it became apparent it would be more useful for this topic, and why the Naturalistic Inquiry method is a better fit.

My analysis began with a focus group of energy-water constituents to formulate semi-structured interview questions and determine which social groups among the range of vested interests and scenarios are actual decision makers in the process. In Chapter Three, a description of this focus group is followed by an overview of the semi-structured interviews I conducted. The intent of my analysis was to gain insight into the social, environmental, political, and economic contexts that affect the decision to use reclaimed wastewater. The final section of this chapter acknowledges the potential limitations to this study, including the limited participating social groups and the difficulty of keeping discussion of each unit of meaning (known in STS literature as codes) separate from the others during interviews.

Chapter Four presents the results of the focus group, peer collaboration, interviews, and analysis. Here, the codes of the system are described in the words of the focus group participants and interviews, as well as a description of how my understanding of these codes changed throughout the process. The second part of this chapter includes an analysis of how people are experiencing the system. I also describe three general patterns I observed with respect to decision-making within the system, including: (1) an over-representation of cost in existing literature, (2) a lack of institutional memory, and (3) a lack of cohesive long-term resource planning.

Finally, in Chapter Five, I provide an interpretation of the system and draw implications from these results. The practical implications for energy and water planners, decision-makers, and educators stem from the low commonality from utility to utility that lead to a system in which: (1) change is primarily driven by those within the industry, and (2) communities do not understand how the system affects them. Next, I briefly reflect on how the system could evolve into an alternative system of governance. I use this alternative model to identify planning implications for moving the system towards a more efficient, transparent, and educated use of energy and water resources. This includes clarifying sources of confusion and increasing awareness among all stakeholders, potentially through a revised scope of organizations like the Texas Municipal Utilities Association (TMUA) and the Texas Municipal League (TML) and integrated energy and water planning through a portfolio approach that identifies and addresses needs of the broader range of stakeholders.

OPERATIONAL DEFINITIONS

The following list defines operational terms that are particularly important for reference or important to distinguish from each other as they are used throughout this dissertation. Additional terms are defined in the Glossary.

Adaptive Management: A systematic process for improving management policies and practices by learning from the outcomes of implemented management strategies and by accounting for changes in external factors in a proactive manner (Pahl-Wostl, 2007, cited in Pahl-Wostl, Jeffrey, & Sendzimir, 2015, p. 294).

Biotechnic: The time when life values should predominate over money or any other purely material valuation (Shillan, 2015, p. 11).

Boundary Work: The discursive attribution of selected qualities to scientists, scientific methods, and scientific claims for the purpose of drawing a rhetorical boundary between science and some less authoritative residual non-science (Gieryn, 1994, cited in Miller, 2011, p. 17).

Coproduction: The mutual construction and reinforcement of ideas about the world in which people live (whether they choose to view that world in social, natural, or some other terms) and the organization and practices of institutions that enable people to act in that world, (Miller, 2001, cited in Miller & Edwards, 2001, p. 285).

Consumption: Water withdrawn that is not returned to its source (e.g., because it has been evaporated, been transpired by plants, or incorporated into products) (U.S. DOE, 2017, p. 15).

Definitional Difference: The documented variations in the definition of terms, categorization methods, and data collection methodologies that can result in different outcomes (Harris, 2017).

Environmental Flow: The amount of water that should remain in a stream or river for the benefit of the environment of the river, bay, and estuary, while balancing human needs (TCEQ, 2019).

Recirculating System: Cooling water is recirculated between the condenser and the cooling system, and withdrawal is equal to the amount of water withdrawn to compensate, or "make up," for losses from the system (Diehl & Harris, 2014, cited in Harris, 2017).

Recycled Water: See "Reclaimed Water."

Reclaimed Water: Domestic or municipal wastewater that has been treated to a quality suitable for a beneficial use. Also sometimes referred to as recycled water or reuse water (Texas Water Development Board, 2011, p. 5).

Sustainability: Meeting our needs today without compromising the ability of future generations to meet their needs (WCED, cited in Agyeman, 2005).

Sustainability Science: An integrative, place-based and problem-driven field with a core goal of linking knowledge to action (Clark, 2007; Kates et al., 2001; Miller, 2011, p. 2).

Withdrawal (for thermoelectric power generation in the cooling process): designates any water diverted from a surface or groundwater source, (U.S. DOE, 2017, p. 13).

> **"Agreed" Withdrawal:** Amount of withdrawal reported in common (Harris, 2017).
>
> **"Discrepant" Withdrawal:** Amounts of withdrawal reported in disagreement with other datasets (Harris, 2017).

Thermoelectric Power Plant: See descriptions and graphics throughout Chapter One.

Chapter 2: Literature Review

As stated in Chapter One, thermoelectric power generation requires significant quantities of water. To put it in perspective, consider that Americans use three times more water using lighting and appliances than taking showers and watering lawns (Hoffmann et al., 2005; Sovocal & Sovacol, 2009, p. 2764). With this statistic in mind, both energy and water conservationists have an interest in this side of the energy-water nexus. As an environmental planner interested in both, I conducted three separate literature reviews to better understand the technical, political, regulatory, planning, environmental, state specific, and STS aspects of this issue.

In the first literature review, my focus was on the technical sides of the energy-water nexus with respect to thermoelectric power plants. As I briefly explained in the Introduction, there are a range of designs that each bring tradeoffs in terms of water use and energy efficiency that also depend on the local or regional topography. In the following section, I summarize the approaches that other researchers have taken to study water use in power plant operations.

As a result of this review, I began to understand that due to the mix of regulated and unregulated states across the U.S. with respect to the electric industry, as well as the differences in natural resources and sociopolitical climates, there are many state-specific aspects to the energy-water nexus. This realization led to a second literature search to understand the specific conditions of thermoelectric power plant operation and water use in the state of Texas. While the literature of both reviews included some brief mentions of political, environmental, and social concerns, it became apparent these aspects were minimal and secondary in the majority of existing literature. With guidance from faculty who have observed this situation in other research, I conducted a third literature review of

Science and Technology Studies theories and methods to inform my understanding, as an engineer myself, of why the dominance of engineering-driven studies of this topic could be problematic. These potential problems are explored at the end of this chapter after the following sections, which describe the existing, primarily technical, approaches to studying water use in thermoelectric power production.

ENERGY-WATER NEXUS IN THERMOELECTRIC POWER PRODUCTION

Fortunately, the energy-water nexus has received increasing levels of attention in research in recent years. Academic and industry research began to focus on the energy-water nexus in roughly 2009. In the beginning, the main areas of research included: (1) county-by-county impacts of severe water shortages (Sovacol & Sovacol, 2009, p. 2767), (2) region-specific water consumption for energy production (Elcock, 2010), (3) identification of links between the energy, carbon, and economic values of using reclaimed water (Stilwell, King, Webber, Duncan, & Hardberger, 2010), (4) water-saving technical solutions (EPRI, 2012), (5) risk assessments (Woldeyesus, 2012), and (6) graphical representation of proposed thermoelectric plants co-located near wastewater facilities (Li, 2011; Schimmoller, 2012). Research then progressed to technical and policy tradeoffs (King et al., 2013, p. 151) and more specific analysis of the significance of pipeline construction costs and the associated impact on other users in the water basin (Stillwell, 2013, pp. 108, 123).

To summarize a common thread expressed in much of this research, water availability can be a valid threat to unrestricted power plant operation. Other research suggests, however, that power plants in areas most susceptible to drought such as the arid west are “not necessarily more drought vulnerable because they have pre-adapted to drought, with low water withdrawals and low reliance on surface water relative to those in the more humid east" (Scanlon, 2013, pp. 3, 7). This means power plants in these areas may be more likely to use designs that are less impacted by surface water, such as those with cooling towers, and indicates that power plants in the water-abundant east may have fewer coping strategies and be more vulnerable to drought.

The other finding significant to point out regarding the energy-water nexus at large is that there is currently no national water database comparable to our national energy databases in quality or quantity. In a comparison of the three dominant national databases for reporting water withdrawal in U.S. thermoelectric power plants between the Energy Information Administration (EIA) and the U.S. Geological Survey (USGS), researchers found a significant difference in water withdrawal data. Many plants were found to have multiple withdrawal values for the same year, and for 54% of plants their largest withdrawal value was twice the smallest values, (Harris, 2017), indicating significant discrepancy.

The widely varied values are attributed to differences in reporting requirements, withdrawal estimation methods, and sources of data. In fact, the EIA revised their forms twice since 2009 to address this issue (Scanlon, Reedy, Duncan, Mullican, & Young, 2013, p. 11326). Additional research found incomplete data for water-related end-uses and site-specific data (Sanders & Webber, 2013). As a result, researchers collectively suggest that both water and energy stakeholders and reporting mechanisms lack adequate information and cross-coordination of the energy-water relationship.

Despite the work described above and others like it not cited here, significant gaps continued to exist in mainstream water and energy literature until roughly 2012. Top water resource and management textbooks such as *Introduction to Water Resources and*

Environmental Issues (Pennington & Cech, 2010) and *Water Resources Planning and Management: An Introduction to Methods, Models, and Applications* (Loucks, 2017) ignored the impact of water on energy or power production, and the reverse was also true. Major reports on U.S. electric infrastructure also largely ignored water management. More recently, energy organizations and departments such as the U.S. DOE and the EIA have significantly increased attention, research, and associated publishing to document and spread awareness of this issue.

Two special considerations warrant specific discussion from the first literature review because of their relationship to the environmental planning associations in which I am interested. First, in an effort to reduce the greenhouse gases released to the atmosphere, efforts to capture carbon dioxide by either geologic sequestration (GS)[11] or carbon capture and storage (CCS) may be applied to power generation waste. Unfortunately, CCS technologies can have significant water and energy performance implications. For example, the use of monoethanolamine (MEA), the current state of the art in carbon dioxide recovery, decreases the plant's energy efficiency and also involves multiple cooling sub-processes that require additional water (U.S. DOE, 2017, p. 32). In fact, research shows that nearly 20-33% more water is required if carbon sequestration is added (Abrams & Hall, 2010, p. 61). Similar to the trade-offs between fuel types and cooling technologies in plant design, work remains to determine the energy, water, and cost savings between various carbon capture options.

Second, existing literature also captures a temporal component from a technical perspective. The dominant plant design for fuel type, or fuel mix, and cooling technology varies with the age of the plant. Coal and natural gas steam turbine systems

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[11] Geologic sequestration is the process of injecting carbon dioxide into deep subsurface rock formations for long-term storage (Environmental Protection Agency, n.d.).

make up most of the generators more than 25 years old, while natural gas combined cycle systems are the primary generators less than 25 years old (U.S. DOE, 2017, p. 22). The same is true for cooling technology. Findings in a publication by a senior manager for Water & Ecosystems programs for the Electric Power & Research Institute (EPRI), Kent Zammit, report increased use of recirculating cooling systems and use of freshwater conserving measures that have reduced water withdrawal per unit of electric power by a factor of three. Unfortunately, however, over the same 50-year period, power output increased by a factor of 15. The result is a five-fold increase in water withdrawal from 1950 - 2000 (Zammit, 2012, pp. 3-4).

Looking forward, the U.S. DOE has summarized the difference in water type between the current fleet of thermoelectric power plants and the proposed cooling systems for 2016-2020. While there is a significant expected reduction of surface water, and a significant expected increase in dry-cooling, groundwater and reclaimed water remain similar for current and proposed systems (U.S. DOE, 2016, p. 31), as shown in Figure 2.1.

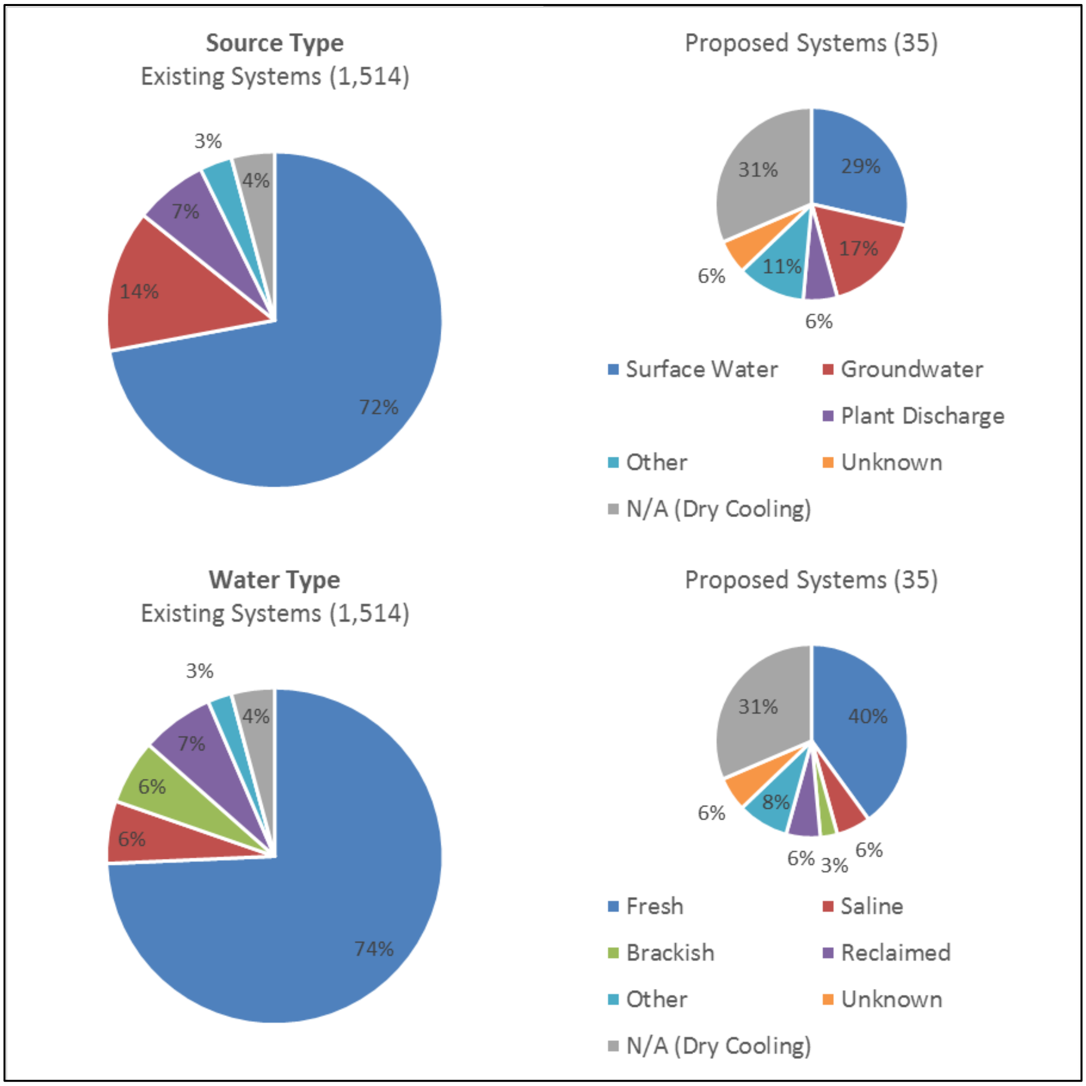


Figure 2.1: Number of existing and proposed (2016-2020) cooling systems by source type and water type (U.S. DOE, 2017, pp 31)

This aspect is important for planning, as it is easier to plan a new plant design for water conservation than it is to retrofit existing plants. One implication is that some power companies may be more likely to retire an older plant than to retrofit their existing equipment if water scarcity were to impact operations.

The issues discussed above apply generally to freshwater and reclaimed water use in thermoelectric power plants. The following section describes state-specific aspects of this issue that are applicable in the state of Texas.

RECLAIMED WATER USE IN TEXAS THERMO-ELECTRIC POWER PLANTS

The state of Texas is a key state in the energy-water nexus and an excellent case study due to its isolated electric grid, size, regional variation in power production and energy sources, and the extreme water variability across the state. State-specific statistics from publications mentioned above include an analysis showing that the typical American household uses 29 kW of electricity each day, and the typical once-through Texas power plant consumes about 10 gallons of water to produce that 29 kW of power (Mills, 2012, pp. 5-2). This number becomes more significant when you consider that the U.S. EIA recently identified Texas as the highest energy-consuming state every year since 1960; it was most recently identified as consuming 13% of the nation's total energy, as indicated in Figure 2.2 (EIA, 2017).

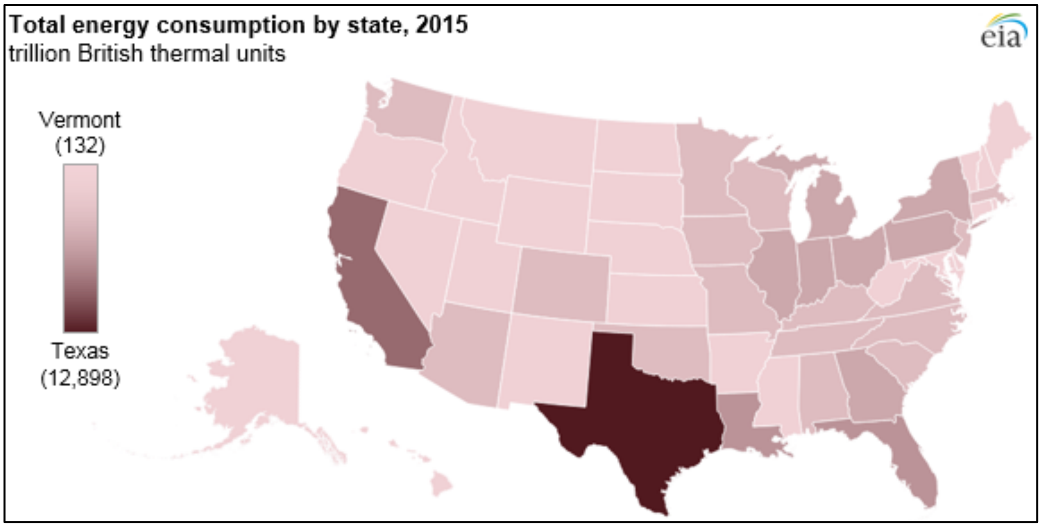


Figure 2.2: Total Energy Consumption by State (EIA, 2017)

Taking this data one step further, Figure 2.3 is provided in a report from the U.S. Geological Survey (USGS) indicating state-by-state geographic distribution of total water withdraws for thermoelectric power across the U.S. This work further states that the largest total withdrawals for thermoelectric power are also found in the state of Texas.

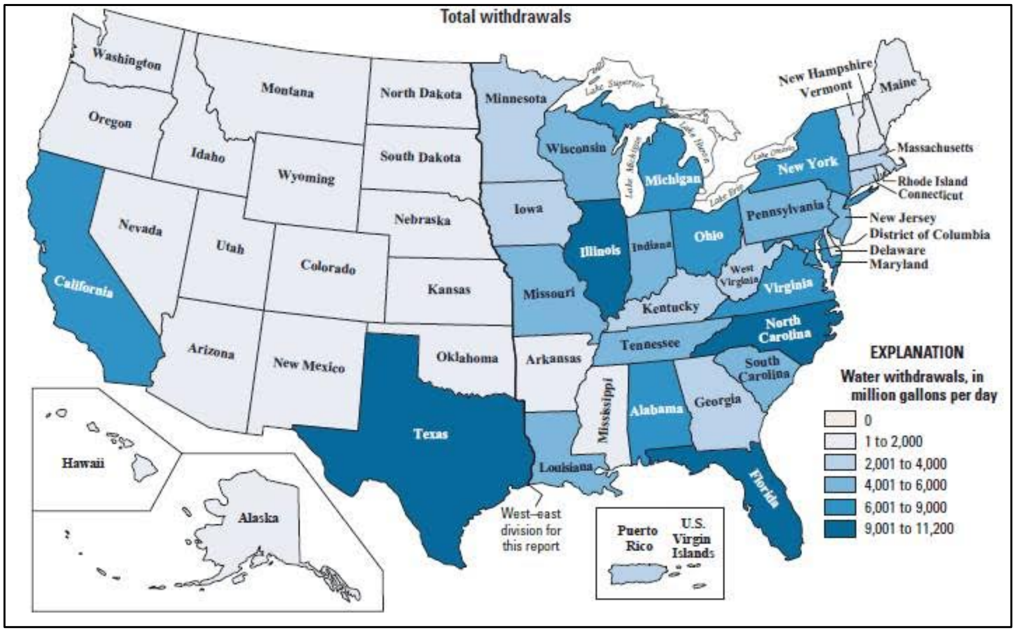


Figure 2.3: Thermoelectric-power withdrawals, by State, 2010 (USGS, 2010).

The freshwater *withdrawal* highlighted in Figure 2.3 for thermo-electric power plants in Texas is important; however, withdrawal essentially constitutes borrowing the water and returning it to the watershed. Freshwater *consumption* in Texas is primarily driven by irrigation and municipal uses as shown in Figure 2.4. The quantitative difference between withdrawal and consumption is likely why water use in the steam electric industry is hidden from the public debate that has historically focused on consumption. This reflection of freshwater use may lead to the lack of awareness regarding the significance of power plant cooling water and is revisited in Chapters Four and Five.

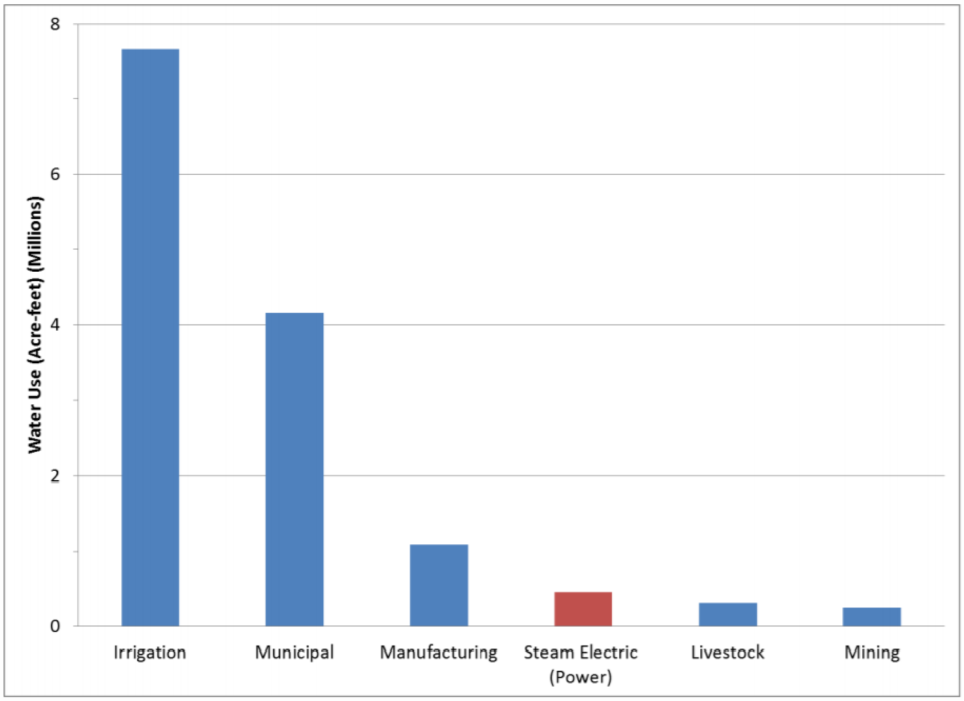


Figure 2.4: Water Use in Texas by Type (Stillwell, et.al, 2009).

Research at Argonne National Laboratory (ANL) indicates sufficient water supplies exist for power plants in Texas until 2030; however, all new development would require currently un-appropriated water sources. They furthermore identify 14 water basins that are currently targeted for the siting of new power plants in which water supplies are already severely limited, (Argonne National Laboratory, 2013, p. ix). Given the low priority that power plants are afforded for water allocation (Zammit, 2012), this may be an important foothold for planners to make a difference in the energy-water nexus.

I find this possibility especially promising considering that in 2016 there were only 16 self-reporting power plants in the state that reuse water. Using data provided by the Texas Water Development Board (TWDB) current as of 2017, I created Table 2.1 to list those 16 as well as the water basin they draw from, (TWDB, 2017). The term "reuse," as it is used here, includes both direct and indirect reuse. Direct reuse occurs when reclaimed water piped directly from a wastewater treatment plant. Indirect reuse is use of reclaimed water that has been discharged to a water supply source, where it blends with the water supply and may be further purified before being removed for non-potable or potable uses as shown in Figure 2.5.

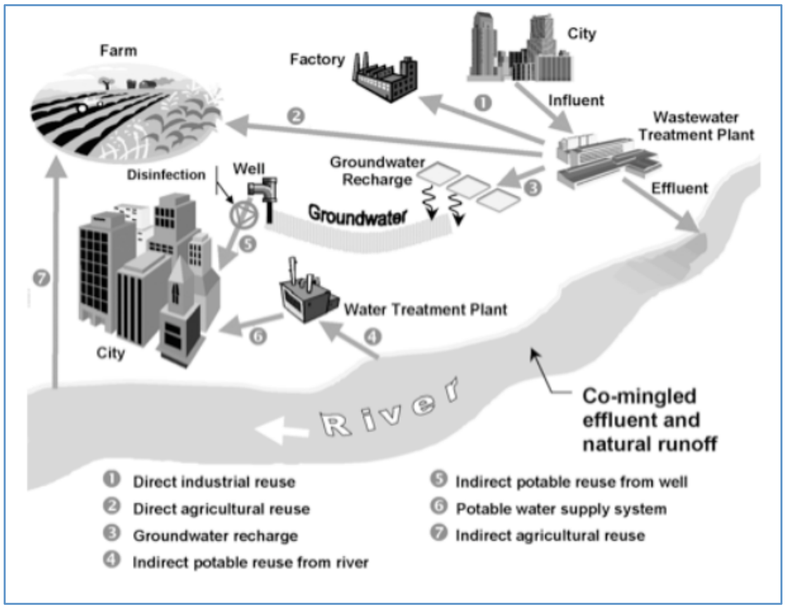
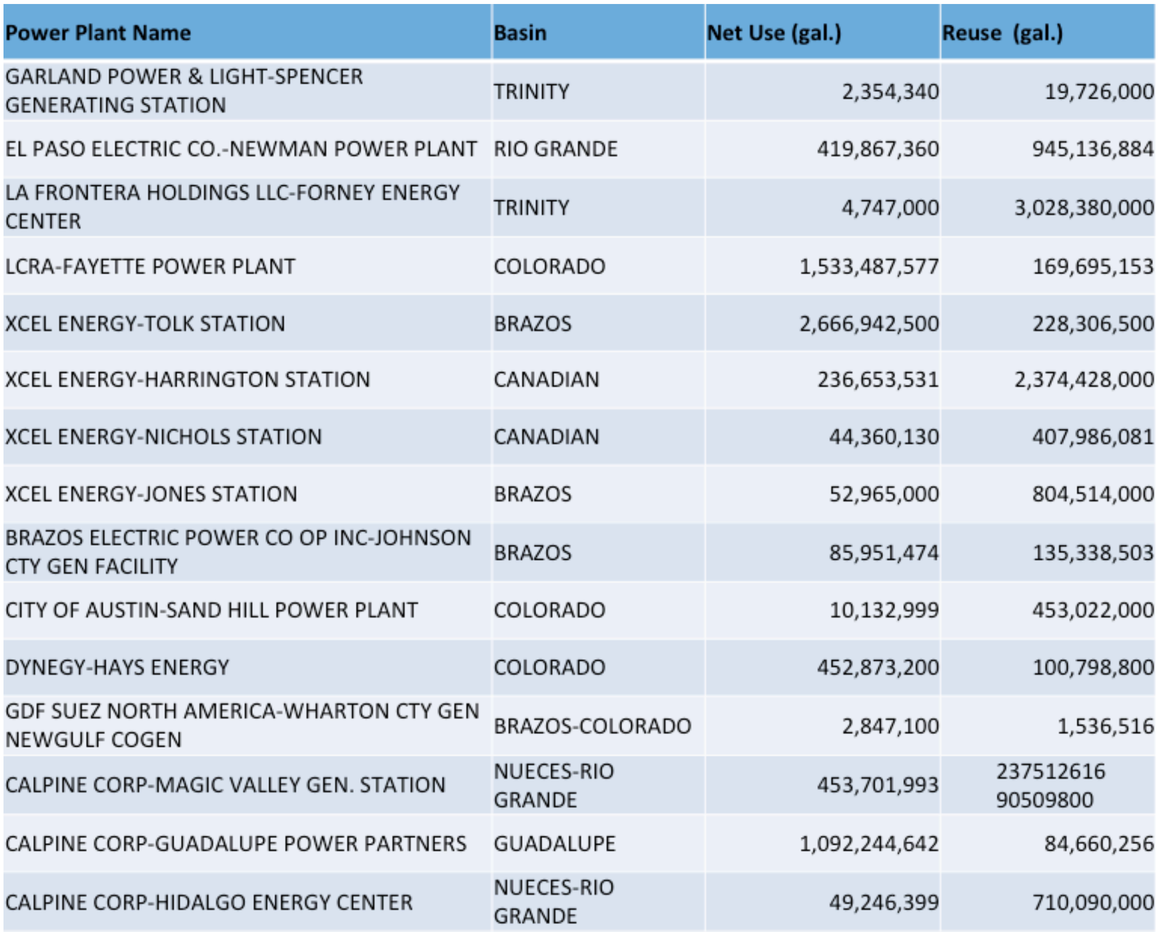


Figure 2.5: Direct and Indirect Recycled Water Use (California Recycled Water Task Force, 2008, p. 11).

To begin to understand why this number is so low, the literature search phase of this research indicates regulatory and economic aspects of this issue. In the following sections, each of these aspects are discussed, and examples are focused in Texas where applicable.

Table 2.1: Self-Reported Texas Power Plant Use of Reclaimed Water (Source: Author via list provided by Texas Water Development Board, 2017).



Power Plant Name	**Basin**	**Net Use (gal.)**	**Reuse (gal.)**
GARLAND POWER & LIGHT-SPENCER GENERATING STATION	TRINITY	2,354,340	19,726,000
EL PASO ELECTRIC CO.-NEWMAN POWER PLANT	RIO GRANDE	419,867,360	945,136,884
LA FRONTERA HOLDINGS LLC-FORNEY ENERGY CENTER	TRINITY	4,747,000	3,028,380,000
LCRA-FAYETTE POWER PLANT	COLORADO	1,533,487,577	169,695,153
XCEL ENERGY-TOLK STATION	BRAZOS	2,666,942,500	228,306,500
XCEL ENERGY-HARRINGTON STATION	CANADIAN	236,653,531	2,374,428,000
XCEL ENERGY-NICHOLS STATION	CANADIAN	44,360,130	407,986,081
XCEL ENERGY-JONES STATION	BRAZOS	52,965,000	804,514,000
BRAZOS ELECTRIC POWER CO OP INC-JOHNSON CTY GEN FACILITY	BRAZOS	85,951,474	135,338,503
CITY OF AUSTIN-SAND HILL POWER PLANT	COLORADO	10,132,999	453,022,000
DYNEGY-HAYS ENERGY	COLORADO	452,873,200	100,798,800
GDF SUEZ NORTH AMERICA-WHARTON CTY GEN NEWGULF COGEN	BRAZOS-COLORADO	2,847,100	1,536,516
CALPINE CORP-MAGIC VALLEY GEN. STATION	NUECES-RIO GRANDE	453,701,993	237512616 90509800
CALPINE CORP-GUADALUPE POWER PARTNERS	GUADALUPE	1,092,244,642	84,660,256
CALPINE CORP-HIDALGO ENERGY CENTER	NUECES-RIO GRANDE	49,246,399	710,090,000

Regulatory Considerations

With respect to the *water for energy* side of the energy-water nexus, there are several government agencies with various roles to consider. The roles of the U.S. government departments essentially break down as follows: (1) the U.S. DOE undertakes technology research and development (R&D) related work, which includes the Environmental Protection Agency's (EPA) role to regulate and research thermoelectric cooling systems, (2) the National Science Foundation (NSF) of the Department of Defense (DOD) supports energy-water nexus research, (3) the Department of Homeland

Security (DHS) has a responsibility to understand vulnerability of both water and energy infrastructure, and (4) the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) also support data collection and research (U.S. DOE, 2017, p. 15).

At the federal level, the Clean Water Act (CWA) is the primary regulation to consider for power plants using reclaimed water from municipal wastewater treatment facilities. Specifically, the CWA requires a permit for all discharges of pollutants to surface waters that may be issued and administered at the state level. In Texas, the Texas Commission on Environmental Quality (TCEQ) developed additional regulations for using reclaimed water. These regulations may be found in Title 30 of the Texas Administrative Code, Chapter 210 – Use of Reclaimed Water (Argonne National Laboratory, 2007, p. 210). The proposed state legislation to watch for in Texas is Texas House Bill HB4206, which would require new generating facilities who require an air permit to demonstrate sufficient water supply for their operations; however, this bill has been "left pending in committee" since 2009 (Texas Legislature On-line, 2018).

With respect to water rights, the Texas State Historical Association provides a concise summary of water right historical development in Texas that dates back 200 years ago to the Spanish settlement of San Antonio. Briefly put, surface water rights are often referred to as a junior-senior water rights system, or "first in time, first in right." This means that the first to secure the water right has higher priority to water than junior right holders, regardless of use. At the time of Spanish land grants, this system may have seemed logical and valid. Today, however, it is a source of confusion, malfunction, and injustice. In fact, the online handbook notes, "Even this brief overview of Texas water law should make it evident that the fragmented institutional structure governing water rights constitutes a formidable obstacle to achieving comprehensive and efficient water-resource management“ (Texas State Historical Association, n.d.). I will revisit in Chapter Five the two sides of “truth” to these colonial documents. On the one hand, these documents are as foundational as the Constitution and have a need for permanency; on the other hand, they need to be adjusted to adapt to the present situation, especially because basic human and ecological rights to water are at stake.

Economic Considerations

From an economic perspective, there are cost considerations to each plant design and cooling technology, as discussed in Chapter One. There are broader economic considerations, however, in the event that a power plant may have to shut down if insufficient water supplies exist. This is most likely to happen during periods of severe or extended drought. In the summer of 2011, for example, customers of the Lower Colorado River Authority (LCRA) were close to mandatory curtailment of water use per the state water plan. Shutdowns of the NRG power generation plant were narrowly avoided, and nearby plants were forced to use water from alternative river sources in order to keep operating (Galbraith, 2011). The potential concern is the economic impact of business interruption losses from blackouts and brownouts when productivity is interrupted.

Politicians contend that the economic impact from these events can also discourage job-creating companies from considering states with electric grid problems. A few Texas legislators are specifically connecting the economic impact to a reduction in new companies who may not be able to trust the Texas grid and the associated need for funding contingency plans for future energy needs parallel to long-term water plans for

Texas (Weissert, 2012). It is beyond the scope of this study to evaluate the validity of this concern; however, some studies stress that public decision-making can have an impact on the percentage of losses from power outages by restoring power to the sectors that contribute most to the gross regional product (Rose, 2004, p. 21). Calculating economic loss from drought is even more difficult due to the long timeframe employed, failure to frame the accounting boundary, overlooking non-market losses, and double counting (Cochrane, 2004, pp. 290-296). Overall, however, most drought economic impact studies do not address the issue of power generation.

The recent severe drought in Texas, which lasted from about 2008 to 2016, provides an excellent example of the potential economic impact of severe drought and illustrates the competing uses in the watershed that include power plant operations, specifically the Highland Lakes area shown in Figure 2.6. The Lower Colorado River Authority (LCRA) has created a water management plan for this area which is approved by the TCEQ in a manner that balances tensions between competing interests upstream and downstream of the City of Austin (LCRA, 2017, p. 3).

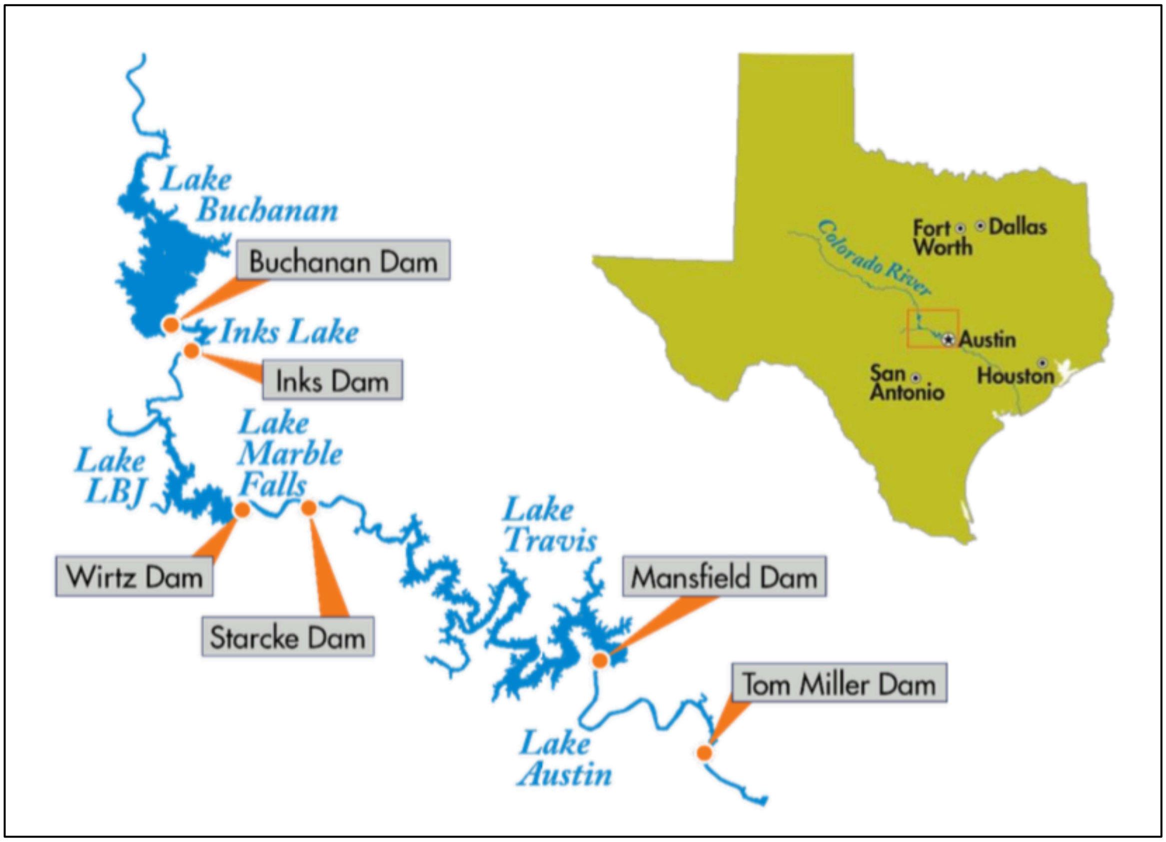


Figure 2.6: Highland Lakes Area Governed by LCRA (LCRA, 2017, p. 8)

This plan includes the requirement during times of drought to curtail the basin's two means of storing water, Lake Travis and Lake Buchanan, such that the basic needs of the downstream cities, businesses, and industries are still met (LCRA, 2017, pp. 8-9). As shown in Figure 2.6, this includes downstream power plants. Figure 2.7 provides a helpful visualization of the risk power plants face as regional water resources are severely strained.

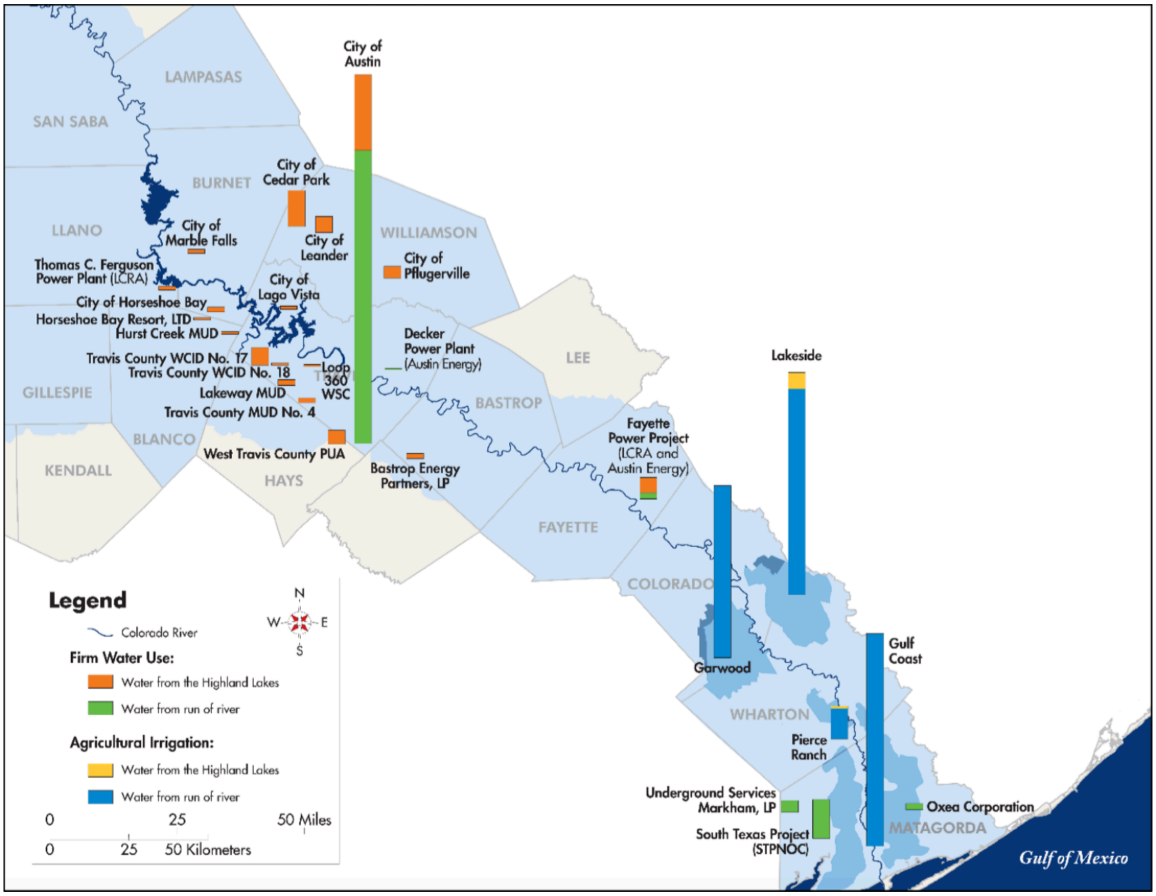


Figure 2.7: Highland Lakes Area Governed by LCRA (LCRA, 2017, p. 9)

Due in part to the drought, and in part to water being released for downstream interests, water resources in the lake community of Lake Travis became increasingly scarce, and the ripple effects extended to local economies. Loading and unloading docks and ramps became increasingly unusable as the water level went down and the lake level dropped, which then reduced the feasibility of accessing the lake. This period lasted for so long that restaurants and local businesses were not able to recover their losses and began closing down. This negative impact on business was felt from marinas and boat traders to reduced property values and reduced tourist activity. Overall, these effects hurt the local lake community's economy.

Despite the fact that power plants essentially borrow most of the water they use, during times of extended drought like the one experienced by the Highland Lakes, every drop becomes competitive. This is especially true in light of projected demands for water in a report from the Bureau of Economic Geology, which estimates that steam-electric consumption will grow to 8% of the state's total water demand by 2070 (Texas Water Development Board, 2017, p. 57). Encouraging new power plants to operate on reclaimed water could reduce at least one of the growing strains on existing freshwater sources.

The Special Case of Municipally Owned Utilities

To supplement the lack of power generation data in drought economic studies, one area for further study may be the impact that a severe drought may have on municipalities who count on power generation as a major revenue stream. Municipally owned utilities (MOUs) play an important role as a source of revenue for a municipality. In the state of Texas, there are 171 utilities of this type. One of these, Austin Energy, is located in Austin, Texas. As a power generator, AE's share of the summer statewide peak demand in the state of Texas was 4% of Austin's $3.5 billion in city funds in fiscal year 2013-2014, as shown in Figure 2.8. Thus, a suggestion for further study is to evaluate the potential impact a prolonged drought may have on the city's power generation and, thus, its revenue source. Determining this impact would contribute to the many factors that influence the ability, cost, and willingness of a power plant to switch to alternative water source. It should be noted that one difficulty in evaluating these factors is the tremendous variability from site to site.

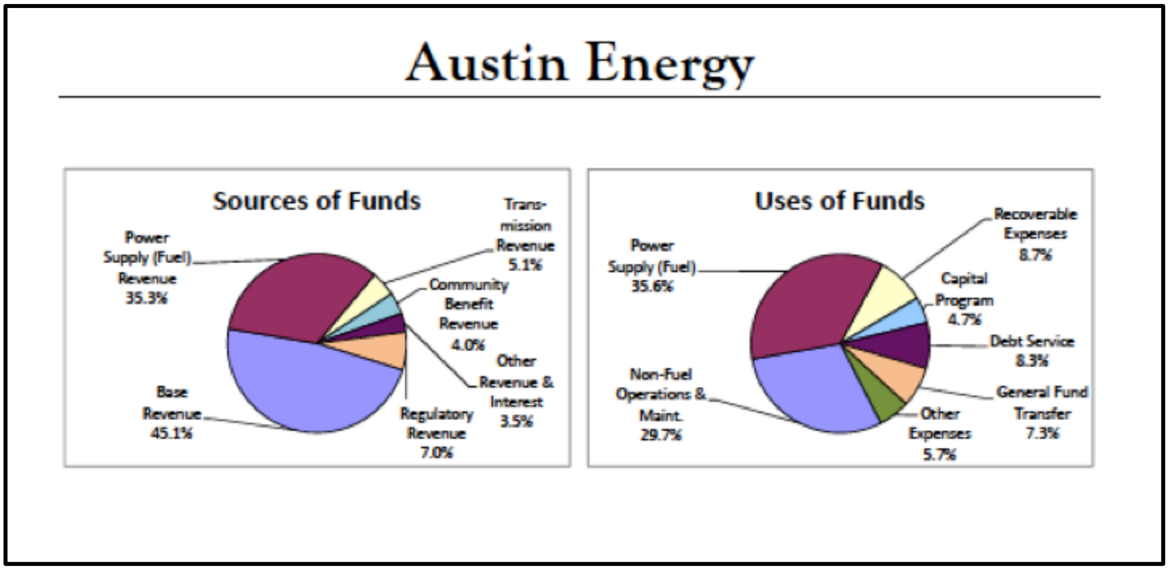


Figure 2.8: Austin Energy Relationship to City of Austin Funds (City of Austin, 2014)

SCIENCE &TECHNOLOGY STUDIES

A key takeaway from these two literature reviews of using reclaimed water in power plants is that existing literature is mostly, although not exclusively, dominated by the viewpoints of stakeholders in the electric and energy fields. More specifically, the majority of studies on thermoelectric power plants have been conducted by experts in these fields, including utility companies, electric or energy research institutions, and government departments.

This observation is consistent with a critique often noted in STS literature regarding the historical tendency towards and asymmetrical documentation of technology focusing on specific events, successes, and inventors. Two parts to this critique are: (1) sociotechnical groups may not be as likely to understand the social and political influence of their technical productivity, and (2) when one social group dominates the development of literature, they are not as likely to challenge themselves as they consider all of the alternatives.

Engineers, for example—such as those dominating the energy-water nexus literature—are not often trained to consider their individual role in history and society. As Feenberg describes,

> Engineering students do not have to learn how this or that regulation was translated into a design specification. The results are technically rational in themselves and presented as such. This gives rise to a characteristic illusion of autonomy... Their past is not a succession of decisions identifying the scientifically validated "one best way," but rather it is the result of social choice between several good ways with different social consequences. (Feenberg in Moore, 2010, p. 277)

Furthermore, when technical decisions lead to social impacts, the engineering-minded may have less understanding of the consequences. This is not to go so far as the claims of "tyranny of expertise" or "conspiracy against society" (Lieberman, 1972, and Illich, 1989, cited in Fischer, 2009, p. 21) that imply intent, especially a negative one; however, it is a recognition and example of a *knowledge is power* argument.

Second, due to the imbalance in information sources, the concern is that misperceptions about the technological challenges, influences, and perspectives of what is considered progress may be created when only a partial technological story is available. This is important and applicable to thermoelectric power plants because the financial power of a major utility company or research institution, for example, may directly determine what knowledge is collected about the use of reclaimed water in thermoelectric power plants. Intentionally or not, these organizations have the ability to fund private research, control what knowledge is distributed, and determine what research is funded and what research is moved to low priority. The bottom line of this issue is that certain types of knowledge or alternatives may never be explored if they are not supported with funding from these organizations.

This exclusion of alternative perspectives is problematic because: (1) these stakeholders are likely to have a technophilic disposition, defined as a disposition that technology is generally good (Moore, 2007, p. 21), and (2) these stakeholders are likely to use language that is less approachable outside of their field (Shapin & Schaffer, 1989, p. 343), and (3) these stakeholders are less likely to envision alternative systems that may not support governing interests. With a predisposition for technology, a tendency for discussion to emphasize industry-specific terms, and a reduced exploration of alternatives, the risk is that other viewpoints may be left out of important debates regarding technology's social, economic, and environmental impacts and range of possibilities.

These problems lead to a critical question posed by sustainability researchers: "How is knowledge to be connected to actions and decision-making that advance our visions of natural and social well-being?" (Bocking & Jasanoff cited in Miller, 2011, p. 3). This question also introduces the question of governance of these actions and decision-making. The power of science to constrain discourse can itself be a form of governance. Thad Miller explores this concept in his dissertation work on the relationship between institutional and epistemological context and societal outcomes with respect to sustainability (Miller, 2011, p. i). Here the concept of boundary work—science versus all other less authoritative non-science disciplines, as defined above in Operational Definitions—is employed. This boundary work leads to the construction of an epistemic authority that controls research goals as well as normative social and political assumptions and discussion.

Unpacking the concept of boundary work further, sustainability science adds a place-based element to the normative dimension assigned to sustainability from the various ways communities interact with and value their environment (Norton, 2005, cited in Miller, 2011, p. 7). This concept rejects a universal definition of sustainability and instead favors context-specific definitions and implementations from community to community, which are potentially a more effective use of science. This means a system of open-ended governance reflecting the sustainability values of each specific community that accounts for the conditions unique to the community in terms of natural resources, economic conditions, and so forth, across both locations and time periods. Miller points out one perspective on this type of sustainability is that although sustainability risks becoming an empty concept, it creates a framework for change (Loorbach cited in Miller, 2011, p. 35).

Finally, the concept of transitions management may be useful as it applies to the potential transition from traditional use of freshwater for power plant cooling needs to the possibility of reclaimed water as the new norm. Transitions management is defined as "a deliberative process to influence governance activities in such a way that they lead to accelerated change directed towards sustainability ambitions" (Loorback, 2007, cited in Miller, 2011, pp. 40-41). These authors point out that transitions management is not only a deliberative process, but also a continual one in the negotiation between actors and strategies. I revisit the implementation of this type of dynamic process as it applies to reclaimed water use in the final chapter, which discusses the implications of this study.

LITERATURE REVIEW CONCLUSIONS

The initial literature review of the energy-water nexus and the potential for reclaimed water use in thermoelectric power plants revealed a growing recognition and understanding of the technical feasibility, costs, logistics, and policies associated with this water use, as well as the need for more knowledge-sharing and cross-coordination between the two fields. Narrowing the focus to the state of Texas (which has unique advantages in terms of resources, isolated electric grid, and geography) further revealed steps authorities are taking to both mitigate and leverage the relationship between energy and water in the state, and specifically to understand the cooling water needed for power plant operations.

Despite an increase in research and recognition of the potential for reclaimed water use, the end-to-end impact to local and regional communities remains minimally understood. Due to the site-specific dynamics of each power plant and the dominance of engineering-based work in this field, the potential advantages and disadvantages of transitioning to reclaimed water need further study from a variety of perspectives outside of the current paradigm. This is important because increased optionality is key not just for helping communities survive the uncertain conditions of the energy-water nexus, but also for providing alternatives that enable communities to thrive in those uncertain conditions (Taleb, 2014, pp. 3, 171).

With these concerns in mind, my research design, described in Chapter Three, draws heavily on methods derived from Science and Technology Studies (STS). It was the initial intent of my research to utilize the visual and digestible products of interactive qualitative analysis to inform and broaden existing study of this topic in a manner that consciously recognizes the sociopolitical impacts to and from the existing dominance of technical approaches in literature and research efforts. As the tightly interrelated aspects of the social and political impacts became apparent, Naturalistic Inquiry emerged as a more appropriate method to capture these dynamics in a way that did not lead to an overly simplistic explanation. My overall goal for this study was to look for potential patterns that may exist in the decision-making of power plant water use and identify recommendations that could inform both those with high and low power to affect those decisions if necessary.

Chapter 3: Theoretical Framework and Methods

My interest in reclaimed water use in thermoelectric power plants is influenced by two distinct theories of planning, including the normative and communicative schools, and the adopted research design is influenced by both. First, my affiliation with environmental planning is based on a normative position that commits to sustainability as good urban form, as providing both the means and the reason to integrate social institutions, and as critical to future generations' ability to live in good health and well-being.

It is important to clarify here that a truly sustainable community would require stakeholders to shut down coal-fired power plants altogether, instead of retrofitting old ones to use reclaimed wastewater. While I certainly support the use of cleaner forms of power generation, I adopt an incremental perspective, recognizing that the transition to these power sources will take decades; in the process, advocates for sustainability will continually fight the vested interests of the current infrastructure. During this transition, I am committed to supporting efforts to capture the above-mentioned benefits of reducing freshwater use for thermoelectric power generation.

The trend in sustainability discourse from modern to postmodern is further discussed in the Modern and Postmodern Sustainability section of this chapter. This trend has led toward recognition of the complicated interaction and dynamic nature of energy and water resources. I drew on Complexity Theory to ensure that my research results reflect the need for interactive and adaptive approach in energy and water planning. I believe this type of critical evaluation using STS methods is especially important in the case of the energy-water nexus, which has many alternative paths and associated impacts that have not been thoroughly explored.

This leads to the second influence in my studies, which is based in the framework of the classical pragmatists who encouraged creative exploration to find "'what works,' in the 'messy world and practical enterprise of living'" (Healey, 2008, p. 278). To find what works with respect to the energy-water nexus, I rely on the communicative school of planning theory, which emphasizes the social context behind energy and water choices as well as each individual's development of understandings, meanings, and values associated with each alternative. The implication of this influence is also further discussed in the Modern and Postmodern Sustainability section of this chapter.

Before addressing how this study is guided by current use of these established theories in planning and research methods, it is important to lead first with a discussion of the specific historical thread in sustainability that informs my study.

PATRICK GEDDES AND THE HISTORIC ROOTS OF SUSTAINABILITY

While there are many historical planners, philosophers, and educators to choose from, I identify most with a forefather of sustainability, Scottish urban planner Patrick Geddes. The common theme highlighted in the many biographies and accounts of Geddes's work is the interdisciplinary nature of his thoughts and teachings on planning, sociology, biology, geography, and other fields. The energetic, holistic, and three-dimensional nature of his vision identifies and addresses problems and solutions across occupations and across time.

A key contribution of Geddes' work is his identification of a series of existing and future, yet also overlapping, societal phases. One of these phases, biotechnics, represents a time when life values are more important to society than monetary and material values. As such, Geddes inferred that policies, infrastructure, and economics, for example, become prioritized accordingly. According to Robert Young, examples of biotechnics include zero-waste systems; living and regenerative systems; active transportation; passive design; bioregional regulation; watershed councils; and the recognition of ecosystem, human, and non-human rights (Young, 2017, p. 8). All of these examples share a focus on life-sustaining methods, planning, and governance instead of neoliberal economically driven approaches. The Ecological Economics section of this chapter discusses Geddes' early work in sustainability and helps illustrate the implications of this work with respect to planning.

Ecological Economics

In the 1970s, ecological economics received broad attention as sustainability rose to a national topic. Book reviewer Tony Leiman explains,

> Students entering a foundation course in economics are often told, "economics is the study of choice; of decisions on the allocation of scarce resources between competing needs." Ecological economics extends this definition to include choices made across time and between generations. In doing so it debates competing views of technological advances, questioning the security they can offer, and interrogates the natures of welfare, growth, development and the measure of them. (Leiman, 2015, p. 1)

These founding concepts, however, had been expressed in the work of Geddes and other scholars long before the renewed interest in the 1970's. Of the many topics Geddes critiqued in the early 1900s, for example, he suggested that one failure of modern economics was its lack of non-monetary measures of progress. The traditional Marxist definition of profit is measured in terms of money and reflects the difference between the cost of production and supply and demand of finished goods. Geddes suggests instead that “profit was actually the interest paid by nature upon the matter and energy expended upon her during the processes of production” (Geddes, 1884, p. 18). Stated more simply, conventional economics does not tend to take the externalities (or what is referred to as output in Figure 1.6) into account. An unwanted health consequence of industrial air pollution such as asthma, for example, and the related health care costs are overlooked in typical calculations of profit and loss.

As an alternative, Geddes suggested ranking every action in society, especially production and consumption, on a moral and economic scale. He thought collecting this type of data would bring awareness to actions that disrupt unity between sociology and ethics (Geddes, 1881, 1884). In fact, Geddes was especially interested in measuring energy use in what he called an “Energy Balance Sheet.” He saw measurements of energy waste as a way to distinguish the difference between two of the other societal phases, paleotechnic and neotechnic. He described the paleotechnic society as one characterized by wasteful and damaging depletion of natural resources in pursuit of cheap energy, as opposed to an enlightened neotechnic society more focused on sustainability and energy efficiency (Geddes, 1912, pp. 176-187). In the neotechnic society Geddes envisioned, better data would lead to more informed decision-making and a better appreciation for society’s impact on the environment.

A current example of neotechnics is the smart electric meter, which shows the public the peak in energy demand at midday and may thereby encourage a behavioral shift toward using appliances during non-peak hours. This idea, however, relies upon a deterministic assumption that additional energy data will lead to more rational choices not just at the individual level but also at the societal level. This assumption is likely to break down for a variety of complex reasons, which will be further discussed in the

Modern and Postmodern Sustainability section of this chapter; however, the intention behind Geddes' work was to encourage societal transitions away from paleotechnic tendencies towards neotechnic, and eventually biotechnic, patterns of behavior.[12]

In summary, ecological economics is a subtopic of sustainability with clear applicability to the energy-water nexus. Scholars within this field recognize the interrelationships between human activity and nature, and they assert that better planning may enable societies to avoid negative consequences for both the environment and the population. The next section describes more recent trends in sustainability discourse, emphasizing the transition from planning under modern sustainability to planning under postmodern sustainability, in order to contextualize the complicated and dynamic nature of the variables under study.

MODERN AND POSTMODERN SUSTAINABILITY

Sustainability derives from the normative position that planners should guide citizens to balance economic growth and development with social equity and environmental impact. In modern sustainability, deterministic dialogue situates these three pillars as trade-offs between each other. The Planner's Triangle (shown in Figure 3.1), developed by planner Scott Campbell, illustrates the genuine clash of interest between outcomes that are socially just, economically productive, and environmentally friendly.

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[12] A fourth societal transition was also identified as Eutechnic, which is moving towards Outopla (No-Place) or Eutopla (Fair-Place) (Shillan, 2015, p. 13). See Shillan, 2015 for more complete descriptions.

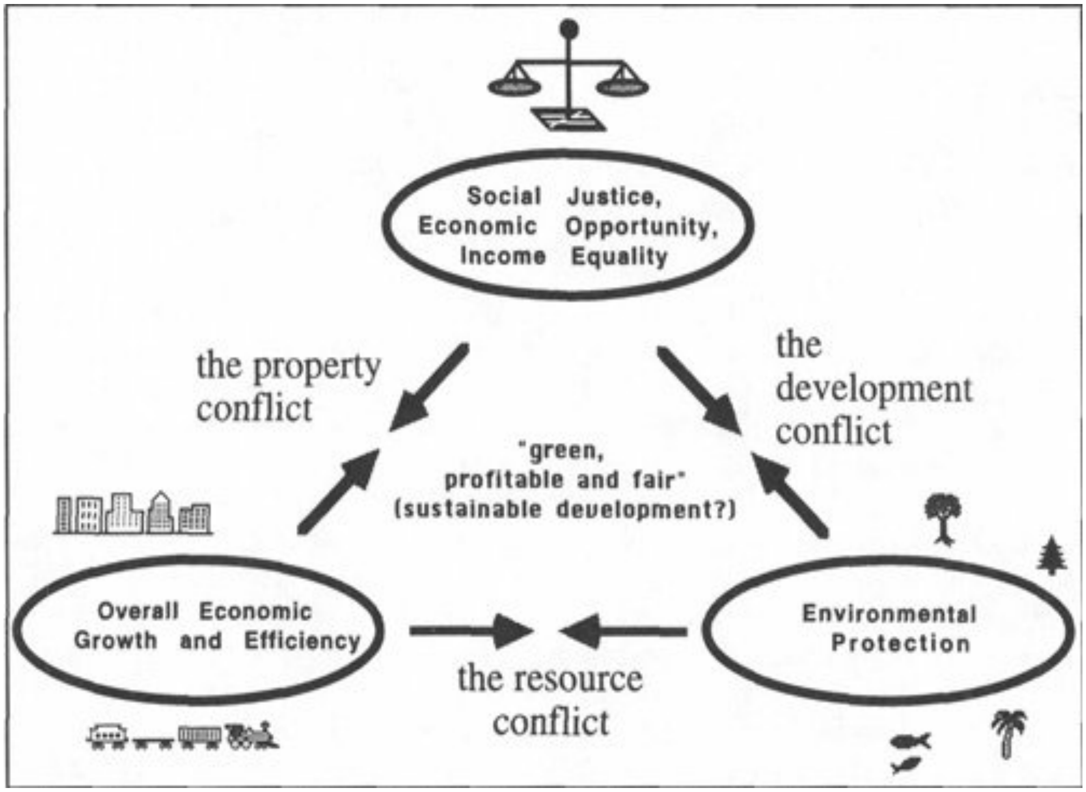


Figure 3.1: Planner's Triangle (Campbell, 2003, cited in Campbell and Fainstein, 2012, p. 415).

Campbell suggests that planners must address all three, "to grow the economy, distribute this growth fairly, and in the process not degrade the ecosystem,"(Campbell, 2003, cited in Campbell and Fainstein, 2012, p. 414). More specifically, sustainable use with respect to water has been defined as "the ability to maintain a current water use for the foreseeable future without 'unacceptable environmental, economic, or social consequences'" (Alley et al., 1999, cited in Chen, Roy, & Goldstein, p. 232). Thus, applying this concept to the energy-water nexus, Figure 3.2 illustrates a scenario of competing interests planners may face as they try to balance the environmental benefit of using reclaimed wastewater with the potential impact to social equity if utility rates increase to pay for the transition, as well as the economic impact of keeping energy costs from increasing.

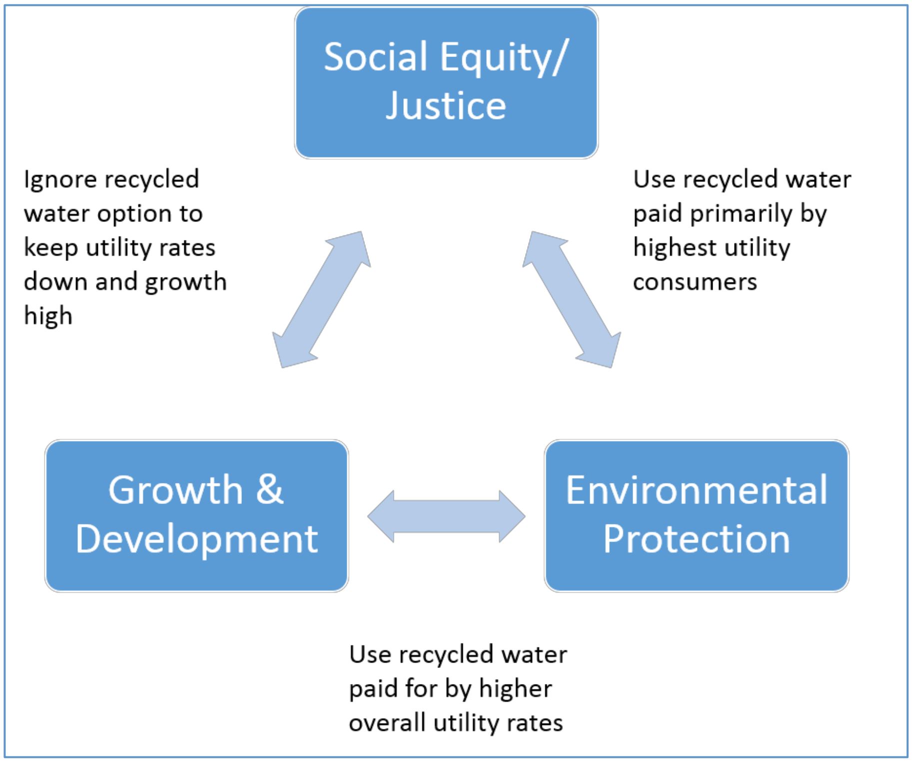


Figure 3.2: Applied Planner's Triangle (Source: Author)

This model reflects a *modern* perspective of the system that relies on simplistic relationships between the variables. A *postmodern* perspective, however, challenges the perception of perfect and continuous balance between these variables. In postmodern sustainability, a greater recognition exists that the variables are greater in number, in complexity, and in unpredictability than those three major pillars. Feenberg specifically points to technological change, for example, that may introduce a new means of providing a sustainable design without reducing profit. He identifies shifting boundaries that make it impossible to accurately measure whether one variable comes at the cost of the other (Feenberg, 2016, p. 279). One of the concepts found in STS literature that is related to this postmodern view is known as complex adaptive systems (CAS).

Lanham et al. describe the characteristics of CAS as having a "non-linear interdependence among agents and the dynamic nature of the landscapes on which sustainability is sought," and they suggest a perspective of sustainable development as,"a dynamic process of continuous evaluation, action, and re-evaluation" (Lanham et al., cited in Moore, 2016, p. 49). This perspective is applied to the energy-water nexus in Figure 3.3, which indicates the dynamic landscape of energy and water with which planners interact.

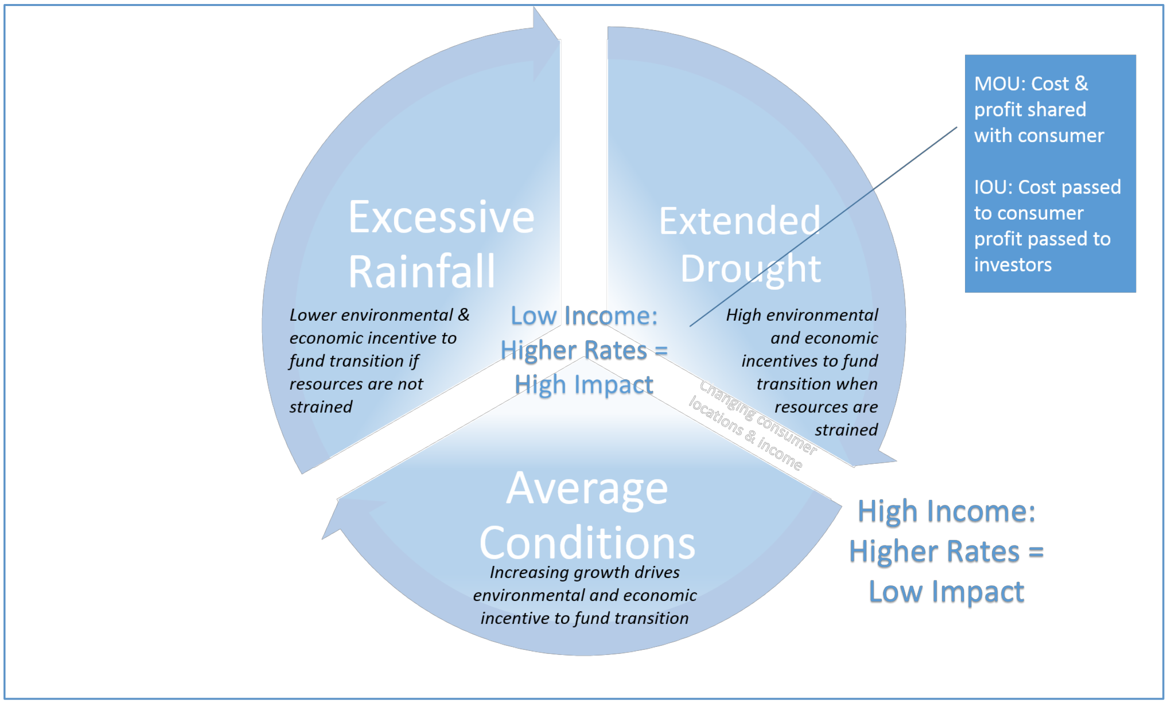


Figure 3.3: Reclaimed Water in Thermoelectric Power Plants as a Complex Adaptive System (Source: Author)

Key characteristics shown in Figure 3.3 that are likely to experience continuous change over time in the energy-water landscape include the following: (1) the incentive and competition for using reclaimed water may significantly change across climate conditions from excessive drought to excessive rainfall; (2) the decision-making process is likely to vary between municipal-owned utilities (MOUs), who share costs and profits with the public, and investor-owned utilities (IOUs) who pass costs to the public and share profits with their investors; (3) a change in utility rates may impact the public differently from high to low incomes; (4) over-allocated surface water may also impact individuals differently, such as reduced water available for low-cost recreation; and (5) the economic conditions from city to city may foster a slow-growth or pro-growth plan that may or may not support the use of reclaimed water for power generation. These conditions are explicitly studied here as part of my commitment to seeking a dynamic and flexible policy framework.

SUMMARY OF THEORETICAL INFLUENCE

While the Planner's Triangle and Geddes' thoughts on the competing interests served by modern economics are a helpful starting point to understand the tensions in the energy-water nexus, there is a growing understanding of the complexity within and between the economic, environmental, and social equity stakeholders. In the book *Pragmatic Sustainability Dispositions for Critical Adaptation*, authors Holly Lanham, Michelle Jordan, and Reuben McDaniel point out that there is significant divergence between stakeholders who hold each of these three perspectives, and each perspective itself contains its own tensions (Moore et al., 2016, p. 51). In some cases, growth and development efforts, for example, can have a positive equity impact on a community by adding jobs and bringing in tax dollars, while for other stakeholders, the effects of increased property taxes may be quite negative. With this additional complexity in mind, the Naturalistic Inquiry section of this chapter discusses the need for a more complex research methodology that could focus on interactions among these tensions as conditions change over time.

As mentioned previously, the relationship between energy and water is a developing field of study, as each of these industries has traditionally been considered independently from the other. My literature search suggests that there is significant room for coordination, information sharing, and understanding between professionals of each field, and that their relations may be improved through increased dialogue and communication. In addition to this need for increased understanding between professionals, my literature review indicates a need for further discussion of how other social groups may be affected by the energy-water nexus. Thus, the focus on *communities of inquiry* in the pragmatic tradition is an especially important tool for energy and water planners.

A joint learning approach will help planners understand the community's perception of the energy-water nexus, explore the range of associated impacts, and potentially expand consideration for future alternatives. What is important about this approach, as a tool for environmental planners and policy-makers, is that it equalizes viewpoints that may otherwise be overshadowed by powerful vested interests in current utility infrastructure. The application of this concept in seeking outcomes in the energy-water nexus is informed by the work of John Forester, who points out the difficulties of navigating toward rational outcomes with distorted information and power dynamics (Forester, 1989, p. 162). More specifically, my intention is to reduce the likelihood that choices in energy-water infrastructure primarily benefit private interests; instead, I aim to improve the ability of members of the public to point out and possibly redirect decisions that are in their best interest. As discussed in the next section, the complex nature of the energy-water nexus includes additional challenges as the public's best interests may change from high to low incomes, across utility jurisdictions, between weather patterns, among resource availability, and among changing market conditions.

NATURALISTIC INQUIRY

To study the interrelations and impacts of these conditions, I chose to study the energy-water nexus in the state of Texas. Given that most U.S. states are served by two electric grids that stretch across the rest of the country, Texas lends itself to a cleaner case study than other states because of the unique position it holds as a state with its own electric grid. Texas is also a key state of study in the energy-water nexus due to the size and regional variation in power production and energy sources, as well as the extreme water variability across the state. Due to the risk of severe drought limiting water supplies, water availability has in fact been listed as the electric industry's top concern in this state (Transmission & Distribution World, 2012, p. 12).

These issues are expected to become more severe as indicated by key statistics from the Texas 2017 State Water Plan. For the period from 2020 to 2070, estimates include an expected population growth of 70%, a 17% increase in water demand, and an 11% decline in existing water supplies. The plan includes 2,400 recommended water management strategy projects through 2070 at a cost of $62.2 billion, but it also estimates annual economic losses from water shortages starting at $73 billion in 2020 (Texas Water

Development Board, 2017, pp A-3). With these statistics in mind, the initial research questions I have studied through my literature reviews include:

1. What are the key interactions within the energy-water nexus that planners (in Texas) must consider?
2. What kinds of interactions lead to transformative hybrid policies and technologies?

Further investigating these questions led to the second set of research questions:

3. What are the common areas of understanding among utilities with respect to the energy-water nexus and their thermoelectric power plants, and where do these areas of understanding diverge?
4. How can the public have more agency in decisions about energy-water alternatives?
5. Can energy and water planners employ a guiding set of cohesive principles to better coordinate and promote these efforts and integrate their respective strategies?

Due to the cultural nature of these questions, STS scholars suggest that they are best suited for qualitative analysis using key informant semi-structured interviews. To guide me through the setup, conduct, analysis, and interpretation of the interview process, I initially relied on the Interactive Qualitative Analysis method which is documented in *Interactive Qualitative Analysis A Systems Method for Qualitative Research* (Northcutt &

McCoy, 2004). A key aspect of this research methodology is that it is designed for understanding a system of elements and the relationship between those elements. IQA accomplishes this through a series of phases including Research Design, Focus Group, Interview, and Report.

Ultimately, after struggling with the rigidity of this method and realizing its limited ability to absorb and react to the data I was collecting in interviews and additional literature research, I switched to Naturalistic Inquiry. This method involves different assumptions about context and the research process, as I explain in the following sections. Both methods study the reality of individual consciousness; however, in IQA, de-contextualization is considered useful and possible (Northcutt & McCoy, p. 17). With respect to my study, this template-like method meant the end results should create a system that describes reclaimed water use in thermoelectric power plants most of the time.

In contrast, in naturalistic inquiry, the intent is not to obtain generalizable results. Instead, this form of inquiry stems from an epistemological position that appreciates the relevance of the results which derive from the particular context being studied. What I appreciate about this perspective is that applying results to another context is taken as seriously as obtaining the results of the first context. With regard to the phenomenon of my study, water use decision-making for power plant operations, I believe the extra work it would take to apply results from plant to plant is a closer representation of reality than a generalizable system that could be usefully applied to all plants in every state, geographic, economic, political, social, and regulatory context. The following four sections discuss why and how I have transitioned to this method.

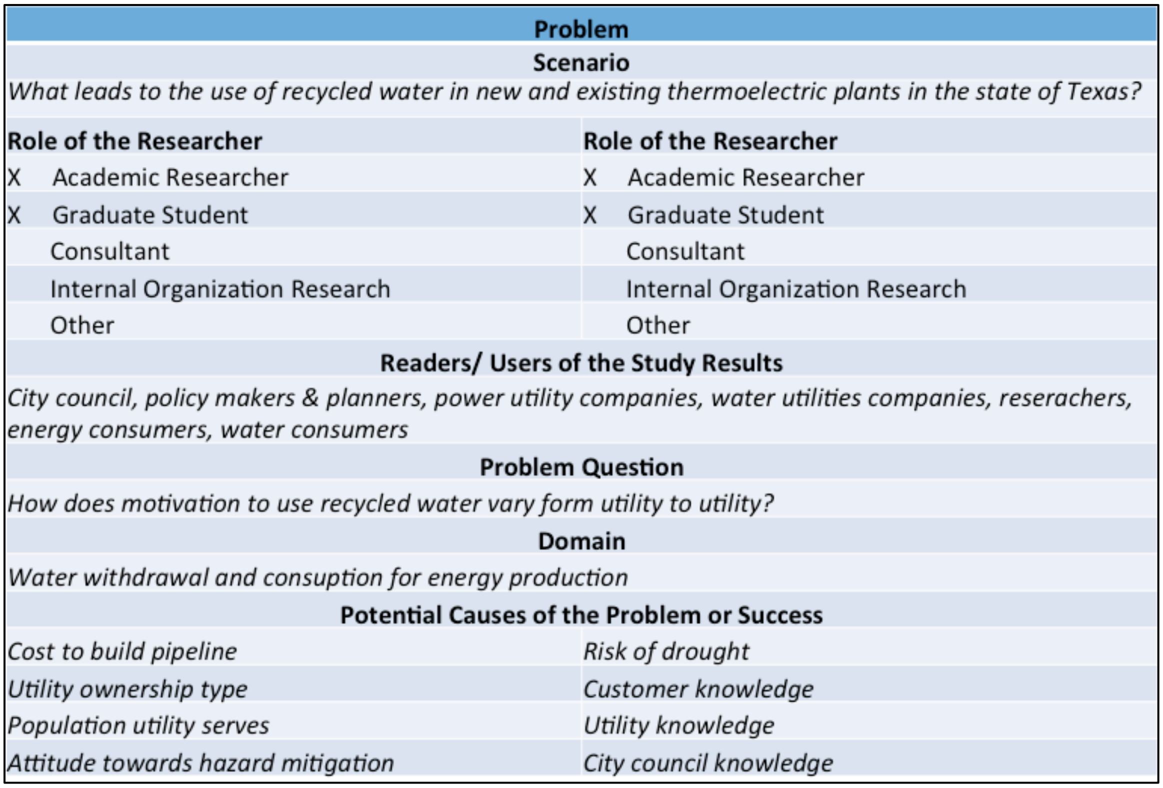
Research Design

Research design using the IQA methodology starts with identification of the problem or phenomenon, identification of constituencies, identification of comparisons of constituencies, and an issue statement. Identification of the phenomenon using this method may begin with a vague concern, an ill-defined phenomenon, or the need to correct a situation.

As noted in Chapter Two, the relationship between energy and water has been under-recognized in scholarship, and the two fields' potential for cooperation is currently limited by poor integration and knowledge-sharing. In particular, with respect to power generation, the ratio of thermoelectric power plants using reclaimed water is found to be significantly lower than those using freshwater despite viable technical feasibility. This knowledge, combined with my epistemological position (described in the Theory section of this chapter) that sustainability is a worthy goal for city planning, led to the general concern that the transition from freshwater to reclaimed water is poorly understood and may benefit from further study.

Through discussion with my IQA process guide and co-advisor, the following table was developed to summarize the problem. The larger domain of this study concerns water withdrawal and consumption for energy production, and the specific problem question is: *What is the motivation to use reclaimed water from utility to utility?* I anticipate readers of the results of this study may include city planners and decision-makers, utility representatives, the public, and other researchers. Based on my literature search, potential causes of the phenomenon are identified in order to begin to frame the study.

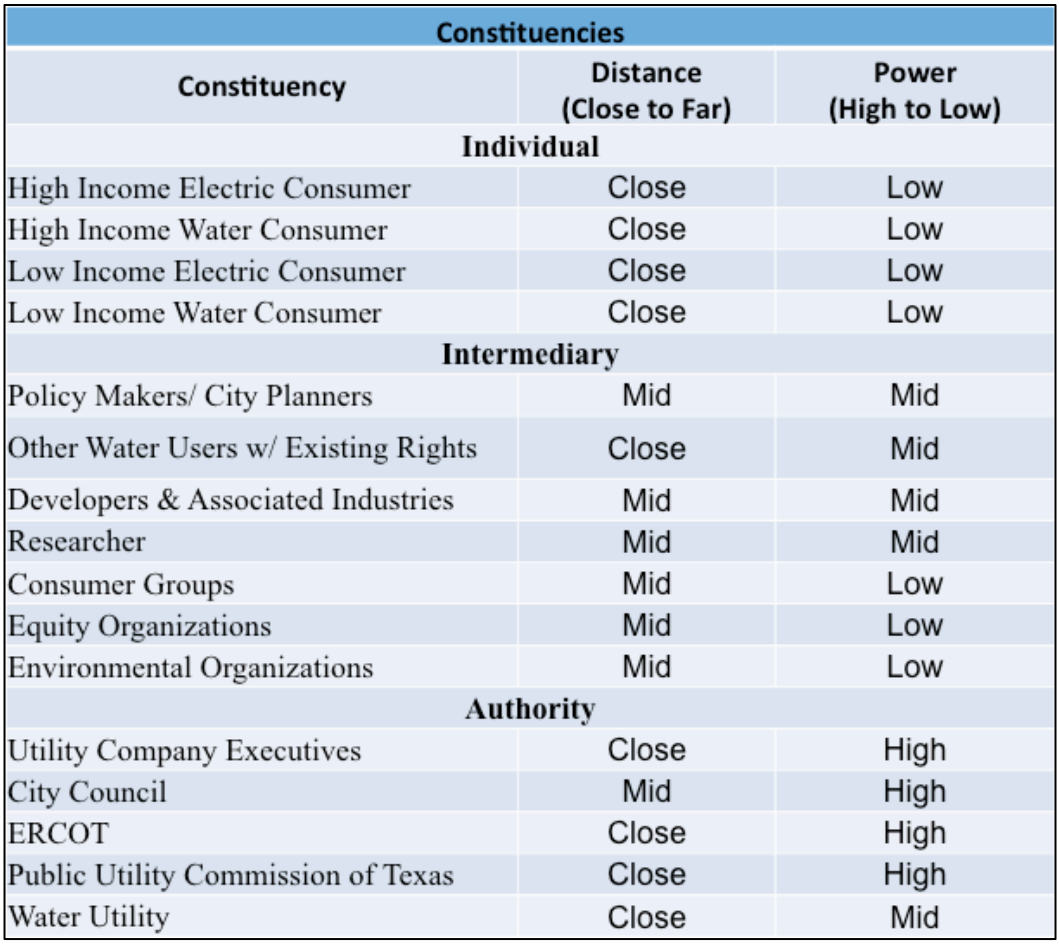
Table 3.1: Problem Summary



Problem	
Scenario	
What leads to the use of recycled water in new and existing thermoelectric plants in the state of Texas?	
Role of the Researcher	**Role of the Researcher**
X Academic Researcher	X Academic Researcher
X Graduate Student	X Graduate Student
Consultant	Consultant
Internal Organization Research	Internal Organization Research
Other	Other
Readers/ Users of the Study Results	
City council, policy makers & planners, power utility companies, water utilities companies, reserachers, energy consumers, water consumers	
Problem Question	
How does motivation to use recycled water vary form utility to utility?	
Domain	
Water withdrawal and consuption for energy production	
Potential Causes of the Problem or Success	
Cost to build pipeline	*Risk of drought*
Utility ownership type	*Customer knowledge*
Population utility serves	*Utility knowledge*
Attitude towards hazard mitigation	*City council knowledge*

Next, Table 3.2 begins to identify possible constituents of the phenomenon and provides an initial estimation of their distance to and power over the phenomenon. A critical distinction to make here is that this study is focused on understanding which factors impact the decision of whether an electric utility uses freshwater or reclaimed water. My position is that only by first understanding what leads to this decision can any effort be effective in trying to influence this decision. Thus, in this study, I have sought to clarify both *who* makes the decision, and *what* affects their decision.

Table 3.2: Summary of Constituencies and Distance/Power Relationships to Phenomenon



Constituencies		
Constituency	**Distance (Close to Far)**	**Power (High to Low)**
Individual		
High Income Electric Consumer	Close	Low
High Income Water Consumer	Close	Low
Low Income Electric Consumer	Close	Low
Low Income Water Consumer	Close	Low
Intermediary		
Policy Makers/ City Planners	Mid	Mid
Other Water Users w/ Existing Rights	Close	Mid
Developers & Associated Industries	Mid	Mid
Researcher	Mid	Mid
Consumer Groups	Mid	Low
Equity Organizations	Mid	Low
Environmental Organizations	Mid	Low
Authority		
Utility Company Executives	Close	High
City Council	Mid	High
ERCOT	Close	High
Public Utility Commission of Texas	Close	High
Water Utility	Close	Mid

Identification of constituencies and their assumed distance to the phenomenon and their power within the phenomenon was the first conflict I had in applying the IQA method. This step was never revisited; thus, from this point on the study was driven by my earliest understanding of the phenomenon. As part of the process, I worked with my methods advisor to review the constituent list and determine who would be interviewed. For this study, that meant deciding who was actually making water use decisions for each power plant. I had significant concern that I may not be correct in my understanding (based primarily on literature reviews) of how water use decisions were made. Despite the entire range of social groups I had identified within the system, following the IQA method meant that utility executives would be the only set of stakeholders to be interviewed, as I discuss below.

Alternatively, an important aspect of naturalistic inquiry with respect to research design is that a specific a priori theory or process does not drive the study. More specifically, this means that the new or revised theories are constructed as data is collected in the context of the study. The benefit of this method is that *the researcher is able to let the design of the study emerge as the researcher continues to improve their understanding of the phenomenon*. This is critical to my study of energy-water issues as I have found significant divergence between existing literature and interview data, and I believe it is an important component of naturalistic inquiry to be able to adapt as the researcher better understands the system. With respect to the early identification of constituents and decision-makers to be interviewed discussed above, the naturalistic inquiry method allowed for the interview list to be adaptive as I continued to develop my understanding of the phenomenon.

A specific example with respect to why opposite opinions existed are the two different opinions on the priority of power plant water rights I discovered across interview respondents. These conflicting responses confused me until I specifically dug into this exact aspect of water rights with a selected interviewee. The interview subject directed me to newly released documentation, a self-evaluation report from a sunset review of the LCRA, which explained that power plant water rights are sometimes considered firm and sometimes considered interruptible. This means the stored water in the Highland Lakes is available even in severe drought to firm water right holders, and may be curtailed in times of drought to interruptible water rights holders. The reasons for this distinction appear to be a complex and long story specific to the history and location of the plant. Given that prior existing documentation did not reflect this understanding, I believe it is highly beneficial to the study that the approach of naturalistic inquiry allowed me to continually integrate new data in whatever form it emerged.

Focus Group

In the second phase of IQA, the Research Design Protocol is used to identify participants for a Focus Group. The participants are chosen based on the IQA preference that they have some level of similar background or experience level with the phenomenon. For this study, I selected participants who lived/worked in the state of Texas and had some level of professional or academic relationship to the energy-water nexus. The focus group is ideally conducted as one co-located group in one setting; however in some cases, as is the case in this study (where participants cannot or are unwilling to travel to the same location), individual data collection may represent the focus group. In this study, individual data was collected both in person and over the phone, using the same process in both settings. Using the Focus Group Warm-up Exercise produced in the Research Design Phase, the participants were asked to brainstorm and reflect on their experience with the phenomenon in the form of bullet points, or one thought per card.

After collecting cards from all of the focus group participants, I organized or "clumped" the resulting cards into groups with similar meaning, and the naming and renaming (axial coding) process began. In IQA, a great deal of importance is placed on naming the affinities such that they have a range of meaning and timbre, and that they neither too specific nor too vague to be useful in the interview protocol. As stressed in

IQA methodology, it is important for the affinity names to facilitate communication with the participants as opposed to creating a barrier. The method stresses simplicity in order to trigger responses without initial explanation by the interviewer.

Emphasis is placed on narrowing down the meanings of affinities by combining, dividing, or renaming them until the smallest number of affinities reflecting the greatest amount of richness is achieved. After collecting focus group data, one thought per card, I initiated the "clumping and dumping" process on my own and suggested seven affinities including: (1) Competition for Water and a sub-affinity for Sources of Water, (2) Cost, (3) Supervision and a sub-affinity for Resource Planning, (4) Political Culture, (5) Physical Environment, (6) Change Over Time, and (7) Utility Company Type. In collaboration with my IQA process advisor, I revised these affinities to the following: (1) Authorities/ Regulation, (2) Water Access/ Availability, (3) Company Organization, (4) Resource Planning, (5) Plant Construction & Operations, and (6) Community Impact. In this manner, I reviewed, discussed, and critically analyzed the data in collaboration with others, thereby bringing additional value to the insights of the focus group responses.

Group data analysis is not a source of conflict between the two methods; both advocate for group analysis to strengthen the quality of the results. I point it out here to note this component of naturalistic inquiry was completed indirectly during the progression of working to IQA.

Next, the affinities are prepared for use in the interview protocol through a systematic process of renaming and reconciling affinities and identifying sub-affinities. In this method, the interview questions are typically created by the focus group participants; however, to test my resulting affinity names, I conducted several test interviews with the resulting interview protocol to obtain affinity names that improved communication and elicit more detail from the interviewees. The test interviews were conducted with non-interview subjects who reflect the community I am interested in before the semi-formal interviews began.

Interviews

Two aspects of interviews that need discussion include the anonymity of the interview candidates and the interview questions themselves. First, the initial candidates for interview subjects came from the constituencies previously discussed in Table 3.2. These included many relevant social groups including utility executives, city council members, members of the public in both low- and high-income groups, city planners, a selection of business owners in energy and reclaimed water fields, key public agencies, environmental protection organizations, regional government authorities, and equity advocates.

I made an independent decision to interview people from all of these social groups even if I could not use the resulting data in the IQA methodology. Thankfully, this decision led me to a far better understanding of the complicated ways in which the water used in a power plant is determined. *One of my key take-aways to date is that the answer to* the question "*who has the greatest power at the closest distance*?" *is mixed and needs to be understood on a case-by-case basis*. I also intentionally interviewed different ownership types of electric and water utilities and ensured that spatial context was accounted for by including a geographically diverse range of utilities across the state, all of which have varied availability of reclaimed water sources and production capability.

I was interested in observing the location of various utilities personally to get a better feel for the environment in which decisions about reclaimed water use are happening. This decision was strengthened by recent research suggesting the impact of water shortages on power plants needs to be evaluated at the local scale (Scanlon, Duncan, & Reedy, 2013, p. 2). This knowledge provides greater insight into how social frames, policies, and environments interact as they change over time and how all of these interrelated focuses may influence the transition to reclaimed wastewater.

The interview protocol includes an open-end axial interview to illicit a rich description of affinities by the interviewees, followed by a structured theoretical interview to identify the relationships between the affinities. As a result of the IQA protocol, which includes requesting interviewees to individually discuss each sub-affinity and each relationship between the affinities in a pre-determined order, I needed 43 different responses from each interview. As I conducted the interviews, however, I learned time was a major constraint on trying to collect 43 responses within the amount of time interview subjects were able or willing to provide. This led to grouping responses and often to interview burnout, with less description in the end than the beginning, irrespective of the respondent's opinion about which items were most important to cover.

The order of the interview questions began to trouble me as well, as their ranking is determined by which affinities the researcher believes are most likely to have the strongest influence on the system. This initial order is thus based on the researcher's literature review and focus group results, and it important to the IQA process not to change this order, even as the researcher develops a better understanding of the system. Under the naturalistic inquiry paradigm, data collection is conducted with an entirely different approach. Not only are all of the interviews considered in the analysis, but prospective participants' lack of time for interviews (or their choice to decline interviews) are important aspects of the context the researcher is trying to understand. In my study, I found a heavy reluctance to participate among individuals who work for private utilities. This trend is a piece of data that informs my understanding of the overall system; it is included in naturalistic inquiry, but it would not have factored into the formal IQA analysis, except in the limitations of the study discussed in the final report.

I also struggled with trying to treat each interview as consistently as possible and stick to the IQA script. In some cases where the interview participant warmed up to the interview and began discussing the affinities, it was difficult to keep the discussion compartmentalized by each affinity. Many of the affinities impact each other in complex ways, so each discussion involved more than one affinity. In some cases, during an interview, I tried to start fresh with the next affinity, and the interview participant responded that we had already covered that topic. Additionally, to discuss all 43 responses in the timeframe of the interview, I had to guide the interview respondent away from drifting too far from the affinity I was asking them about. With infinite time, I could ask what the responded believed was the most important aspect of the phenomenon at the end of the interview, but in reality, I could not even get close to all 43 responses by the end of the session.

The second key part of the IQA interviews is identification of the relationships between the affinities. Interviewees are asked to identify this relationship and describe it. In every case, my interview subjects stated that the relationships were too complicated to say that any one affinity drives the other, and that the reality was a much more complex inter-relationship. As opposed to this type of rigid cause and effect data collection, the naturalistic inquiry method identifies the complexity of relationships as *mutual simultaneous shaping*, as described here by the two original authors,

> Everything influences everything else, in the here and now. Many elements are implicated in any given action, and each element interacts with all of the others in ways that change them all while simultaneously resulting in something that we, as outside observers, label as outcomes or effects. But the interaction has no directionality, no need to produce that particular outcome… there is a plurality of shapers, with each becoming meaningful in ways that depend on varying circumstances or conditions. (Lincoln and Guba, 1985, pp. 151-152)

This reflection of complex interaction is more aligned with the feedback I was receiving from interview participants and I believe produced results that reflect this complexity as opposed to results that indicate a misleading attempt to clarify what most impacts water use decisions in an ordered list or one-dimensional diagram.

Analysis and Report

Another major distinction between IQA and naturalistic inquiry is that in IQA, all interview responses are anonymous, and the results are combined for analysis. This is aligned with the overarching goal to understand a phenomenon so well in one context that one could find a similar situation and understand it by understanding the first.

With the exception of knowing which social group the stakeholders represent, this restriction removes all other context from the interviewee's perspective. *In the case of my study, the highly contextual dependency of what county or city, geographic location, water district, regulatory structure, etc. the power plant has been or is being developed in significantly impacts how decisions about water use are made.* Throughout my on-going state of research I have yet to identify a way to generalize how these decisions are made that does not have to be adjusted to each case. The following figure is a summary of the geographic and stakeholder dispersion of my participants, which will be discussed further in Chapter Four: Results/ Analysis.

Table 3.3: Summary of Geographic/ Stakeholder Dispersion of Study Participants

Respondent Groups (Geographic Distribution)	Focus Group Participants	Test Interviews & Interview Memos	Interviews and/or ART, Interview Memos
Authorities/ Regulators		TX Regional	Federal, Highland Lakes
Utility Representatives	Cities in central and west Texas		Cities in central and south Texas (6 declined)
Business Owners	Statewide	Statewide	Statewide
"Select" Consumers		City in central and west Texas	
Environmental & Social Equity Advocates		All declined	Statewide
Educational/ Research Org	City in central Texas		Federal organization, City in central Texas
Continuous Document Collection & Review			

A second piece of data analysis is the attempt to understand variance across different stakeholders. In IQA the language of each interview response is analyzed to determine either positive or negative connotation and the individual and collective diagrams are color-coded accordingly. I appreciated this idea for the easy visualization to the reader that indicates the connotation of the variables and I intend to continue to study the connotation of the interviews within the naturalistic inquiry approach. In the IQA method, however, the responses are not attributed to their source which leaves out an important contextual understanding of why some responses seem negative and others positive. Business owners had negative connotations towards authorities and regulations, for example, but advocacy groups were more interested in making sure authorities and regulations are appropriately regulated.

The naturalistic inquiry method allows me to consider not only the connotation of each response, but also allows for consideration of the source of these responses and analyze why they may be different. I believe it is important for readers to understand why these are different from stakeholder to stakeholder and blindly combining results from only one of these stakeholders doesn’t provide the additional context to understand these dynamics.

Thus, while the IQA diagrams are a helpful visual aide, the predetermined nature of using a specific set of affinities determined at the beginning of the study is limiting in its ability to convey all of the nuances and complexity of the phenomenon. The flexibility of nationalistic inquiry method promotes the human as a research tool, and thus the flexibility to create visual interpretations that the researcher believes will be most helpful to readers.

STUDY LIMITATIONS

As with any methodology, data collection, and analysis, this study has limitations. My primary limitation for this study is data collection from all potential constituencies identified in Table 3.2. This section is intended to convey that as the researcher I understand these limitations and how they may impact the study.

Methodology & Interview Range

The origination of IQA in Total Quality Management (TQM) means one of the basic assumptions is that people closest to a job have the best understanding of what is wrong with the job and how to fix it. With respect to interview participants I found people closest to the job, in this case the very specific topic of "reclaimed water use in thermo-electric power plants" – did in fact have, *perhaps not the best understanding, but the only understanding I could capture of the job*. This result is consistent with the IQA assumption. Interview participants that are too distant from the phenomenon either declined to be interviewed, or tried to interview and had very little to convey about the topic of my study.

More specifically, participants who worked directly for a power utility or a tightly related organization tended to have the most experience and deepest knowledge of the subject and could respond to every affinity. Removing one step from that inner circle, I found knowledge to be a patchwork of information and in some cases included misinformation[13], such as the existence or accuracy of an existing regulation. Removing yet one step further from that inner circle I found almost no experience with the topic. Potential participants in this third category declined to interview due to their limited experience with the energy-water nexus, and especially limited awareness that power plants required water in their cooling systems. I found this to be true for all participants that I either interviewed or tried to interview that were in social groups with greatest distance to the phenomenon.

During the interview process, for example, I unexpectedly found the environmental and social equity groups in the later category of limited experience with

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[13] Misinformation is not taken lightly in this comment and is strictly intended to include the example provided with respect to existence of a law or regulation or policy. By misinformation I do not include cases were participants have different opinions, which was the heart of data collection.

the topic. As mentioned in the discussion of Figure 2.4, the reflection of steam electric water consumption may create a misconception about the industry's freshwater use when withdrawal is absent or essentially hidden from public discourse. I return to this in Chapter Five; however, the existing networks and communication platforms of these organizations potentially make them an excellent candidate to improve experience in the system.

A second example of limitations in data collection is that the identified stakeholders consist of large social groups that may miss key individual experiences in the system. One example of a key individual is the lone inventor who may have a unique understanding of the system and innovative ideas for alternatives. Two parts that contribute to their perspective staying hidden is that not only are these individuals difficult for a researcher to identify for an interview, but they also may not know how to gain attention for their idea.

As discussed in the Science & Technology section of Chapter Two, however, identification of what is wrong and how to fix a phenomenon is unfortunately limited if left to a specific set of social groups to share their perspective and consider alternatives. Feedback from only the social groups that are closest to the phenomenon may constrain the understanding and descriptions of what stresses decision-makers balance when determining the water source for a particular power plant. Specifically, there is a concern that those closest to the phenomenon may: (1) think and act within the same pre-disposition, for example – technology or existing infrastructure, (2) may be limited by their similar social, educational, and institutional frameworks, or (3) may have similar vested interests in minimal change to the status quo.

Thus, working with data that could be handicapped by any of these three concerns means the results could miss a different perspective of the phenomenon as well as different perspective of how to fix the phenomenon. This leads to the second key study limitation which is *the lack of participation by private utilities and their missing perspective in my data that may include different insight into how to influence the phenomenon*. The data I have collected so far suggests people do understand water use decisions are political and it is rational that everyone has their own interests in the phenomenon. In the final chapter I speculate within reason about what the interests of private utilities are in order to further the conversation of the social understanding of these decisions.

Chapter 4: Analysis of "Water Use Decision Making in Thermoelectric Power Plants" System Elements

The intent in the first half of this chapter is to describe the primary variables within the system of "Water Use Decision Making in Thermoelectric Power Plants." As shown in the top left of the process diagram in Figure 4.1, these variables were first determined by conducting a focus group in which a group of participants were asked to freely write all thoughts about the system. Similar thoughts were then categorized into *units of meaning* that reflect the participant's feedback about the system instead of my own reflection of what I saw as the variables of the system. These categories are known as *affinities* in the IQA method but are typically referred to as *codes* in STS studies. I will refer to them as codes to be consistent with STS literature at large. The initial eight codes listed on the left of the diagram became the basis for an interview protocol which was used to evaluate how the range of interview subjects interpret these units of meaning. I refer to their interpretation throughout the rest of the chapter as the participant's *frame of interpretation*. An in-chapter summary of these terms is provided below in Table 4.1 for reference.

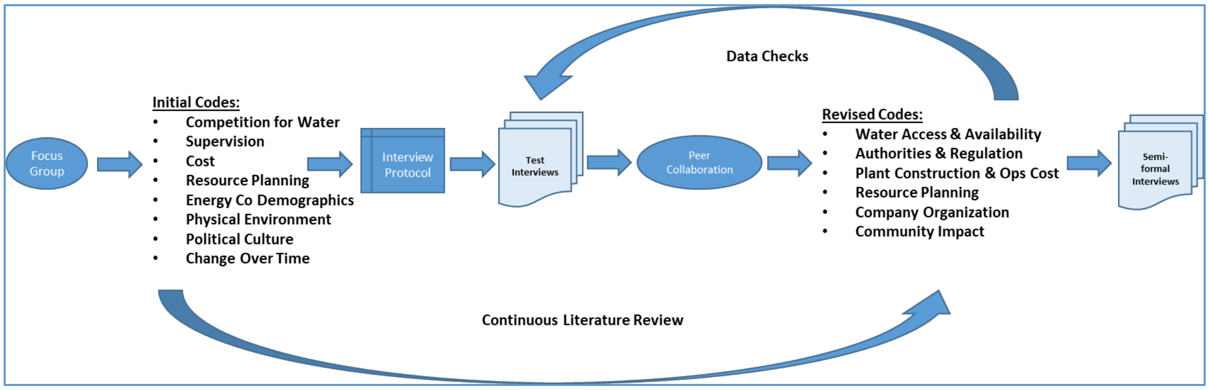
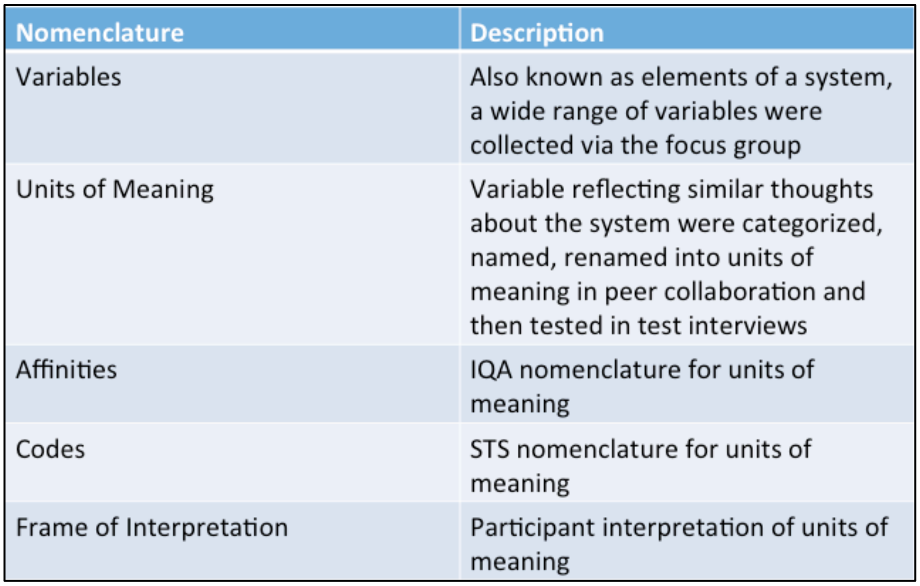


Figure 4.1: Code Development Process (Source: Author)

I also tested these codes in a handful of test interviews. My intention for conducting test interviews was to test the language I developed for the code names to describe what the focus group data actually meant to respondents and clarify language that would cause confusion or need explanation in the next phase of semi-formal interviews. It is important that the names chosen for these units of meaning did not require significant explanation from me during the interview, or convey a positive or negative connotation, so that the interview data would reflect the participant's perspective instead of my own perspective. Therefore, after the test interviews I discussed the codes that seemed to generate confusion in peer collaboration with one of my advisors and we lightly revised them to the six codes listed on the right of the above diagram. The changes made to the code names are described below. Along with descriptions of each code name, I also provide highlights from interviews that briefly indicate in the participant's words their experiences with these areas of the system.

Table 4.1: Clarification of Nomenclature



Nomenclature	Description
Variables	Also known as elements of a system, a wide range of variables were collected via the focus group
Units of Meaning	Variable reflecting similar thoughts about the system were categorized, named, renamed into units of meaning in peer collaboration and then tested in test interviews
Affinities	IQA nomenclature for units of meaning
Codes	STS nomenclature for units of meaning
Frame of Interpretation	Participant interpretation of units of meaning

CODE DESCRIPTIONS PRE- AND POST- PEER COLLABORATION

To increase transparency in how code names were chosen, this section describes the original code names that resulted from the focus group and were used in the test interviews. For a variety of reasons discussed in detail below, the results of the test interviews were analyzed in peer collaboration and lead to a revised set of code names used in the actual interviews. The first “From” column of each table below includes the original code names and the individual thoughts that led to those names. The second “To” column includes the revised code names and the re-organized position, or the combining of the individual thoughts that led to them.

Code 1: From *Competition for Water* to *Water Access and Availability*

Competition for Water is the code the focus group participants used to describe the competing uses of water that may impact the "Water Use Decision Making in Thermoelectric Power Plants" system. As described in Chapter One, the availability of water has a critical impact on steam-driven power plants which require sufficient water supplies to run their cooling operations. One of the participants from a university organization described competition in the following way,

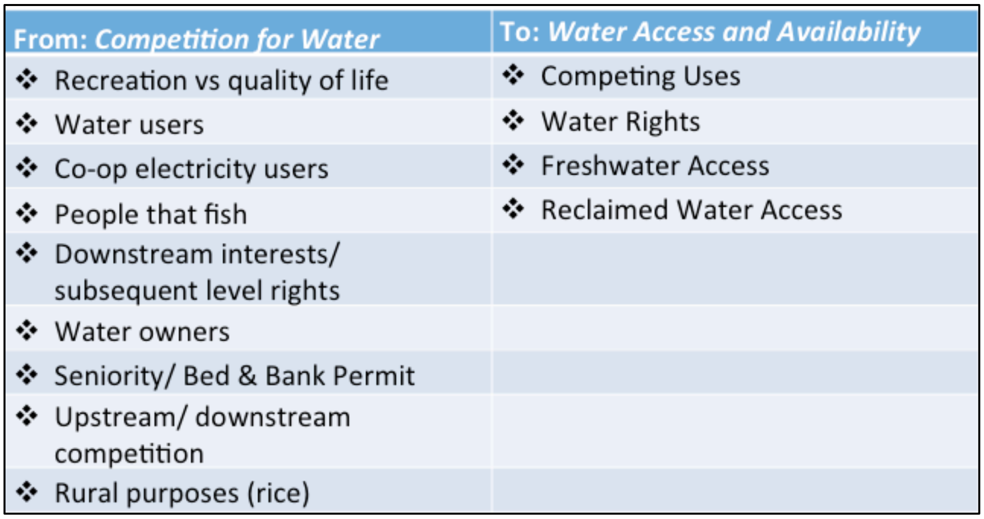
> *Very stiff high competition, more by the day. Water resources are getting to be, a determining factor in thermal power plants. The water wars are getting greater for many types of thermal plants. It simply isn't an option if the resources aren't there. (University Organization Test Interview)*

The thoughts identified by the focus group that led to the code name *Competition for Water* range from agricultural use for crops and livestock to recreational use such as fishing and swimming as reflected in the focus group results in the first column of Table 4.2. They also include water users with grandfathered water rights as described in the literature review of Chapter Two and the utility interview quote below, and new water users trying to secure their own water rights.

> *Existing rights holders might feel one of two things. "Gosh is this going to effect my ability to get water?" Two, they might be wanting to utilize their water rights to sell to the plant. Those water rights are take or pay contracts…, paying a lot and you're not really using them." (Central Texas Utility Interview)*

Due to the slightly negative connotation of the word competition, my IQA advisor asked me to revise this code name to language that had less *a priori* connotation. Thus, the *Competition for Water* code was revised to *Water Access and Availability* as shown in the second column of Table 4.2 and the associated thoughts from the focus group were regrouped as well. “People that fish” and “rural purposes (rice),” for example, are now combined as “Competing uses” in the *Water Access and Availability* Code.

Table 4.2: Summary of *Competition for Water* Code.



From: *Competition for Water*	To: *Water Access and Availability*
❖ Recreation vs quality of life	❖ Competing Uses
❖ Water users	❖ Water Rights
❖ Co-op electricity users	❖ Freshwater Access
❖ People that fish	❖ Reclaimed Water Access
❖ Downstream interests/ subsequent level rights	
❖ Water owners	
❖ Seniority/ Bed & Bank Permit	
❖ Upstream/ downstream competition	
❖ Rural purposes (rice)	

An important aspect of *Competition for Water* reflected in the test interviews was the time sensitive nature of the strength of competition. Participants left strong indications that when water sources are strained competition is intense and reflected a negative connotation; conversely when water sources are available competition seemed to exist more peacefully. The impact of this timing sensitivity is further discussed in Code 6: *Change Over Time*.

My own interpretation of this code is that competition, while removed from the title of the code for the purposes of the interview, is the key language that came up in most interviews with the most passion. It is my understanding that when the rivers are flowing this competition is manageable, but during periods of drought the difficulty of balancing competing tensions escalates very quickly. Additionally, most of the sources included in my literature reviews indicate existing competition will increase due to increasing water demands; however multiple interview subjects from regional and federal government organizations indicated the amount of water is less of an issue than managing the people themselves. Thus, when discussing and reading about this code I found widespread disagreement and misunderstanding of how competing uses emerge, how they are governed, and how they are mitigated. In other words, part of the conflict is resource scarcity and part of the conflict is that *each relevant social group experiences water availability differently*. This indicates resolution of the conflict is not simply about redistributing water access and availability, it is also addressing various perceptions of the system. I explore this further in the Planning Implications of Chapter Five.

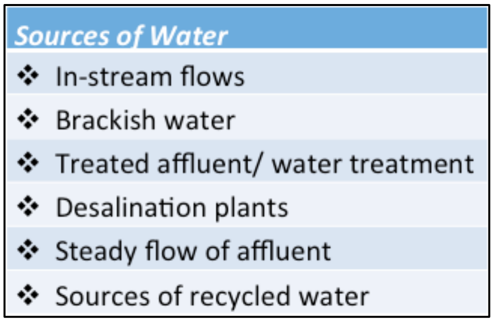
Sub-Code 3.1: Sources of Water

Sources of Water is the sub-code name identified to reflect the focus group participants' identification of various sources of freshwater and reclaimed water that may impact the "Water Use Decision Making in Thermoelectric Power Plants" system. This includes the various levels of treated water from brackish to fully treated effluent as described in the literature review in Chapter Two. A Central Texas utility participant describes an important difference between freshwater and reclaimed water as the following,

> *Depending on where you are in the state, availability in the river system is completely different than availability of the reclaimed. Water off the sewer is rock steady solid and always there. (Central Texas Utility Interview)*

The sources of water identified in the focus group are listed here in Table 4.3. This sub-code was later absorbed by the *Water Access/ Availability* code after peer collaboration revised the code name to language that included these thoughts.

Table 4.3: Summary of *Sources of Water* Code.



Sources of Water
❖ In-stream flows
❖ Brackish water
❖ Treated affluent/ water treatment
❖ Desalination plants
❖ Steady flow of affluent
❖ Sources of recycled water

My interpretation of this former sub-code is that the sources of water will become more and more creative as the competition increases as the following interview quote from a regional electric authority suggests,

> *We were building combined cycle power plants which were more modern or new and we had some plants that were already buying recycled water from a carpet manufacturer's wastewater… It was cheaper to get that recycled water than it was to get a water source that would have been cleaner. (Regional Authority/ Regulator Test Interview)*

When discussing the differences between sources there are frames of interpretation that recognize all water is reclaimed, and another range of viewpoints that feel considerably different about the level of treated water and their associated use. I also discuss this in the planning implications of Chapter Five.

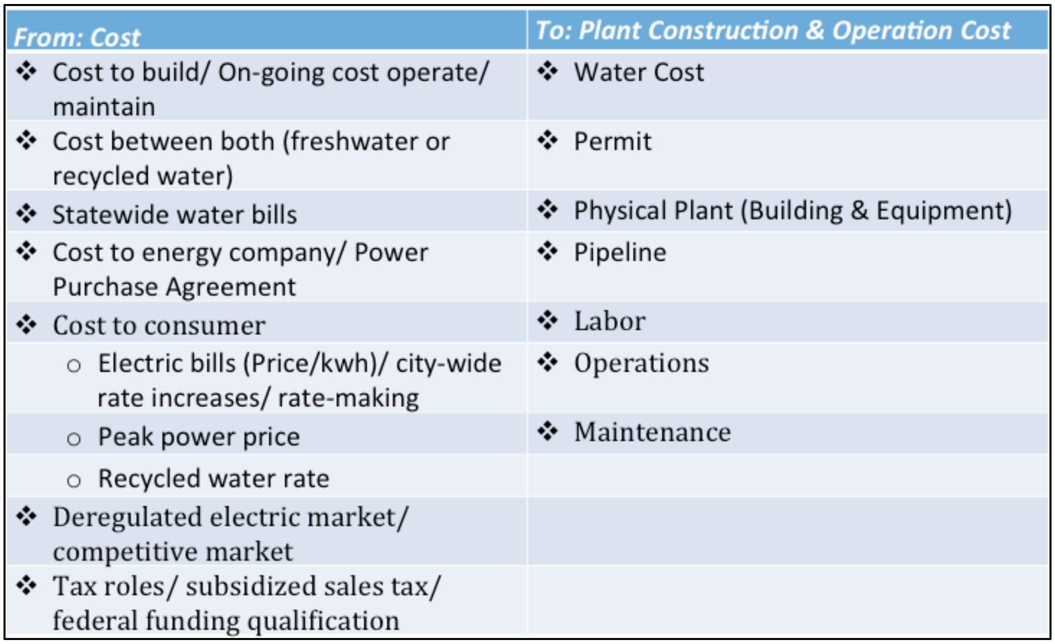
Code 2: From *Cost* to *Plant Construction & Operation Cost*

Cost represents the original code name reflecting focus group participants identification of various costs associated with the "Water Use Decision Making in Thermoelectric Power Plants" System. As shown in the first column of Table 4.4, this affinity name reflects not only the cost to the energy companies, but also consideration for costs passed to the public in utility rates. Additionally, it includes the differences between freshwater and reclaimed water in up-front costs such as pipeline construction to a wastewater treatment plant versus a freshwater reservoir, but also long-term costs such as operations and maintenance. Taxes, subsidies, and other federal funding could also impact how much of this cost is passed to the utility companies and the public. The way that all of these contribute to cost is complicated and difficult to understand as reflected in the following interview with a public citizen,

> *Our rates keep going up, but I don't know why. (Public Citizen Interview)*

The name of this code was narrowed in scope during peer collaboration to *Plant Construction & Operation Cost*. The test interview results indicated *Cost* was too broad to elicit a detailed response about the same topic from interview to interview thus, we limited the possible frames of interpretation to obtain meaningful responses.

Table 4.4: Summary of *Cost* Code.



From: Cost	***To: Plant Construction & Operation Cost***
❖ Cost to build/ On-going cost operate/ maintain	❖ Water Cost
❖ Cost between both (freshwater or recycled water)	❖ Permit
❖ Statewide water bills	❖ Physical Plant (Building & Equipment)
❖ Cost to energy company/ Power Purchase Agreement	❖ Pipeline
❖ Cost to consumer	❖ Labor
o Electric bills (Price/kwh)/ city-wide rate increases/ rate-making	❖ Operations
o Peak power price	❖ Maintenance
o Recycled water rate	
❖ Deregulated electric market/ competitive market	
❖ Tax roles/ subsidized sales tax/ federal funding qualification	

Based on existing literature, my expectation of this code at the beginning of the study was that cost would be a key factor in determining the water source for a power plant. The reality expressed to me through the interviews from utility managers, wastewater treatment plant managers, and utility construction companies, however, was that although it is important to be able to estimate these costs, the cost itself is a minimal deciding factor between freshwater and reclaimed water. I discuss this further in the "Indications of Patterns in Decision-Making" section of this chapter; however, my takeaway is that power plants are not driven to look at reclaimed water until their freshwater sources aren't available and at that point there aren't many other choices. As expressed in an interview with a wastewater treatment plant manager,

> *If we are close to using all of our water resources then it is time to think outside the box. Desalination is an option, but it is more expensive. (Wastewater Treatment Plant Interview)*

These comments lead me to believe *it is the extreme variation in overall cost and availability that are more disruptive to the system than the initial cost, likely due to the fact there are few interchangeable resources.*

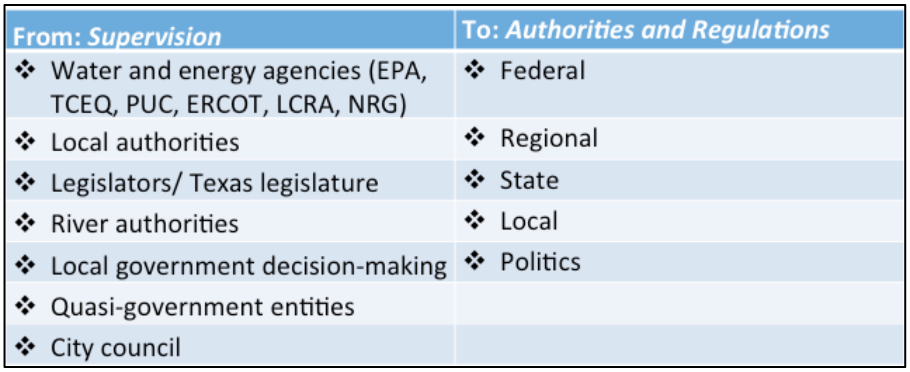
Code 3: From *Supervision* to *Authorities and Regulation*

Supervision is the original code name chosen to reflect the focus group participants thoughts describing the various regulatory entities associated with the "Water Use Decision Making in Thermoelectric Power Plants" System. This includes not only the organization, but also the rules, regulations, and laws that they produce and the influence they have on the system, shown in the first column of Table 4.5. Participants noted the strong impact that operating within the current regulatory structure has on the decision, but also noted the impact of what the expected changes coming to the regulatory structure have on the decision as reflected in the following quote from a regional electric authority. Again, the impact of this timing sensitivity is captured more distinctly in Affinity 6: *Change Over Time.*

> *There is a benefit to regulation. You hope that it all fits into a master plan and avoids the state being in a real tough spot, because there are so many competing needs. When it gets to the point where you start seeing people having legal challenges and it gets really competitive for water it makes you wish you had better planning and consider things you never thought was ever viable. We draw a box, but then we see an extreme boundary we start thinking outside that box. Start to expand the box. (Regional Authority/ Regulator Test Interview)*

Supervision was changed to *Authorities and Regulations,* as shown in the second column of Table 4.3, after the test interview participants seemed confused as to what they were being asked about. This indicated Supervision was not a clear name for the code. After analyzing this result in peer collaboration, the long list of authorities and regulators identified were grouped into more specific categories of federal, regional, state, and local as shown in the second column of Table 4.5.

Table 4.5: Summary of *Supervision* Code.



From: *Supervision*	To: *Authorities and Regulations*
❖ Water and energy agencies (EPA, TCEQ, PUC, ERCOT, LCRA, NRG)	❖ Federal
❖ Local authorities	❖ Regional
❖ Legislators/ Texas legislature	❖ State
❖ River authorities	❖ Local
❖ Local government decision-making	❖ Politics
❖ Quasi-government entities	
❖ City council	

My own interpretation of this code is that it is the most complex of all the codes to understand considering the multiple governance boundaries that exist from federal to local, for myself as well as the people within the system. I found it to be the most difficult code to determine where to look for information and have confidence all bases were covered. As a water competitor, *I believe this code is also complicated due to the difficulty of estimating where final authority lies within overlapping system boundaries as well as where new competition may enter the system from.*

The individuals running these governing organizations also have to be carefully diplomatic due to the high tension between competing sources. I believe this is likely why much of the official public documentation appears vague, broad, and cautiously seeks to maintain constant conditions. I will return to the issue of governance in Chapter Five as it is a key to the decision-making within this system with respect to how decisions get made, by whom, and whom they effect.

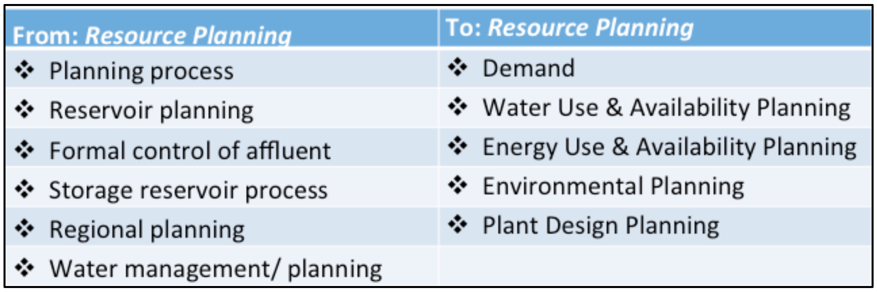
Sub-Code 3.1: Resource Planning

Resource planning represents what I originally identified as a sub-code of *Supervision* for thoughts the focus group participants used to describe the various energy and water planning efforts that may impact the "Water Use Decision Making in Thermoelectric Power Plants" System, shown in the first column of Table 4.6. In a test interview a university organization participant described the lack of cross-planning between energy and water planning similarly to the second quote from a regional electric authority,

> *There isn't really any cross planning going on the energy side. The energy managers have to include water in their planning. On the water side the owners of the water utilities, energy is just a cost factor to them. (University Organization Test Interview)*
>
> *Not a lot of people [at organization X] that are part of the integrated planning discussions… Some power plants use as much water as small cities. Water planners should be making these projections, that's what (the energy side) does. (Regional Authority/ Regulator Test Interview)*

The absence of cross-resource or integrated planning is noteworthy and is also a key point made in existing literature. Thus, after peer collaboration my IQA advisor and I decided to elevate *Resource Planning* from a sub-code of *Supervision* to its own code name in the subsequent interviews.

Table 4.6: Summary of *Resource Planning* Code.



From: *Resource Planning*	To: *Resource Planning*
❖ Planning process	❖ Demand
❖ Reservoir planning	❖ Water Use & Availability Planning
❖ Formal control of affluent	❖ Energy Use & Availability Planning
❖ Storage reservoir process	❖ Environmental Planning
❖ Regional planning	❖ Plant Design Planning
❖ Water management/ planning	

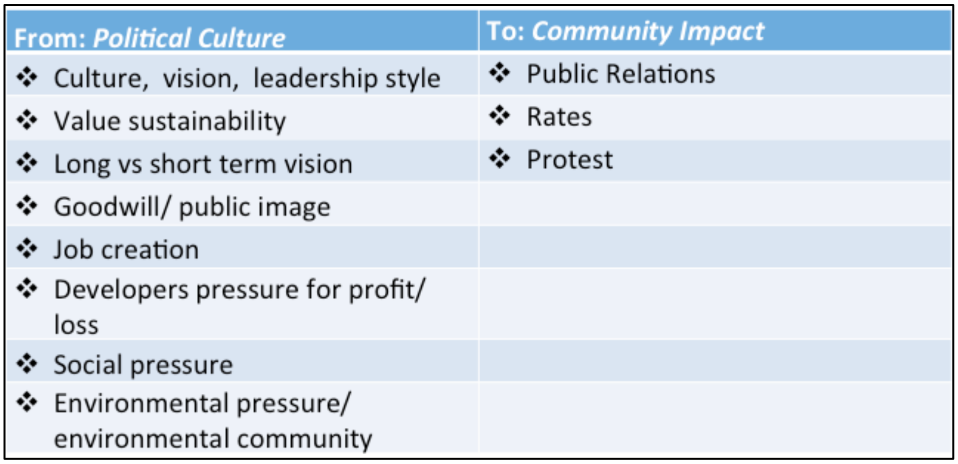
My own observation of this code is that it is consistent with existing literature which indicates the lack of cross-planning, or more specifically the lack of planning between the related systems of water and energy. This is eventually problematic for suppliers of either water or energy - *when they experience conflict they begin to realize they don't control a primary variable in the system which they are a participant*. However, in practice it seems this is primarily impacting energy suppliers, such as the most recent drought that caused near shut-downs in multiple locations as discussed in Chapter One. This is likely one of the reasons any cross-planning that is happening is being primarily driven by the energy side.

I understand this to be true within each industry as well, meaning *there is more integration within the energy industry, likely due to the connectedness of the electric grid, than there is with the water system whose basic infrastructure is more fragmented and less visible to water engineers and other water professionals*. With a base infrastructure that is foundationally tied together as one major electric grid, the industry is inherently more hierarchical and incorporated in a way that transcends the differences in local jurisdictions more than the water infrastructure which is far more limited in reach. However, as pointed out in the interview quote above, there is a need for the water side to be aware and prepared through planning with the energy side due to the criticality of water to support power generation.

Code 4: From *Political Culture* to *Community Impact*

Political Culture represents the code name chosen to reflect the focus group participant's identification of the various political and cultural impacts associated with the "Water Use Decision Making in Thermoelectric Power Plants" System. *Political Culture* was too broad and required significant explanation in the test interviews; thus, after peer collaboration the name was revised to *Community Impact* as shown in Table 4.7. The thoughts originally grouped under *political culture* were either moved to other codes or combined with other thoughts. In the first row of Table 4.7, for example, "culture, vision, leadership style," now exists in Table 4.9 under the *Energy Company Demographics* code as vision, culture and values, and leadership. This change significantly helped focus the subsequent interviews.

Table 4.7: Summary of *Political Culture* Code.



From: *Political Culture*	To: *Community Impact*
❖ Culture, vision, leadership style	❖ Public Relations
❖ Value sustainability	❖ Rates
❖ Long vs short term vision	❖ Protest
❖ Goodwill/ public image	
❖ Job creation	
❖ Developers pressure for profit/ loss	
❖ Social pressure	
❖ Environmental pressure/ environmental community	

In the test interviews when I asked about political culture, the university organization participant described the political pressure of an environmental group and the regional authority participant was more focused on political pressure from the public:

> *The environmental groups are powerful, they won't get a plant built if they have enough influence to sway his decision. (University Organization Test Interview)*
>
> *My perception is that the politics plays a role when we get in those situations and we start to see shortages. Then the topic starts coming up more and more, then the people's dislike for it and the politics get amplified. (Regional Authority/ Regulator Test Interview)*

After this code name was changed to community impact, a water utility interview participant described the impact of a community's perception of reclaimed water,

> *We wouldn't want to use potable water for that (power plant cooling), so reclaimed water is really the right solution, if raw water isn't there. Actually, I'd rather use reclaimed water anyway because we still have a little bit of the yuck factor of direct reuse, so it makes more sense to use it in this fashion than to push to the next level which is direct reuse for consumption. (Central Texas Utility Interview)*

My interpretation of this code is mixed. Since the general public isn't typically aware that power plants use water, the idea of protest and securing public relations doesn't appear to be a strong driver in this decision. That is magnified for two reasons. First, is the fact that power plants sell their power to the electric grid manager and not directly to the public. Thus, if there is a rate change it is one step removed from the power generators themselves, and the cost of their water. Second, when a new power plant requests a new water right permit, per the Texas Administrative Code Title 30, Part 1, Chapter 295, Subchapter C Rules include: (1) a publication "in a newspaper of general circulation within the section of the state where the source of water is located," in Rule 295.152 and (2) notice by mail to "other persons who, in the judgment of the commission, might be affected," in Rule 295.153, (Office of the Secretary of State, 2019). In an interview with a member of the TCEQ, this was explained to me as existing water right holders not likely the general public. While these are both a good start, I discuss in Chapter Five the potential for reaching out to the community in a more meaningful way that catches their attention and improves the education of stakeholders as well as governance of the system.

I believe, however, this is the code that has the most potential for change and ability to make a significant impact. *With a clearer understanding of the impact water choices have on the community, perhaps new social pressure could drive the choice that is right for the community instead of being outside of this decision.* Again, this will be further explored in Chapter Five.

Code 5: From *Physical Environment* to Inclusion in Other Codes

Physical Environment is the original code name representing the focus group participant's description of the various impacts of the physical environment associated with the "Water Use Decision Making in Thermoelectric Power Plants" System. This code name included the climate conditions in which the utility companies are located such as a drought-prone area or an area with high annual rainfall as shown in the first column of Table 4.8. It also includes the potential environmental impact concerns of the particular area. One way in which this may have an impact is if a pipeline must be diverted around a protected area thereby incurring additional cost, or it could be a water source that is in the area but not available due to its role as a habitat of a protected species.

In the test interview a university organization participant described the impact of climate:

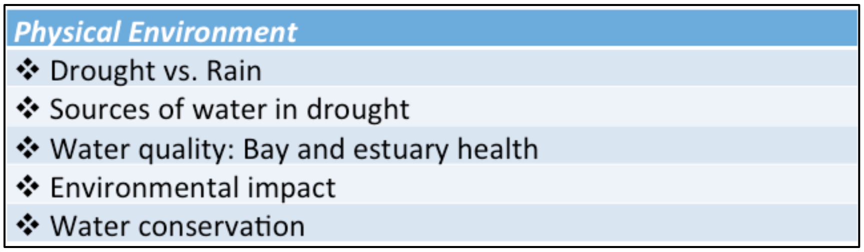
> *If you haven't been in drought before you're not prepared for drought. For example the northwest Seattle hydro facilities, when they go into drought what do they do? You can't build a plant in 6 months…The ones in drought already don't depend on a lot of water. (University Organization Interview)*

In a formal interview a local business owner further described the impact of climate, more specifically drought, as providing a pivot point for change:

> *During that drought (2009) we cut off the interruptible uses, never been done in 75 years. It's easier when we have show and tell. Every 10 years the state updates their water management plan, it used to be a rubber stamp. Everybody gets what they want. Based on trigger points, if there is x amount of water we're allowed to do this. We've moved those trigger points. (Business Owner Interview)*

This code name needed significant explanation and was too broad to relay the same intent to each participant. The thoughts that made up this code were combined into other affinities for subsequent interviews.

Table 4.8: Summary of *Physical Environment* Code.



Physical Environment
❖ Drought vs. Rain
❖ Sources of water in drought
❖ Water quality: Bay and estuary health
❖ Environmental impact
❖ Water conservation

My interpretation of this code has changed twice. Initial literature reviews placed a great deal of emphasis on the physical environment, specifically drought, as a driver; this formed my first interpretation. Recent research changed my opinion due to new claims that plants in the most drought-prone areas have already taken the risk of drought into consideration. For power plants this means the plants in drought-prone areas have considered their water constraints when choosing a design for their system which mitigates the potential loss of shutting down due to a lack of cooling water to operate. An example of this is an air-cooled power plant. As opposed to cooling the steam with water these systems cool it with air. They are an unpopular design due the significant efficiency penalties in terms of electricity produced; however if there isn't enough water in the area the efficiency penalty is more likely to be accepted. The interviews reflect this second opinion, and it is the code from which I was least able to draw a response from.

My specific concern however is that as weather patterns change from their historical disposition, some institutions will find themselves newly at risk for drought conditions without cooling systems designed to meet extreme drought conditions. T.

Miller and his colleagues point out a broad concern that the *climate is changing faster than our institutions and infrastructure can keep up with it*. They encourage questioning the institutional knowledge systems which they define as, "the organizational practices and social structures that produce the information, data, and expertise on which engineers, designers, and decision-makers rely," (Miller & Chester, 2018, p. 47, 54). Failures in these knowledge systems have been exposed after extreme weather disasters show that even over-designed infrastructure for a rare extreme weather event experiences massive failure when those events occur. The alternative requires rethinking how we design infrastructure and aligns with a "safe-to-fail" approach, "systems that do not promise absolute protection but result in limited damage when they do fail," (Miller & Chester, 2018, p. 56). In the case of power plants, *the institutional knowledge system has led to a short-term vision of cooling water supplies based on current climate conditions*, which is why I believe this should become a critical piece of the decision to use or not use reclaimed water in the future.

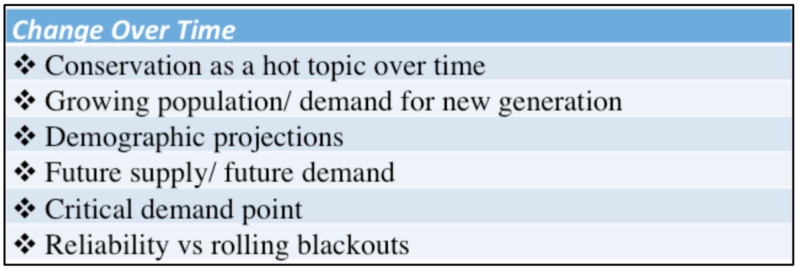
Code 6: From *Change Over Time* to Inclusion with Other Codes

Change Over Time represents the code the focus group participants used to describe the way in which all the variables of the "Water Use Decision Making in Thermoelectric Power Plants," System may change over time as shown in Table 4.9. It is important to clarify this code is not about the size of a population, or a particular amount of future supplies, *it is about the impact that a change in population or supplies has on the system*. As one participant notes below, utility companies are impacted by current regulations noted in Code 3: *Supervision*, but they also act based on how they predict regulations are changing.

> *When you make a decision for a 30 yr power plant you have to take into account current regulations, and where you think the trend is going. For example when carbon was going to be taxed, we thought we gotta get out of coal… (University Organization Test Interview)*

This code name was vague yet complicated and confused interview participants. Thus, the thoughts that made up this category were moved to other codes or combined with thoughts listed under other codes in the final interview protocol. I made a deliberate attempt to recognize when interview participants discussed changes over time and reflect these concerns in the final analysis.

Table 4.9: Summary of *Change Over Time* Code.



Change Over Time
❖ Conservation as a hot topic over time
❖ Growing population/ demand for new generation
❖ Demographic projections
❖ Future supply/ future demand
❖ Critical demand point
❖ Reliability vs rolling blackouts

My interpretation of this code is that it is as difficult as any other topic to predict how any one or all of these factors will change in unprecedented ways. Stakeholders try to predict in a system with many uncertainties how things will change over time, as in the interview quote above regarding carbon tax. The first and obvious concern is the likelihood conditions will change over time is given low priority when water is abundant and the urgency to prepare for future low water supply subsides. When water levels are outside of normal standards, then a great deal of attention is brought to the issue but with a reduced ability to mitigate negative effects. The second concern with this approach is the inability to know how conditions will change as pointed out by environmental systems researcher Claudia Pahl-Wostl, et al.:

> *Today's 'conventional' approaches are rooted in a Newtonian influenced 'command and control' paradigm that assumes that complete knowledge of system behavior is both possible and exploitable for management purposes…views uncertainties as a nuisance which need to be reduced through deeper knowledge… (Pahl-Wostl, et al., 2011, p. 293)*

As the concept of reducing uncertainty comes under question, the current institutional and organization frameworks that form existing knowledge systems also needs to be reconsidered. As a possible alternative I discuss the potential *of adopting a relational concept of management* in the final chapter to align with growing concepts of co-evolution and complex adaptive systems. Specifically, the principles of Integrated Water Resources Management (IWRM) are suggested as a starting framework for its' proactive approach to systematically learning and adapting with changes in external factors.

Code 7: From *Energy Company Demographics* to *Company Organization*

Energy Company Demographics is the code name representing focus group participants description of the various impacts of energy company demographics associated with the "Water Use Decision Making in Thermoelectric Power Plants" System. This code represents a range of demographics of the power plant such as the technical feasibility and the size of the plant, as listed in the first column of Table 4.10. As described in Chapter Two, the technical feasibility of a plant relates to the extensiveness of a retrofit to use reclaimed water as well as the age of the plant and whether the effort is worth the number of years left the power plant will continue to be in operation.

The size, of either the generation capacity or the population served, and location of the plant may also influence the type of fuel used, and could drive the distance to a reclaimed water source, most often a wastewater treatment plant. This code also includes ownership type, which ranges from privately owned to publicly owned utilities also as described in Chapter Two, and the influence of executive management versus the engineering staff. The following quote from a university organization test interview reflects the potential power of citizens in influencing more or less sustainable water choices:

> *Publicly owned would be more favorable to use recycled water. The environmental consequences are more popular among the public. The water is probably coming from a public entity. The same public decision making body, city council is making both decisions. That can make it a lot easier. Private companies would only get recycled water from a public entity. (Utility Interview)*

The name of this code was slightly modified to *Company Organization* as shown in the second column of Table 4.10 after demographics was found to be a confusing name to interview participants.

Table 4.10: Summary of *Energy Company Demographics*

From: *Energy Company Demographics*	To: *Company Organization*
❖ Who owns plants?	❖ Ownership
❖ Executive management vs staff level (analysts and engineers)	❖ Leadership
❖ Size of plant	❖ Vision
❖ Rural areas	❖ Culture & Values
❖ Siting	
❖ Distance to WWTP	
❖ Technical feasibility/ How to design	

Additionally, this code also consists of the embedded knowledge system mentioned above. A state water organization interview reflects the influence this variable may have on the system:

> *I work with some utilities that have good leaders that have visionaries that are better at thinking outside the box than others. Sometimes I work with people and it is very frustrating because they come at the solutions from a narrow-minded standpoint. (Regulatory Organization Interview)*

My interpretation of this code is that Energy Company Demographics has a much stronger influence than the interviews or mainstream literatures reflects; however, my original reasoning for this has changed. Initially I expected the difference between a publicly owned utility, who are owned and accountable to their own customers, versus a privately owned utility who is responsible for returning a profit to its stockholders, would be a key influence in the decision to use reclaimed water or not. More specifically, supporting a transition to reclaimed water for ecological or social purposes seemed out of range of the intent of a private company with capitalistic objectives. There are now two reasons I reject this initial assumption. First, my interview with a private utility changed my opinion when they pointed *out whether you return profit to stockholders or the community, both types of utilities are trying to secure water for the cheapest price*. Second, I now believe *the risk of insufficient water to continue power plant operations will outweigh the cost of the transition to reclaimed water*.

I still contend this code has an exceptionally strong influence; however, my reason is now reflective of the technological momentum concept found in Science and Technology Studies (STS) mentioned in the Chapter Two. *The agency of the existing system has both technical and a social component in public and private systems*. Not only does the vastness of the current infrastructure between power plants and freshwater mean that the technical side alone supports the status quo, but the technical components of the system become reflective of the social components which further engrain the existing system. Departments, such as maintenance, accounting, or administration are reflective of the technical components they are managing. These departments are the social components where decisions are made among social norms of communication and understanding. Social groups tend to support their own security and aren't typically organized or able to visualize any other type of system, thus they deploy the technology that is consistent with their frame.

With the code descriptions provided above, I use the next section to discuss the actual interview data collected after the code names were revised, and describe how I believe people are experiencing the system based on this data.

HOW PEOPLE EXPERIENCE THE SYSTEM

The intent of the second half of this chapter is to individually and collectively describe and analyze the results of the interviews. At the start of this work I was interested in identifying the most influential aspects of the codes; however, the feedback from interview participants was total agreement the influence of these codes are too intertwined to treat them separately. *Each power plant has unique circumstances and are influenced by multiple factors at once thus, to separate and rank them was not a useful way to describe the system.* I refer to and further discuss the following illustration of energy, water, pollution, and human activity flow, Figure 4.2, in these final sections to highlight the various layers of influence in the system.

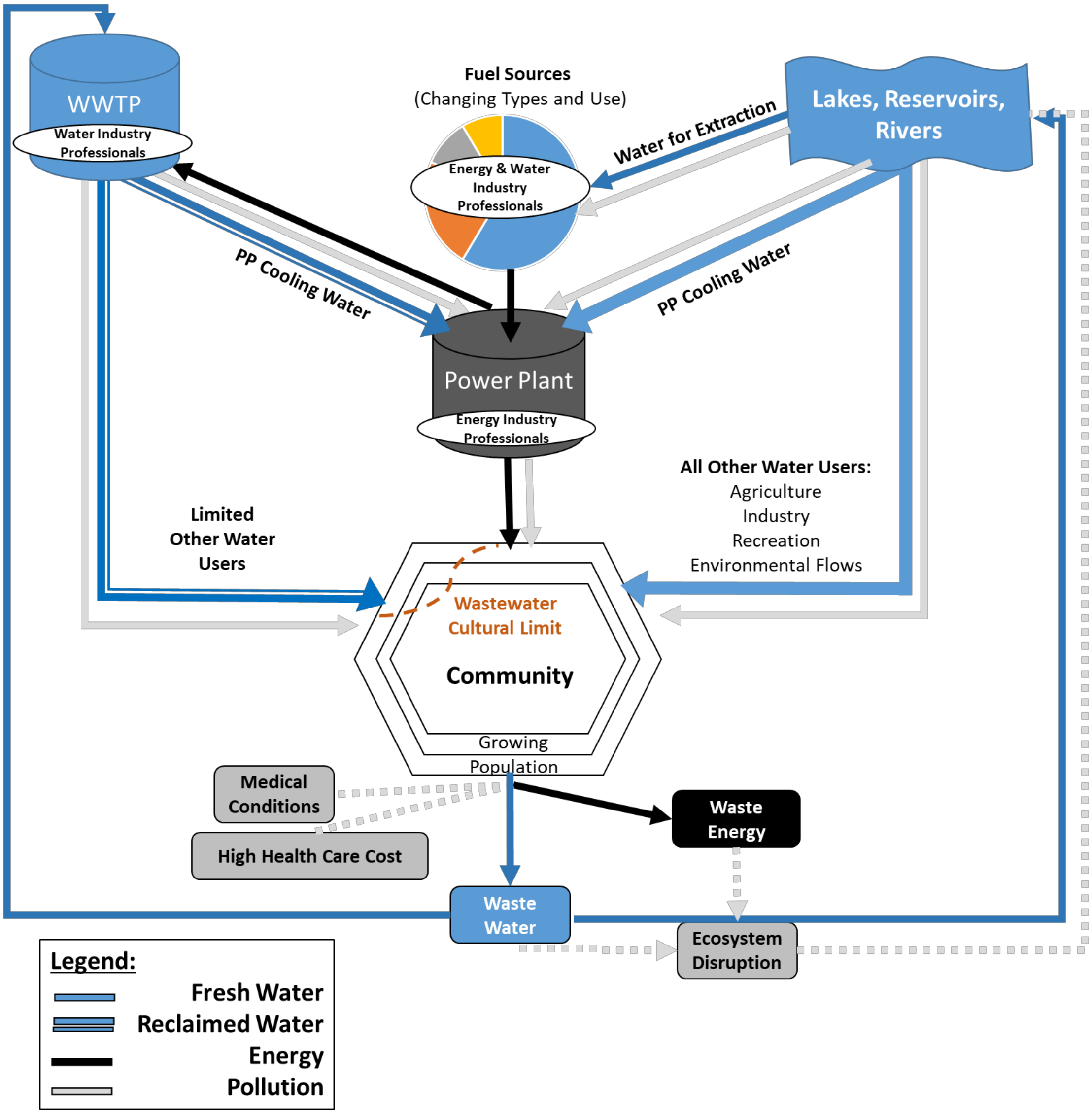


Figure 4.2: Considerations for Power Plant Water Use Decision Making (Source: Author)

Recall from Chapter Two that there exists a lack of commonality from plant to plant considering the location of the power plant may lead to withdrawing water from a lake, a river, or a self-created reservoir. As shown in this diagram, they have varying distances to wastewater treatment plants, operate on a different mix of fuel sources, are of different age and design of the plant, exist in different local/ regional geographies and climates, and each have different social constraints on the entire system. As shown with a burnt-orange dashed line above titled “wastewater cultural limit,” for example, each community may have a different level of acceptability of reclaimed water for a particular intended use. In the bottom of the illustration, consequences such as medical conditions, increasing health care costs, and ecosystem disruption are externalities that are difficult to tie back to a specific cause. We can, however, justify making some assumption that power plants and wastewater treatment plants contribute to the pollution that in some ways contribute to these issues.

The difficulty of understanding all of the factors that contribute to water use decision making comes not only from the magnitude and complexity of issues that can lead a utility towards one option or the other, but also the frames of interpretation from any given set of stakeholders. Each interpretation, within the power plant and WWTP as well as outside of it, leads to a position that seems rational to the individual or their organization. The authority, self-esteem, and ability to meet family responsibilities that derive from participation in a particular profession, for example, in turn drives each individual to support the continued existence of the institution that provide this structure. A difference in these perspectives, such as the scale of a particular perspective, is noted by a water organization interview:

> *There are so many constraints. Politics is there, money, resources, people’s ability and what scale of how they can look at these issues. (Water Organization Interview)*

This is important due to expert culture issues discussed above in Chapter 3. The imbalance of research perspectives and studies with respect to reclaimed water use in thermo-electric power plants leads to the question of whether the end-to-end potential benefits to society, the environment, and the energy-water nexus itself is well understood by planners, city authorities, and other stakeholders that could influence this transition. *Limiting the interpretive frame of how to adapt and respond to changing conditions in the energy and water industry runs a double risk of a lack of diversity in discussion of alternatives, and also limits the ability to influence change outside of a system that benefits the existing stakeholders.*

Therefore, my revised analysis goals are to understand the way people are experiencing this system, compare those responses to each other and to existing literature to see what is consistent, what is inconsistent, and what sources of confusion within the system are. To do this I identify conflict in frames of interpretation found in the points where interview data from one interview or stakeholder group conflicts with other interviews or stakeholder groups, and existing literature. Finally, I look at the collective data and attempt to find indications of patterns in decision-making. With this insight, the final chapter discusses pragmatic and planning implications of what these results mean with respect to future planning and governance.

Conflict Between Stakeholders

Over the course of this study I have observed one of the first water users blamed in general conversation of the water competition in central Texas tends to be the downstream rice farmers. From 2000 to 2011, these water users accounted for 70% of LCRA's total annual water use, (LCRA Self-Evaluation, 2017, p. 2-4). I notice this trend in general conversation as well as many of the interviews I conducted such as the following interview quote:

> *There is no incentive for them to conserve. Those rice farms sit over the aquifer with wells and access to their own water, but they sell their water to industrial users for high dollar. They buy our water for cheap and waste it. (Business Owner Interview)*

The frustration, as noted in this quote, is that interruptible water rights, the majority of agricultural water rights, are cheaper to purchase than firm water rights. The majority of interruptible water rights are agricultural water rights that were grandfathered, dating back to Spanish land grants, thus the potential exists for this cheaper water to be wasted or resold at a profit. The TCEQ rules govern the determination of firm yield of water as the following:

> *Naturalized stream flows will be modified as appropriate to account for the full exercise of upstream senior water rights is assumed as well as the passage of sufficient water to satisfy all downstream senior water rights valued at their full authorized amounts and conditions (LCRA Self-Report, 2017, p. 3-1)*

Thus, there is also frustration that the water the farmer's purchase is a threat to the water available for everyone else as noted in this interview quote:

> *Our general problem is that they (regulatory body) sell more water than they have. What they are doing is betting that mother nature will cover their transgressions. Sometimes she does and sometimes she doesn't... (Business Owner Interview)*

According to the LCRA Self-Evaluation Report rice farmers pumped approximately the same amount of interruptible water, 254,083 acre-feet, as all firm water users, 247,845 acre-feet, in 2016, (LCRA, 2017, p. 10). An important distinction to make however, is that only 7,655 acre-feet of the interruptible water pumped for agriculture water customers is from the Highland Lakes as shown in yellow in Figure 4.3. This means the majority of agricultural water is from the run of the river, the level which LCRA must balance including other firm water users, such as the Fayette Power Project shown in orange below. In other cases, however, often privately-owned power plants, water rights aren't firm; rather, they are interruptible. I point this out to provide an example of the complicated and unclear story of competition directly from any particular end user.

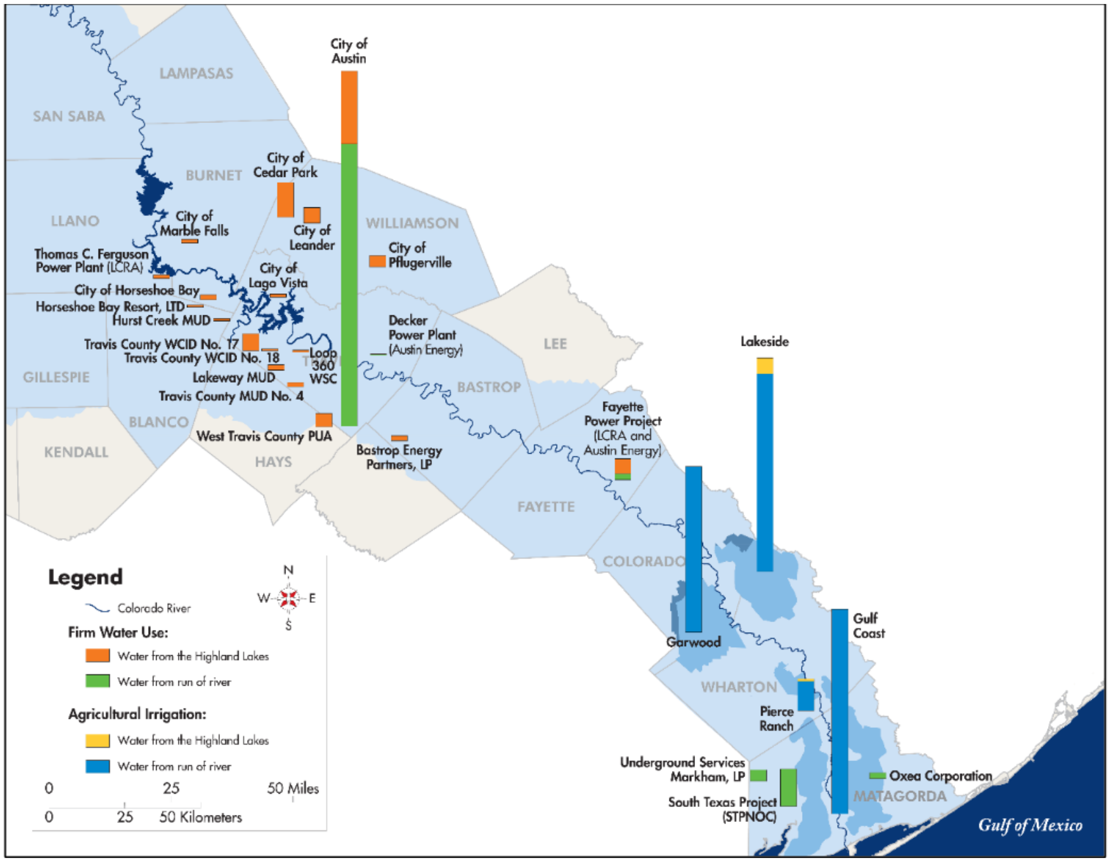


Figure 4.3: 2016 Total Water Pumped by LCRA's Customers, (LCRA Self-Evaluation Report, 2017, p. 9)

While the LCRA is not a state agency, it does have a great deal of power. Perhaps more significant, is LCRA's decision-making power is subject only to minor oversight by TCEQ in the review of the State Water Plan. This leaves the question as to what constitutes their open-ended governance. Recalling from Chapter Two the concept of governance includes more than official oversight. It also includes what is valued by a community and how that value is reflected in the relationship between an institution and societal outcomes. A closer look at official LCRA language unfortunately presents a confusing trail of what their priorities are in comparison to the communities' values.

> *When making decisions regarding the daily operations of the Colorado River and Highland Lakes, LCRA first considers the location, amount and timing of the demands of major customers that take water from the Colorado River below Mansfield Dam, and the environmental requirements for instream flows and freshwater inflows to Matagorda Bay. LCRA next considers the requirements of all water rights and agreements that apply to each demand and uses the best information available at the time to estimate the amount and timing of run-of-river inflows... (LCRA Self-Evaluation Report, 2017, p. 5-5)*

Consider, for example that golf courses and landscape irrigation are firm water rights holders instead of interruptible, yet recreational uses such as fishing, boating, swimming, park visiting, and related local economies around the lakes are "difficult to accommodate":

> *LCRA also supplies water, primarily on a firm basis, for other beneficial uses, such as golf course and landscape irrigation and household use. (LCRA Self-Evaluation Report, 2017, p. 1-6)*
>
> *Because the reservoirs were built for flood management and water supply and not constructed to maximize recreational use on the lakes, the demands for higher lake levels can be difficult to accommodate. (LCRA Self-Evaluation Report, 2017, p. 1-7)*

This is an example in which *there is divergence in the experience of the system between stakeholders, which leads to different frames of interpretation*, in this case between the rice farmers upstream businesses, cities, and industry. I point this out because I believe it is this type of inconsistency that increases tension and conflict described in the following interview of a regulatory body that tries to balance these tensions:

> *When the lake is down.., people come out of the wood-work. Phone-calls every day. Protesting is too strong of a word for it, but people were hiring lobbyists, spending time at the capital. Trying to get the [governing body] to look at the water plan in favor of them. (State Water Organization Interview)*

The above example illustrates just one of many sources of divergence, and sources of conflict, between stakeholders in the system. In the next section I look at divergence within stakeholders of the system to further the point made in Chapter Two that the system is too complex to simply lay out preferences for stakeholders of a particular group. Even within a social group there are many factors that complicate the system.

Conflict Within Stakeholder Groups

The entire system of water use in power plants includes a variety of stakeholders that with a change in any direction make the topic very controversial. As shown in Figure 4.4, an economic representation of the system, every flow of energy, water, pollution, or human activity could have financial consequences driven by any change to the system.

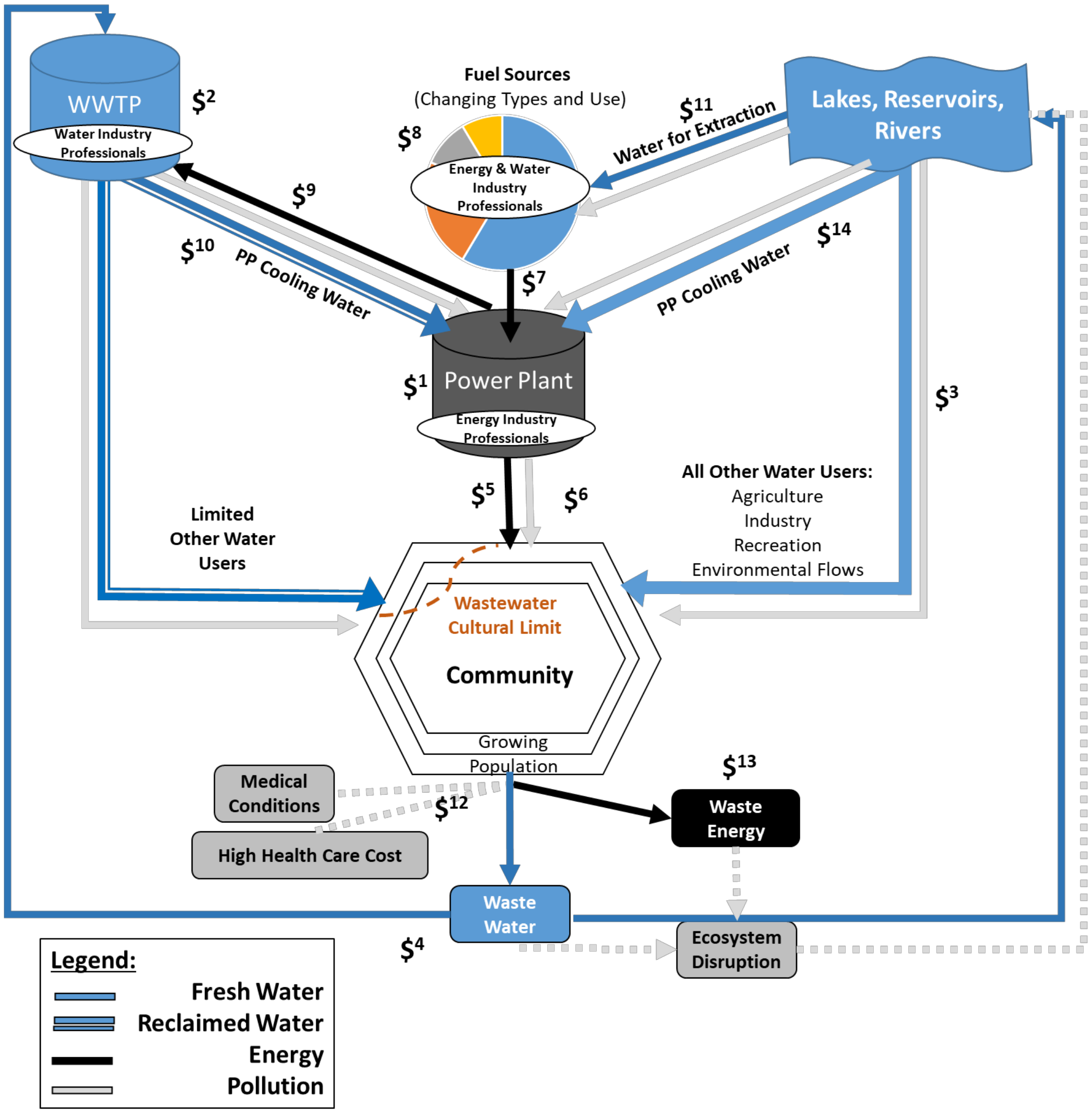


Figure 4.4: Economics in Power Plant Water Use Decision Making (Source: Author)

Each dollar sign represents a financial aspect of the system, and also associated private business or public welfare interest briefly summarized in Table 4.11. Note this list is not in a prioritized order of importance or magnitude.

Table 4.11: Summary of Financial Costs Within the System

Cost	Description
$\$^{1}$	Power plant costs to operate, maintain, manage, etc.
$\$^{2}$	Wastewater treatment plant costs to operate, maintain, manage, etc.
$\$^{3}$	Cost to convey, treat, pump, heat, cool freshwater for other intended uses such as agriculture, industry, recreation, etc
$\$^{4}$	Cost to collect grey water such as building and maintaining stormwater infrastructure
$\$^{5}$	Costs to transport energy to intended uses
$\$^{6}$	Power plant pollution control costs such as Carbon Capture and Storage (CSS)
$\$^{7}$	Cost to extract and transport fuel sources
$\$^{8}$	Cost of changing fuel types over time such as new infrastructure, new regulations
$\$^{9}$	Energy costs to operate a wastewater treatment plant
$\$^{10}$	Costs to transport wastewater to a power plant such as building new pipeline, permits, etc
$\$^{11}$	Water costs for fuel extraction
$\$^{12}$	Cost of externalities such as ecosystem disruption and increased health care costs
$\$^{13}$	Cost of water and energy waste such as sewer systems or nuclear storage
$\$^{14}$	Power plant costs of freshwater such as building a pipeline or reservoir

As conditions change, however, balancing just the financial interests alone is really a goal of making everyone the least unhappy as expressed in the following interview quote from a state level water organization:

> *Very controversial water supply issues and the planners at all levels are sort of all coming at it from their viewpoint. Of how these things need to be analyzed and what the potential solutions are to the problems. What we'll do is come in and again take a balanced approach, we'll take what the state wants, we'll look at what the locals want, we'll look at the farmers, maybe oil and gas, we'll look at different stakeholders, we try to be truly fair and balanced in what will play out. (Regulatory Organization Interview)*

As noted in the critique of the Planner's Triangle in the Theoretical Framework discussed in Chapter Three, it is more complicated than balancing just three types of economic, social justice, and environmental stakeholders. Not only do stakeholders have multiple inter-related interests, these planning efforts are perceived differently even within a similar stakeholder. Consider the following two separate interviews with business owners in the energy and water industries illustrate this point. In the first, there is a positive perception of planning and decision-making within the system:

> *I look at where we are today and where we were 20 years ago, I don't think people making all these decisions are doing a bad job. You rarely run into anything where something can't happen because there's no water or power. They figured it out. (Business Owner Interview)*

In the second, there is a completely reversed perception of planning and decision-making within the system which again reflects concern with the over-arching institutional knowledge system:

> *We plan infrastructures, but we don't plan enough into the future. They aren't open minded enough. We have to learn by history. If we didn't learn already, what says we are going to learn. They should be out in the counties, not our city. Because you didn't plan properly other people suffer. It wasn't one person that made the same bad decision, it was a series of people over and over again. (Business Owner Interview)*

As noted in the Chapter Three discussion of postmodern sustainability, conflict between stakeholders is intuitive; however, the main point here is to unpack the conflict within similar stakeholders and then to point out that this conflict can exist in multiple layers in which similar stakeholders agree on some pieces and disagree on others. The complexity of these conflicts adds to the difficulty of governance of the system. Disagreements exist among each layer and stakeholder preferences aren't always clear even if they could all be satisfied collectively. The misinformation and general confusion mentioned above also adds to the difficulty of how governance of the system currently is setup as well as how it could be established in an expanded set of boundaries that includes more stakeholder input from the community that is impacted by the system.

INDICATIONS OF PATTERNS IN DECISION-MAKING

I have observed three primary patterns and sources of confusion within the "Water Use Decision Making in Thermoelectric Power Plants" system including: (1) respondents affiliated with all of the thermoelectric power plants interviewed are trying to secure water at the cheapest price; however reflections on the importance of cost and the priority of freshwater rights varies across literature and interview locations, (2) institutional memory of historical decisions aren't well documented or understood by the next generation of stakeholders, and (3) there are few examples of advance financial and resource planning in a long-term cohesive strategy; however the utilities that were able to do so expressed financial and political advantages of doing so. A cautious takeaway from this observation with respect to the balance between planning ahead and avoiding inflexibility is further discussed in Chapter Five.

With respect to the first pattern, it is intuitive that all of the power plant representatives interviewed are trying to secure water at the cheapest price whether the profits return to their customers or their stakeholders. A source of confusion, however, is that both the initial costs of transitioning to reclaimed water and the priority power plants receive for freshwater varies within literature and across interviews. As discussed in the Chapter Two I found a great deal of importance placed on the cost to build pipeline to a wastewater treatment plant both in research and as a potential source of prevention for utilities to make this transition; however utility owners as well as utility construction companies interviewed both downplayed this as an issue as reflected in the following two quotes from both a utility company and a utility construction company:

> *Cost is somewhat of an issue, not as big of an issue. Depending on the resource and distance, cost may be higher or lower. (Central Texas Utility Interview)*

> *The planning doesn't matter. Pipe is pipe. There is no additional cost either way. The treatment process is already in place. It's the same as the conventional source of sucking out of the lake. (Utility Construction Company)*

As mentioned in the Chapter Three discussion of switching to the IQA methodology, some literature indicates power plants receive low priority as freshwater users, while other literature indicates power plants receive high priority as freshwater users. I have found instead *that this is context-dependent based on the location and ownership of the plant that determines if water rights are firm or interruptible.*

The second pattern identified is a lack of institutional memory, which I believe is related to both changes over time as well as the difference from plant to plant in terms of location, regulation, fuel source, water source, company organization, and so forth. The following interview quote is an example of how complicated just one of these aspects can be:

> *The state of Texas manages water rights completely different than the state of Colorado and Oklahoma and so forth. Then it varies with groundwater management versus surface water management. And then you get into differences within each county and across counties you've got different regulations. So these things are complicated and it varies in intensity. (State Water Organization Interview)*

Unfortunately, it may be this complexity that leads to a lack of understanding about the historical factors that determined the water sources for power plants. The following excerpt is from a utility company that uses reclaimed water, however existing employees were unsure what lead to that choice.

> *Our planning was done in the 1950s and 1960s so it is hard to say what the vision was but we are sure water availability was the issue. (Utility Interview)*

From this perspective *it doesn't appear the engineering community places significant importance on the context of why past decisions were made about water for power plant operations*. In Chapter Five I refer back to retaining institutional memory as a recommended area for planners to promote that may help the next generation of decision-makers consider how their current context is similar or different than others and potentially lead to more educated decisions and outcomes. Better retention of context-dependency of historical decisions may also be less difficult to address than some of the greater political or financial obstacles.

Finally, the third pattern I observed, which is consistent with existing literature, is that *there is a significant lack of planning between energy and water stakeholders*. The physical structure and management of the electric grid, which is for the most part connected throughout the state, versus the independent structure and management of water infrastructure is a likely historical factor that lead to this lack of planning:

> *I feel like the planning for electric and the grid.. is almost well, its planning is separate from water resource planning. While the grid is an interconnected and any power plant siting and all that goes through the PUC and ERCOT and all that good stuff, Water utilities are not as inter-connected.. I know there is the state water plan, and each region does its own plan that is very regional, I don't*

> *know how the regions sync themselves up to make sure its is integrated. It is not nearly as integrated as ERCOT. (Utility interview)*

While I found this to be confirmed by most interview subjects, I also found a general trend that combined energy and water planning is becoming more and more prevalent:

> *The progressiveness of the water system allowed that relationship to happen, lead to cooperation between water and energy utilities. Before it was like we don't really need to talk to each other, but now we do. We meet with (X organization) on a lot of projected projects. (Utility interview)*

Additionally, the utilities that did have the vision for planning reflect excitement and appreciation for the managers and employees that did so:

> *As a utility we do a LOT of master planning. We don't have to be told by council. We are ahead of the city on planning. Very forward planning. We don't like rate shocks. It is very balanced out. Part of the job is advanced planning. We're responsible for managing the utilities money. Very smart about it. Helps low bond rating. Don't get that good rating by just being a good banker. We use technology, good staff, and secured water rights in advance. We were forward thinking and got out there sooner. (Central Texas Utility)*

This perspective reflects both financial planning and resource planning that turned out well for this utility. For others, perhaps the risk of water shortage seemed less pressing of an issue than it is today:

> *Make an assessment that building a 30-40yr asset with only lesser number of years of a water plan, some have tried to match those up better. Some have built where they think they can get that renewed. Then you look for recycled water, see if you can make an arrangement. Then if you can't get that you go to dry-cooling and take the efficiency penalties. (Utility interview)*

There is a natural need to ensure the power plant which is a multi-decade asset, will also have a secure water supply source of some type for that length of time. As water becomes more competitive, the trend seems to be that water and energy planning is at the beginning stages of becoming more integrated. *As this trend leads to changes in planning and decision-making, perhaps it is also the right time to consider a more contemporary form of governance of this system.*

RESULTS AND ANALYSIS SUMMARY

Starting with the focus group to initially layout a loose boundary of the system and identify units of meaning from people experiencing the system, code names were identified as a tool to employ and investigate this meaning. After using these code names in test interviews to see how well they would illicit response or create confusion, these names were revised to improve their utility as a tool for investigation and communication. My own understanding of them also evolved throughout the interview and analysis phases of this work.

The evolution of code names is a key take-away for communicative planning that stresses the need to clarify language differences in the system between stakeholders and also identifying what language creates misunderstanding between stakeholders. The interview data that grounded this study made it critically important to capture experiences accurately which means the language used to communicate in interviews needed to be straightforward. This lead to revising code names in peer collaboration and double-checking interview data with participants to confirm I had captured their experience and understanding of the system.

Considering the system as a Complex Adaptive System leads to a second contribution to communicative planning with respect to the importance of identifying actors within the system and understanding the difference between their experiences. As discussed in the research method change to Naturalistic Inquiry, communication needs to be understood from the context from which it is being given. This includes not only which stakeholder expresses a viewpoint, but also recognizing that the same stakeholder group can have different viewpoints which could also change over time. In Chapter Five I further explore how capturing these experiences and relating them to their context also leads to increased agency of a broader set of stakeholders in the system.

Recognizing the sources of conflict and patterns within the system of decision-making helped highlight some inconsistencies in the literature such as the importance of cost, and the understanding of water rights allocation and renewal. Chapter Five uses this insight about sources conflict and patterns in decision-making to articulate practical implications of the current system. The chapter concludes with an exploration of planning implications to work towards a more comprehensive and integrated system between energy and water stakeholders.

Chapter 5: Interpretation and Implications

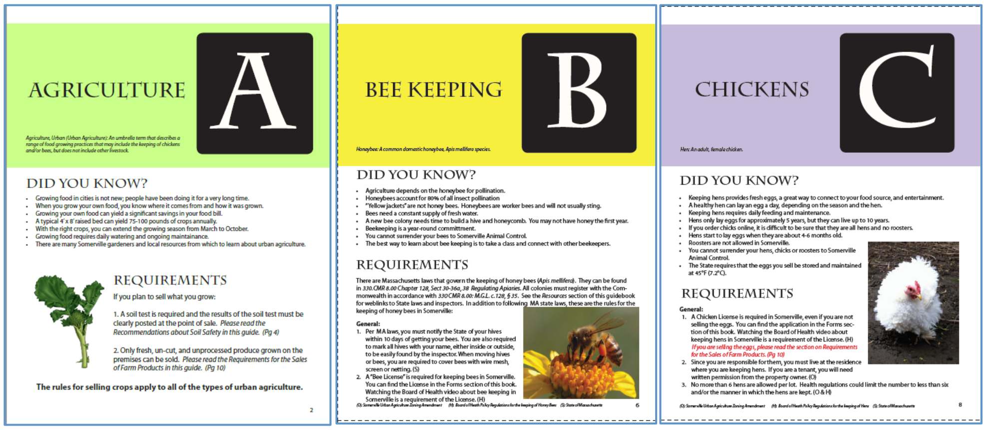
The intent of this chapter is to apply results of the first analysis goal, *understanding the way people are experiencing the system*, to the second goal of *identifying practical and planning implications for existing governance and future planning*. The complexity of this issue leads to practical implications that I encourage educators and researchers to retain when spreading awareness of this topic. The low commonality of eco-socio-techno-political variables from utility to utility and the lack of carrying forward historical lessons learned with respect to cooling water decisions means that awareness of this issue is cloudy even for engrained stakeholders, and almost non-existent for many outside of the energy and water industries. This scenario leads to two main observations: (1) *influencing change currently comes only from those within the industry, and (2) communities do not understand how the system affects them*. Unfortunately, neither of these observations are positive for the stakeholders in this system and both observations reflect a poor state of governance of the system.

Visualization of an alternative system can help from a planning perspective to theorize what types of system evolution could lead to an improved system if not ever a perfect one, as well as think through how to mitigate some of the sources of conflict described in Chapter Four such as the outdated structure of water rights in the system. In the next section I take a moment to visualize within reason, what an alternative system model might look like if it could be designed without a few of the existing constraints.

Keeping an alternative system model in mind, there are a few planning implications from this study for policy-makers and planners to consider when trying to move the system towards a more efficient, transparent, and educated use of energy and water resources. One of the first considerations is simply to clarify sources of confusion and increase awareness to all stakeholders. Given all utilities are not equal in terms of size and resources for planning and community education, this may be one area in which a statewide or regional strategy could be devised to provide additional support for local energy and water planning that is more reflective of the communities being served.

A few existing institutions could be leveraged to accomplish this. For instance, the scope of the Texas Municipal Utilities Association (TMUA) is to *promote the professional development of municipal utility managers*. Similarly, the constitution of the Texas Municipal League (TML) is "*to render services which individual cities have neither time, money nor strength to do alone*," (Texas Municipal League, 2019). *Working together, these institutions are strong candidates to promote the energy-water nexus education of smaller municipalities when siting for new power plants are being approved*. Another opportunity may exist in the statewide planning process executed by the TWDB by inserting personnel who are specifically responsible for providing utilities and city councils a broader energy-water nexus education. Additionally, an emergent opportunity might exist for Planet Texas 2050, an eight-year project seeking to find solutions to the state's rapid population growth and weather related challenges expected through 2050 (Planet Texas, 2019). The design of their metro-scale data and communication platform could include plant-to-plant experiences in their water for energy choices.

This step could include, for example, a simple ABC guide of the energy-water relationship such as the sample from the City of Somerville shown in Figure 5.1. Coupling this guide with a series of lesson plans could articulate historical lessons learned and explain what is understood about the relationship between energy and water under a range of community specific conditions and scenarios.



AGRICULTURE A

Agriculture, Urban (Urban Agriculture): An umbrella term that describes a range of food growing practices that may include the keeping of chickens and/or bees, but does not include other livestock.

DID YOU KNOW?

- Growing food in cities is not new; people have been doing it for a very long time.
- When you grow your own food, you know where it comes from and how it was grown.
- Growing your own food can yield a significant savings in your food bill.
- A typical 4' x 8' raised bed can yield 75-100 pounds of crops annually.
- With the right crops, you can extend the growing season from March to October.
- Growing food requires daily watering and ongoing maintainance.
- There are many Somerville gardeners and local resources from which to learn about urban agriculture.

REQUIREMENTS

If you plan to sell what you grow:

1. A soil test is required and the results of the soil test must be clearly posted at the point of sale. *Please read the Recommendations about Soil Safety in this guide. (Pg 4)*

2. Only fresh, un-cut, and unprocessed produce grown on the premises can be sold. *Please read the Requirements for the Sales of Farm Products in this guide. (Pg 10)*

The rules for selling crops apply to all of the types of urban agriculture.

2

BEE KEEPING B

Honeybee: A common domestic honeybee, Apis mellifera species.

DID YOU KNOW?

- Agriculture depends on the honeybee for pollination.
- Honeybees account for 80% of all insect pollination
- "Yellow jackets" are not honey bees. Honeybees are worker bees and will not usually sting.
- Bees need a constant supply of fresh water.
- A new bee colony needs time to build a hive and honeycomb. You may not have honey the first year.
- Beekeeping is a year-round committment.
- You cannot surrender your bees to Somerville Animal Control.
- The best way to learn about bee keeping is to take a class and connect with other beekeepers.

REQUIREMENTS

There are Massachusetts laws that govern the keeping of honey bees (*Apis mellifera*). They can be found in *330.CMR 8.00 Chapter 128, Sect 30-36a, 38 Regulating Apiaries*. All colonies must register with the Commonwealth in accordance with *330 CMR 8.00: M.G.L. c.128, § 35*. See the *Resources* section of this guidebook for weblinks to State laws and inspectors. In addition to following MA state laws, these are the rules for the keeping of honey bees in Somerville:

General:
1. Per MA laws, you must notify the State of your hives within 10 days of getting your bees. You are also required to mark all hives with your name, either inside or outside, to be easily found by the inspector. When moving hives or bees, you are required to cover bees with wire mesh, screen or netting. (S)
2. A "Bee License" is required for keeping bees in Somerville. You can find the License in the Forms section of this book. Watching the Board of Health video about bee keeping in Somerville is a requirement of the License. (H)

(O): Somerville Urban Agriculture Zoning Amendment (H): Board of Health Policy Regulations for the keeping of Honey Bees (S): State of Massachusetts 6

CHICKENS C

Hen: An adult, female chicken.

DID YOU KNOW?

- Keeping hens provides fresh eggs, a great way to connect to your food source, and entertainment.
- A healthy hen can lay an egg a day, depending on the season and the hen.
- Keeping hens requires daily feeding and maintenance.
- Hens only lay eggs for approximately 5 years, but they can live up to 10 years.
- If you order chicks online, it is difficult to be sure that they are all hens and no roosters.
- Hens start to lay eggs when they are about 4-6 months old.
- Roosters are not allowed in Somerville.
- You cannot surrender your hens, chicks or roosters to Somerville Animal Control.
- The State requires that the eggs you sell be stored and maintained at 45°F (7.2°C).

REQUIREMENTS

General:
1. A Chicken License is required in Somerville, even if you are not selling the eggs. You can find the application in the Forms section of this book. Watching the Board of Health video about keeping hens in Somerville is a requirement of the License. (H) *If you are selling the eggs, please read the section on Requirements for the Sales of Farm Products. (Pg 10)*
2. Since you are responsible for them, you must live at the residence where you are keeping hens. If you are a tenant, you will need written permission from the property owner. (O)
3. No more than 6 hens are allowed per lot. Health regulations could limit the number to less than six and/or the manner in which the hens are kept. (O & H)

(O): Somerville Urban Agriculture Zoning Amendment (H): Board of Health Policy Regulations for the keeping of Hens (S): State of Massachusetts 8

Figure 5.1: Sample ABC Guide From the City of Somerville[14]

Existing mechanisms such as the interactive part of the TWDB website used for regional water planning groups and shown in Figure 5.2 for example, could be utilized for this transformational purpose. Longer term goals for these personnel may include the responsibility to streamline the tangle of existing regulations and lack of transparency in order to make decision-making easier and potentially more effective.

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[14] A sample ABC Guide from the City of Somerville in regards to urban agriculture: https://www.somervillema.gov/sites/default/files/abc-urban-agriculture.pdf.

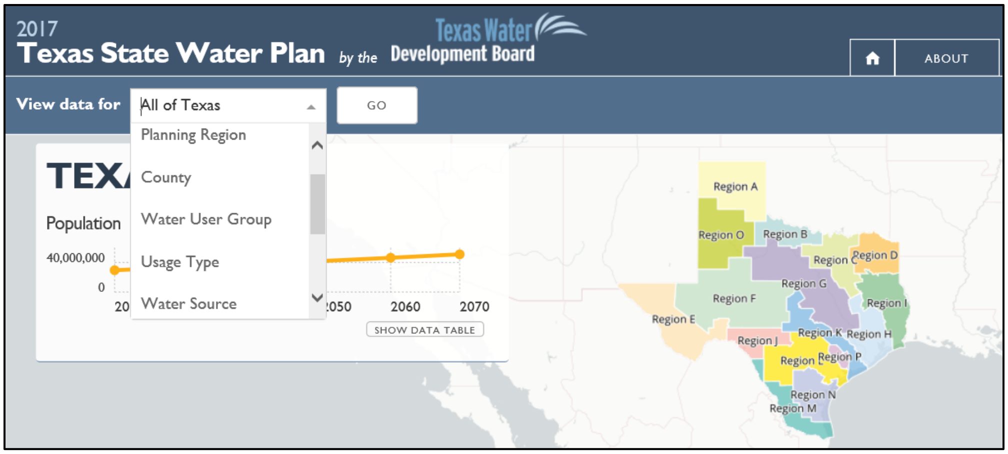

Figure 5.2: Sample of TWDB Interactive Website (TWDB, 2019)

The second main suggestion for what seems to be an initial start at integrated planning in the energy-water nexus is a specific effort towards *a portfolio approach that identifies and addresses the needs of the broader range of stakeholders*. Up to this point, governance of the system seems to have been driven more by institutions within the system and not necessarily included explicit citizen representation outside of city councils that may or may not have a broader understanding of the energy-water nexus as a whole. This may be accomplished by a third-party organization that holds neither progressive nor conservative social values and is thus able to educate, and solicit citizen participation and advocate energy-water solutions that benefit a fuller range of stakeholder interests. The challenges to this effort will include how to ensure the knowledge created and used by an organization of this type, as well as its processes and representatives can be: (1) validated and achieve credibility among the range of stakeholders, and (2) strengthened by a broader range of knowledge sources. Later in this chapter I explore key questions to consider identified in the work of Clark Miller in his research on climate change and sustainability on a global scale.

PRACTICAL IMPLICATIONS

After conducting and analyzing interviews around the state it is my takeaway that the people responsible for making a power plant's water use decisions understand the energy and water constraints under which they are working. What may be less clear, even to the most deeply embedded stakeholders, is how their experience contrasts from plant to plant. In multiple interviews, the interview subjects referred to other nearby cities with a somewhat differential attitude that indicated they had a few opinions about other utilities and some amount of regional knowledge for the conditions they are under, but not a confident understanding of another utility's specific constraints:

> *X [central Texas city] will give you the opposite answer, low money high debt. They make us look good. We're just fortunate to have good staff and good management. (Central Texas Utility Interview)*

This is understandable considering the complicated and fragmented nature of the entire system as previously discussed. Unfortunately, information does not flow freely in this type of uneven knowledge system which makes it even more difficult for anyone outside of the industry to have an awareness of how the system impacts them and what impact they have on the system. This was reflected in the interview quote mentioned in Chapter Four by the public citizen who knows their rates continue to rise, but don't have an understanding of why. As I also mentioned in the study limitations discussed in Chapter Three, when I tried to interview anyone too far removed from energy and water industry, I did not find general awareness that power plants withdrawal a significant volume of water. As noted in the discussion of Figure 2.4 in Chapter Two this lack of awareness may be due to the lower quantity used for consumption that contributes to the hidden nature of the system. It is important that the general public, including water rights holders, understand how the system may be affecting them in terms of the entire energy-water system of their local or regional community. *I believe the biggest impact that is missing from most awareness, is that although power plants mainly borrow water from the watershed, when resources are highly strained every drop is a commodity in a competitive system.*

This competition is magnified in arid areas or in times of drought when dialogue and processes that may typically run smoothly in normal operating conditions turns heated as water users begin to find themselves with shortages. As a result of the severe drought in the state of Texas ranging from 2008-2016, for example, the TCEQ had to notify some of their water right holders in the Sabine River Basin that their rights were being suspended due to rights from a hunting and fishing club that pre-dated theirs. In that timeframe 1,200 water rights were suspended throughout the Brazos, Guadalupe, Colorado, Sabine and Neches river basins, (Eckhardt, 2018). It was one of the main times in the state's history the junior-senior water rights system became a widespread and contentious issue. Thus, as populations grow and consume more water, the siting of new power plants in the watershed is another strain that could be eased by using reclaimed water.

With respect to power plant infrastructure, the agency of the existing infrastructure is inherently resistant to change. In his 1969 essay, "Technological Momentum," author Thomas Hughes uses the term technological momentum to describe why. He identifies the characteristics of technical systems including: (1) acquired skills and knowledge, (2) special purpose machines and processes, (3) enormous physical structures, and (4) organizational bureaucracies as building durability and encouraging growth of the system as the vested interests intended (Hughes cited in Smith & Marx, 1995, p. 108-111). While Hughes indicates the political, economic, and organizational interests are substantial, he also indicates they are not irresistible and provides the following distinction for the strength of this momentum. He determines, "younger developing systems tend to be more open to sociocultural influences while older, more mature systems prove to be more independent of outside influences and therefore more deterministic in nature," (Smith & Marx, 1995, p. 101). The good part about the fragmented aspects of the power plant cooling water knowledge system described above then, is this may make it easier to influence change. In addition, with less of an imposing hierarchy to resist change, and it also provides the opportunity to compare unique systems in an effort to identify those that are working well.

SYSTEM EVOLUTION

Given the complicated nature of the entire system, it is helpful to look ahead and conceptualize what might be alternative systems if we were able to create one without existing constraints. Assuming we continue to need power plants as a primary energy source for the foreseeable future, visualizing changes to the system may include many different options. I explore five possible changes shown in red in Figure 5.3.

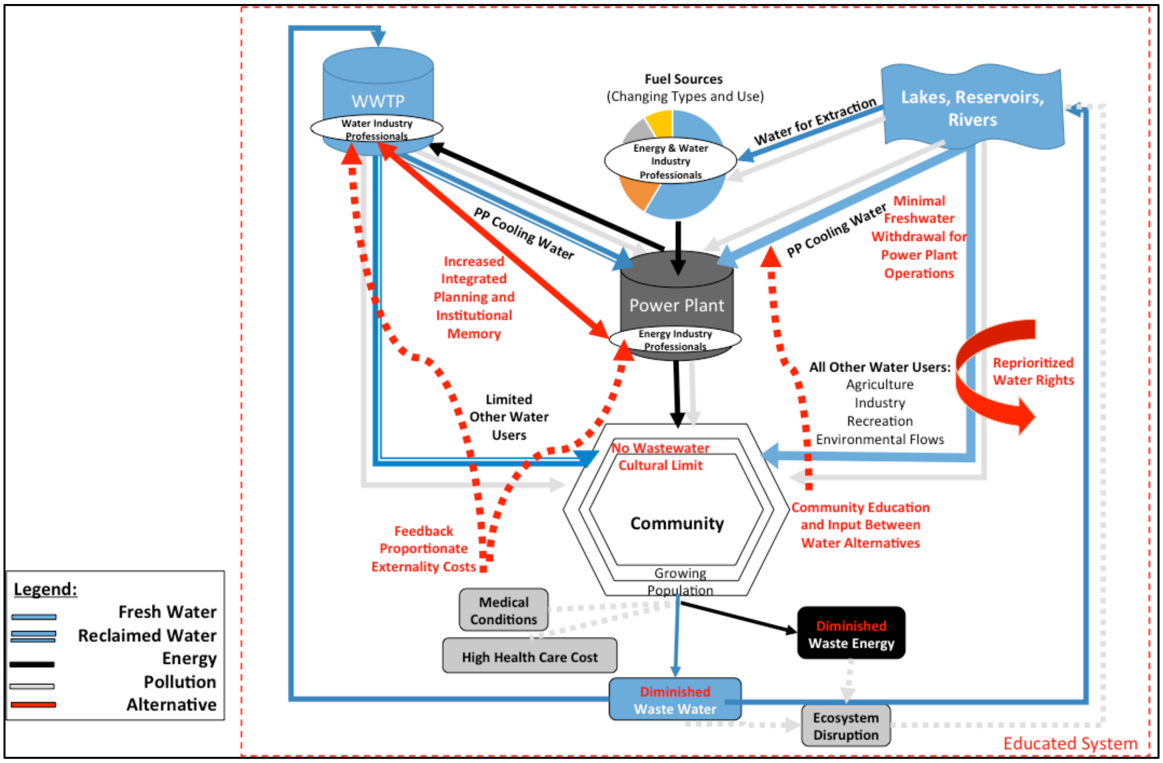

Figure 5.3: Alternative System Model (Source: Author)

First, the cultural limitation that restricts the use of reclaimed water is eliminated in the alternative model. This limitation is sometimes referred to as "toilet to tap." The mental image of recycling black water to potable water, despite replicating nature, is out of accepted norms except in areas where the water needs are so severe and other alternatives are limited. It is my assumption that as competition for water increases the acceptable uses for reclaimed water will evolve from experience until the limitation is eliminated altogether. While this may end up being in competition with the availability of reclaimed water for power plant cooling, I include it here because I believe this is the direction cultural perception is and should be moving.

Second, power plants might be restricted from borrowing additional freshwater from the watershed and operate primarily on reclaimed water. The two benefits to this suggestion is that first, it would avoid further strains on existing freshwater supplies and second, this option is a steady supply of reclaimed water that is not subject to drought. However, in some cases such as the state of California, reclaimed water is as competitive as freshwater at which time it may not be the most beneficial to the entire system to draw from reclaimed water for power plant cooling needs. The point of emphasis, again is to *view the entire energy-water portfolio as an integrated whole instead of making short-term decisions without keeping the system at large in mind.* This approach takes a step towards overcoming the fragmentation of the current system, but recognizes the relevance of local ecological, social, and technological context.

Third, if historical constraints such as water rights that were sold hundreds of years ago based on circumstances that no longer apply could be reconsidered, a new priority of water rights may be better structured to account for a truer value of water that matches the value of the use. This suggestion aligns with Geddes' concept of balancing the profitable or beneficial use of a particular resource against the negative effects discussed in Chapter Three. This is not to suggest blanket redistribution of water rights without regard for those with historical value tied to these rights, but *it is to suggest some type of compensation could be given to existing right holders for the greater goal of ensuring a water right system that makes sense in current conditions.* Basically, as the context within the system evolves so should the eco-social-technical pieces of the system.

I leave determination of adequate compensation and the associated constitutional debate for others; however, the idea deserves to be mentioned because Texas' junior-senior water rights system not only lacks consideration for importance of use and leaves no incentive for conservation, in some cases it may actually dissuade conservation by allowing users to take what they can while they can. In a bio-technically designed system the water rights would be allocated with consideration for conservation and the value the water user provides to society, as well as letting economics become a participant instead of a driver. This type of structure would intrinsically dictate water becoming more competitive and thus expensive the lower the value of the use, and more viable and less expensive for higher valued priorities.

Also, outside the scope of this project but deserving of mention due to the injustice of the current system, is the assumption that pollution leads to many negative externalities on the community and the ecosystem. These externalities are an example of the negative effects on society that Geddes' encouraged weighing against the benefit of incurring them. Combined with the knowledge that several aspects of the water used in power plant systems contribute to different types of pollution, *stronger efforts could be made to shift the financial burden of the externalities back to the higher consuming energy or water users or the industries profiting from the current system.* Again, I leave the difficult question of injustice for other work, but include it for a more complete alternative model system.

Finally, the fifth piece of this model for an alternative system is the suggestion for *increased education and input to and from the community, as well as increased integrative planning and education between water and energy industries.* The first component of this suggestion is intended to transition the community's currently hidden experience in the system to one with greater agency as stakeholders in the energy-water nexus. Existing social networks and communication platforms of environmental and social equity groups may be an efficient place to start the dual process of: (1)

communicating energy-water relationships to the public, and (2) communicating the community's experience in the system to energy and water industries. The second is necessary such that scientists and other industry professionals have a broader understanding of the impacts their techno-political components have on the system. Both efforts create a stronger collective voice for social and environmental interests to balance the existing dominant interest in the system.

The second component of this suggestion is the increased integration between energy and water industries. While it is evident increased integration is necessary for the success of both, this suggestion needs further investigation with respect to the formality or informality of the relationship. The potential advantages of formal integration from an engineering standpoint include an improved ability to optimize design, align schedules, funding, and decision-making. A potential disadvantage that needs special consideration is that water management is inherently more difficult and requires significantly more effort due to its continuously evolving state. One possible suggestion for increased integration is for each industry to conduct a review of the other, such as the TCEQ sunset review of the LCRA discussed in Chapter Four. This type of effort may help each industry understand the other better, as well as provide an opportunity to make the urgency of their integration more visible to both sides.

I understand several of these strategies will be resisted, however, entertaining discussion and thought about the many options for an alternative system model create a hypothesis for an agenda that may help planners and policy-makers experiment in taking steps to overcome specific problems of inefficiency and injustices within the current system. For these strategies to become operational, it will likely take those who benefit in the existing system to see change as in their best interest as expressed in this interview with a public citizen:

> *Everyone wants a better place to live. It just has to be presented in a way for them to realize it is in their best interest. (Public Citizen Interview)*

In this manner Geddes' suggestions for a reprioritization around life itself is intended for the best interest of all, but may take many evolutions of the existing system to achieve. With this in mind, the next section discusses planning implications for influencing a change in the existing dynamics.

PLANNING IMPLICATIONS

As a researcher who grew up in a small town, I am particularly interested in how smaller city councils are engaged on specialized issues such as the energy-water nexus, that are outside of the educational or professional domain of those within the community. This isn't to suggest that there aren't highly qualified people serving smaller city councils. There is a smaller range of occupations the city council is created from, and the competition for the job encompasses a smaller number of people as reflected in the following interview:

> *Most of the people we are doing stuff for which are small, MUD, just a bunch of normal people. It's a small governing board which was created to take care of a subdivision. It's the politics of a small city council. Some people get voted on because they are popular. Its not always that they are qualified, they're just people. (Public Citizen Interview)*

There are at least two sides of this issue. On the one hand, as discussed in Chapter Two with respect to STS, there is the risk of expert culture. This is the risk of elite professionals who don't live like ordinary citizens driving decisions that knowingly or unknowingly continually support their own institutions and professions while other alternatives remain ignored, understudied, or passed over. Additionally, some of the biggest social-economic disasters in history were based on the best expertise of the time. On the other hand, as Fischer points out, "Given the technical and social complexity of most contemporary policy issues, a significant degree of competence is required of citizens and their politicians to participate meaningfully in policy discussions," (Fischer, 2009, p. 1). Thus, there lies the challenge for how to deliberately leverage expert knowledge while embracing community participation in the decisions that affect their lives.

Thinking about the diverse range of utilities from large municipalities to rural cooperatives, the size and population served has a lot of variation in expertise. I point this out specifically because there is a larger quantity of utilities that serve smaller populations who may not have either energy or water planning backgrounds, than large ones who may hire experts not tied to the local community. The following interview quote provides a lot of insight into the way that some of these utilities plan:

> *Smaller utilities may not have as many resources as bigger utilities. And so they may have access to more resources, the bigger ones, to do better planning. But on the flip side a lot of times they are working with some of these consulting firms that perhaps they have been working with a long time and don't do a really good job of overseeing the type of decisions being made at their level that are informing the utilities. Because a lot of these utilities don't have the in-house expertise to do all the planning, they contract that stuff out. (Regulatory Organization Interview)*

This may be one area in which planners have a chance to influence how energy and water decisions are made if planning strategies aim for a more dynamic way of interpreting local conditions and how they may impact the area's energy-water system.

As I mentioned in Chapter Four, characteristics of the IWRM approach are attractive in this effort. This type of management is based on 'joined-up planning' among a wide range of stakeholders in order to reflect the complex reality of relationships in the system. It is important to stress the relationships in the system are broader than existing governance boundaries that are spatially mismatched to energy and water physical boundaries. These physical boundaries are an important influence on how communities interact, or should interact, with their environment that is unfortunately undervalued by limitations in existing governance. Bioregionalism is an attempt to address this problem by encouraging a framework for integrating efforts around environmental boundaries. The distinct ways in which the region encourages human-ecosystem interaction are important for thriving in that location and may be more suited to an IWRM-like approach.

It is also important for these efforts to include impacts to downstream users for not only freshwater, but also reclaimed water use. As mentioned in the Chapter Five system evolution discussion, some states such as California may need both fresh and recycled water more than they need additional power production and thus limit using recycled water for power plant cooling. Whatever the local conditions are that lead to one choice or another, it is important to consider the end-to-end impacts in future dialogue.

Specific applications that could be engaged in this approach include group exercises that create visual aids such as mind maps to reveal the complexity of influences in the system, such as stakeholder assumptions both collectively and individually and how they relate and link to each other. This is especially important where trying to achieve effective management of the resources that are currently split in management between multiple governance boundaries. In these cases visual aids may improve the understanding between stakeholders of each other's constraints. An advantage of using these types of learning tools as a base level for understanding the energy-water nexus is that they are helpful outside of the conventional scenario development for energy and water resources that focus on climate or population trends. In addition to the data from these more traditional energy and water models, qualitative data collection methods like cognitive mapping, provide a learning tool that brings in a third dimension of how society may react in the various potential trajectories missing in existing decision and policy-making. These approaches also provide a tool of communication for dissolving language barriers that reduce the ability to understand the system.

Fortunately, there are existing institutions already organized to reach out to the range of energy and water actors that may be good candidates for implementation such as the previously mentioned TMUA, TML, the TWDB water planning process and interactive website, or emerging opportunities in Planet Texas 2050. Whether an application-based strategy ends up as a process or as part of a tool the challenge will be inserting flexibility, open-mindedness, and patience for long-term change into these institutions such that adaptive policy-making and decisions can succeed.

In doing so, some of the key questions borrowed from C. Miller's investigation of global climate policy should be considered including:

1. Who should be granted authority?
2. How can the high risks of action and inaction be balanced?
3. How can we cope equitably with heterogeneous costs, risks, societies, and environments?
4. How can we meld value commitments to environment, development and human rights?

He also lists more detailed elements to consider that I find relevant to the energy-water debate including expert affiliation, methods of appointment, the balance of experts, methods of review, committee structure, duration, and lines of authority, (Miller, 2001 cited in Miller & Edwards, 2001, p. 256). Each of these detailed elements are likely to be important considering the vast discrepancy between existing reporting methods for cooling water consumption mentioned in Chapter Two. *The potential for conflict may be reduced with prior agreement to these questions as reporting methods are standardized or enforced.*

C. Miller suggests the social interactions that create a community and form meaning over time may flush out the social norms that answer these questions, and even still these norms will be in constant renegotiation in society and its' institutions, (Clark A. Miller, 2001 in Clark A. Miller and Paul N. Edwards, 2001, pp 247-280). This type of localized *coproduction of knowledge* and decision-making from increased engagement between the community and utilities and has other benefits as well. First, utilities express a positive relationship with the community is important when they need to make a rate increase or conduct other activities that may be disruptive to their customers such as construction for new lines:

> *We have great relations with the chamber, university, the city. When you get out there and you communicate with the leaders in the community they can help tell your story. Developers are in there and understand the challenges you deal with. Impact fees, are connection fees. Want new development to pay for itself. That philosophy is prevalent in the community. (Central Texas Utility Interview)*

Second, planners have to consider the collective social, environmental, and political implications of their influence that is especially true given permanency and agency of major infrastructure. Policy-makers and other decision-makers that wait to analyze their local impact after water sources are strained are likely to miss the opportunity to affect the design and location of a new plant that is likely to stay in place for another 50 years. Considering the potential impact before tensions rise in the case of strained resources may also make it easier to come up with transformative ideas that may have a better chance of finding solutions that are mutually beneficial to the stakeholders. Some in the industry already work from the beginnings of this strategy as expressed in the following interview quote from a regulatory organization; however, there is still a dominance of the more traditional mindset of compromise,

> *Ultimately the cost and maintenance and permitting, rate structure and how they're going to pay for it all should be understood in the context of the broader set of criteria. A portfolio approach that includes a broad look at all sorts of things. (Regulatory Organization Interview)*

Consider a regulatory view of the system as shown in Figure 5.3. In this diagram I indicate existing regulation for key flows of water, energy, and pollution directly from a power plant, fuel extraction, or wastewater treatment plant as well as regulation on the flows returned to each respective water source after it has been used. While not an exhaustive list of federal, state, and local laws, a few key regulatory sources related to power plant cooling water are highlighted for demonstration. I also make a logical assumption that unfortunately not every source of pollution can be regulated, nor are all existing regulations fully enforced or comprehensive which creates a system of selective governance. Thus, despite the regulations that are in place there is still an unregulated flow to people and the ecosystem. Unfortunately, the connection from various sources of pollution to people's experience of the system in terms of medical conditions and high health care costs, for example, is not straightforward and remains primarily unregulated.

The flow of freshwater to water users, for example, is regulated with permits for water rights regulated by the TCEQ. In 2007 the Texas legislature also passed bills[15] to regulate water resources for in-stream inflows and freshwater, indicated below as environmental flows. More specific to power plants, the environmental impact of cooling water intake[16] of freshwater is regulated by the EPA's National Pollutant Discharge Elimination System (NPDES) permit regulations to protect organisms killed by the heat, physical, or chemical stress from being pulled into the intake structure.

On the discharge side are the Clean Water Act permits mentioned in Chapter Two that requires a permit for all discharges of pollutants to surface waters. Similarly, the flow of air pollution from a power plant plume is regulated at the federal level with the EPA's Clean Power Plan which sets limits on the amount of carbon dioxide released. It

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[15] House Bill 3 and Senate Bill 3, 80th Legislature, 2007
https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/eflows

[16] 40 CFR Parts 122 & 125 (Subparts I, J, & N)
https://www.epa.gov/cooling-water-intakes

should be noted this regulation is under review for curtailment per executive order from the current administration.[17]

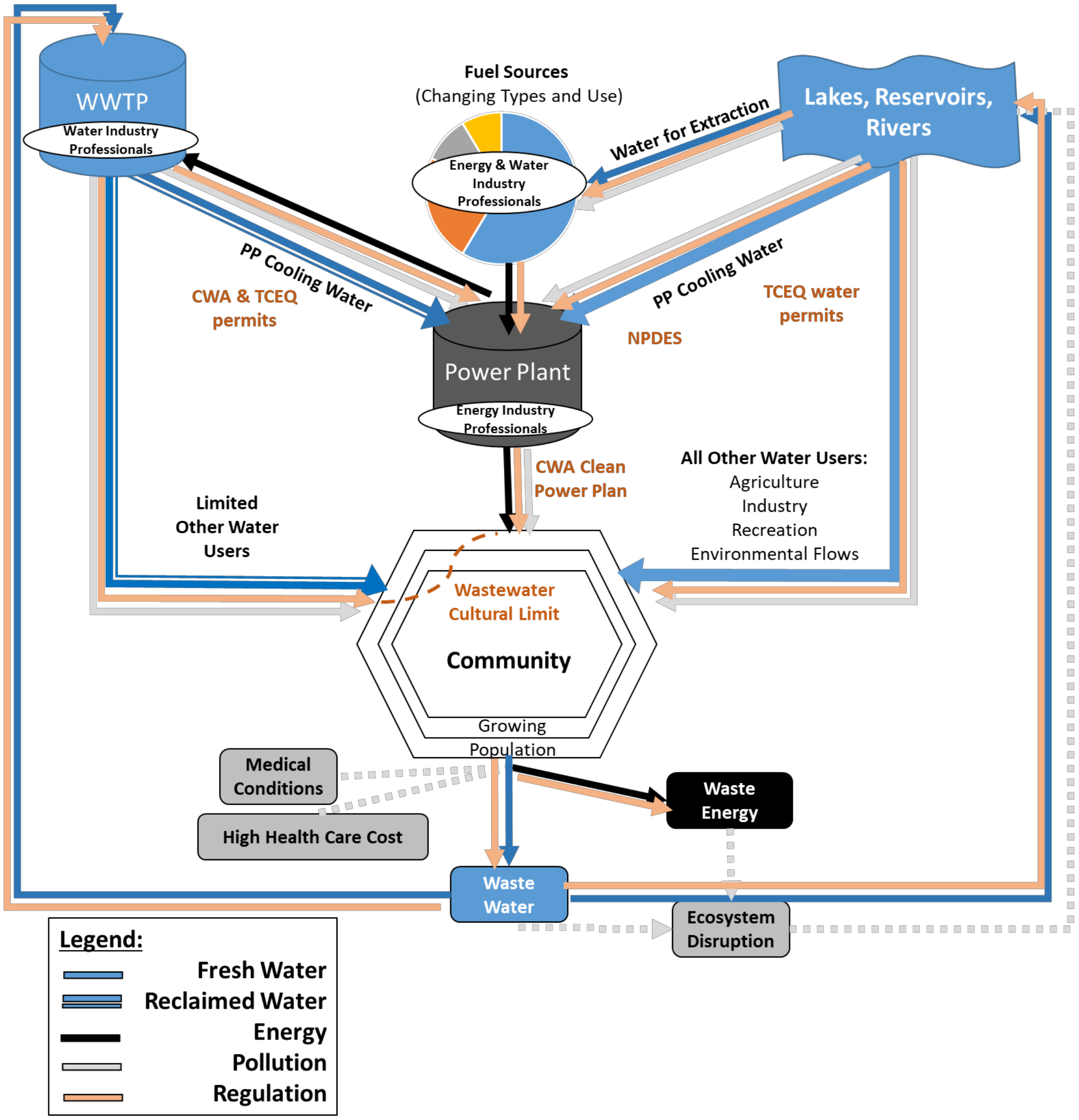

Figure 5.4: Regulatory Perspective of Power Plant Water Use Decision Making (Source: Author)

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[17] United States Environmental Protection Agency. "Complying with President Trump's Executive Order on Energy Independence. 2017 https://www.epa.gov/energy-independence

This is an important point for planning consideration due to the years and effort it can take regulation to get into place but be easily removed by a new administration. Political interests will constantly fight against the cost of applying, reporting, and monitoring adherence to these restrictions, thus being prepared for those interests in advance may help resistance. I point this out because the new requirement for a sunset review on the LCRA mentioned in Chapter 4 was already under heavy pressure and considered for removal in the Texas congress a year after it was created, (Price, 2017). This pressure is directed at the cost of the review, however, there is high likelihood lobbying of special interests is responsible. These stakeholder-to- stakeholder conflicts are tough to mitigate as indicated in the following interview with a state water organization,

> *Generally speaking I don't think our country has a water crisis. I don't think we have a significant water problem. I think we have a people problem not a water problem. Willingness to pay, just an overall lack of education. Lack of true value for water. (State Water Organization Interview)*

In light of the tensions between all of these regulations, between all of the stakeholder conflicts, and between experts currently running the system and those that are not even aware they are in the system, I end with discussion of an alternative form of governance in final summary that that may help design better experiences for both the system's citizens and ecosystems.

SUMMARY

The progression of studying this aspect of the energy-water nexus began with collecting the various literature and experiences of people in and around reclaimed water use in thermoelectric power plants. It included analyzing this information through Interactive Qualitative Analysis, and adjusting my analysis method to better reflect the incoming data through Naturalistic Inquiry. It culminates with the identification of conflicts and patterns in the decision-making, and critically thinking about what an alternative model system could include in order to suggest implications for future planning in the energy-water nexus. My final impression is that current governance of the system is driven primarily by the institutional and professional experts that have the closest ties to water and energy industries despite the impact the system has across regions and communities. Supervision of the existing system is driven primarily by these experts throughout the governing bodies and regulations at all levels of government, the research organizations, educators, and the private energy and water business owners. Yet, *I found even among these highly qualified individuals, it is difficult for anyone to understand the entire system of influence on how these decisions get made, and even more so for anyone further removed from these institutions.*

I suggest that future governance should include not only supervision by these experts, but should also be driven by community impact due to the legitimate claim and responsibility communities have to be engaged in governance of their energy and water resources. *Expanding the system boundaries in a way that considers a wider range of stakeholder and ecosystem impacts leads to a more diverse range of perspectives and rationalities in this decision-making.* Fischer calls this an integration of “sociocultural rationality with the technical perspectives of the experts“ (Fischer, 2000, p. 148). This type of governance is stressed because there appears to be an insufficient match between the institutional hierarchy and a mutually beneficial system among stakeholders which is a key issue in the way water choice decisions will be made in the future.

One way to change the current governance is to address the complexity, fragmentation, and agency of the existing system that leads to some information being readily available while other information is missing, misrepresented, or misunderstood. As mentioned above, a fragmented system fosters this kind of broken flow of information, however, it may also be easier to influence than one that is more hierarchically driven, inflexible, and slow to change. This is where some modification in scope of an existing organization such as the TMUA and TML may be useful. What I like about these organizations are that they embrace the professional growth of utility managers and advancement of cities of all sizes, both urban and rural. I believe leveraging all layers of the existing network, relationships, values, and frames of reference could allow for an expanded mission as both negotiator, communicator, and educator on this aspect of the energy-water nexus in order to evolve the current system of governance.

This is not to suggest a specific solution, or adoption of any one particular model of the system, but to suggest a possible way to answer the first research question on how might energy and water planners can employ a guiding set of cohesive principles to better coordinate and integrate their respective strategies. The goal is to create an organizational structure that supports dynamic and flexible governance across the state that is context driven by each utility's politics, technology, ecology, and history. A few of these actions may include increasing awareness of local conditions from both a regional and statewide context, the development and use of digital scenario planning tools, or the development of a new governance models that are a better reflection of contemporary conditions and environmental justice. These actions along with digital documentation and transparency may make it easier to improve the lack of institutional memory discussed above, but also make it easier to fill some of the gaps I have pointed out in existing literature with respect to the lack of sociopolitical study of this topic. The statewide breadth and local depth of this type of traceability would further the second research question of how the experiences of utilities compare as well as how they diverge beyond what I have captured in this study.

These suggestions also provide a means to the research question of how the public can have more agency in energy-water alternatives. The educational outreach potential of the TMUA and TML can be used initially to reach the community's representatives in city council, who can then engage their own citizens in ways that are appropriate for their communities.

An important point to stress is that this is not a continuous effort for each utility. Due to the temporal component discussed in the introduction, the long-life span of a power plant indicates many older plants are more likely to retire than to retrofit or build new pipeline to a WWTP. These utilities already have deeply embedded social and ecological agreements in the existing system. Thus, it is possible to incorporate the symbiotic relationships I suggest with the siting of new plants. This also means the educational outreach on the option of cooling with reclaimed water is suggested primarily at the time of siting of new power plants, the timing of which will come and go for communities across the state. In the physical context of constructing new power plants, new social and organizational relationships can emerge.

Glossary

The following list defines terms used throughout this dissertation.

Condenser Duty: The amount of waste heat transferred to cooling water in a plant's condenser (Harris, 2017)

Ecology: The study of the flow of energy and the cycles of materials in ecosystems (Martinez-Alier, 1987, p. 1)

Generation: The amount of electrical energy that a power plant produces, generally measured in kilowatt-hours or megawatt-hours (Stillwell, et.al , 2009, p. 47)

Normative Approach (in planning): A belief in self-organizing principles based on durable, time-tested truths and that the search for good city form is a worthy goal, (Talen & Ellis, 2002)

Pragmatic Theory (in planning): A resistance to the rule-following behavior of positivism encouraging creative exploration to find 'what works,' I the mess enterprise of living,' (Healey, 2008)

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