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Evaluating the Key Societal Factors and Utility Priorities That Drive the Potential for Water Reuse Success

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EVALUATING THE KEY SOCIETAL FACTORS AND UTILITY PRIORITIES THAT DRIVE THE POTENTIAL FOR WATER REUSE SUCCESS

by

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Evaluating the Key Societal Factors and Utility Priorities
that Drive the Potential for Water Reuse Success
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Find that both the content and the form meet acceptable presentation standards
Of scholarly work in the above mentioned discipline.

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Evaluating the Key Societal Factors and Utility Priorities that Drive the Potential for Water Reuse Success

Thesis directed by Professor Karl Linden

Long range planning for utilities implementing water reuse is very complex due to the interplay of numerous issues and factors. A method that uses a computer-aided decision tool incorporating scenario analysis was tested to determine whether it was effective at helping entities determine the potential for successful water reuse schemes under certain factors (such as economics, water supply, and demand) that act in society, and given the individual priorities of the planning entity. Two methods were used to determine effectiveness: analysis using multiple approaches and objective validation using retrospective case studies. The multiple approaches include surveys, expert workshops, scenario studies, and statistical analysis. Two studies were also performed using the computer-aided decision tool. The first was a sensitivity study done to determine the key societal factors and entity priorities that, in general, have the most impact upon water reuse. The second study illustrated possible applications of the decision tool by using it to assist a utility with their long-range planning efforts.

DEDICATION

I dedicate this work to my husband, Garry. There are not words to express my gratitude for your love, friendship and support. I could not have completed this without you.

This dissertation is also dedicated to my daughters Jean and Jessy, and to everyone who seeks their passion. Chase your dreams and find your shooting star. Make it happen. You can do anything you set your mind to.

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Chapter 1

INTRODUCTION

With the pressures of increasing populations, maintaining water quality, and combating water stress, utilities worldwide are considering implementing, or have implemented, water reuse into their portfolio of water supplies. Planning for water reuse is very complex, dealing with aspects that encompass multiple disciplines of engineering (civil, environmental, water treatment, wastewater treatment, and water resources management), as well as issues that stretch beyond the technical and into the socio-economic, sociological, legal and regulatory realm.

Briefly, these issues include planning for climate change, integrating reuse into water resources management, maintaining an adequate water supply and water quality, assuring the protection of public health, ensuring public acceptance, developing reasonable standards, economic viability, finding a balance between high quality water and the intensive energy consumed to treat it, maintaining soil productivity with reclaimed irrigation water, advancing technology, and addressing water rights, water ethics, and cultural norms.

Because of these complexities and uncertainties, many utilities and municipalities have developed decision tools to help them decide how to best implement or plan for water reuse. Scenario studies have also been performed to help consider the future and help ensure that uncertain future circumstances are considered in their decisions. Many water reuse related questions, feasibility studies, and policy choices have been evaluated using decision tools and scenario studies (Hochstrat, 2006; Jaksimovic et al, 2006; Hidalgo et al, 2007; Makropoulos et al, 2008; Rozos et al., 2010; Zarghami et al., 2008). Often these tools are limited in the number of factors that can be considered before they become too complex. Because water reuse is surrounded by so many issues and factors, it can be very difficult to determine which of them should be considered in these decision tools, and which should become a priority of the utility in order to ensure water reuse success in the long term. Currently, many rely on their instincts, past experience, or available data to choose the factors that are used for decision-making processes.

Little research has been performed to develop methods to ensure that the factors and priorities chosen for consideration in these scenario studies and decision tools will help to provide the most effective, robust solution. Due to the extent of complexity and uncertainty involved in water reuse planning and the limited number of factors that can be considered by decision tools and scenario studies, this sort of research is essential (Miller, 2006). This study aims to provide a more robust alternative for selecting the key factors used for long range water reuse planning.

1.1 Hypotheses and Research Objectives

This dissertation investigates the issues and factors related to water reuse, determines which are most important to consider and keep as a priority, and provides a computerized tool that will assist planners in determining which factors and priorities are most important to focus upon for their unique situation, that can be incorporated easily into their planning schemes.

Key questions that are investigated include the following: Should a specific utility implement water reuse practices or not? Which societal factors affect water reuse the most? How do the priorities of the utility or planning entity affect the potential for water reuse success? Answers to these questions can serve to help those conducting long range planning for water use and reuse be sure that they are evaluating their policy choices using the most relevant criteria.

HYPOTHESES

1. Using multiple methods to analyze the key factors that affect water reuse will lead to agreement upon which factors are most important

Multiple methods were used during this study to determine which of the factors are most influential and thus most important to include in a computer model. These methods include surveys, expert workshops, qualitative scenario studies, statistical analysis, and computer analysis with a hybridized tool. The philosophy behind using multiple methods was to start broadly, including as many factors as possible, and using the subsequent methods to reduce the number of key factors that must be considered in order to attain a small subset of factors with the most influence over water reuse. It is hoped that multiple methods will provide some agreement as to which factors are most important.

2. Water supply needs and economics are the key factors in society that affect water reuse. Maintaining public acceptance is the factor most important for water reuse providers to have as a priority in their operations.

A sensitivity model was created using the hybridized decision tool methodology. This model will be used to determine the key factors in society that have the most weight in determining the success or failure of water reuse. It is also used to discover the factors that utilities providing water reuse services must keep as a priority in their operations in order to help ensure success.

3. The method of using a computer-aided model coupled with scenario analysis can effectively determine key factors that influence water reuse.

This dissertation will show that using a hybridized computer model that incorporates scenario analysis can help to inform utilities which factors and priorities they should consider and be concerned about – either for development of their decision tools, long-range planning, or policy analysis. This hybridized tool can help to address the uncertainties of the future and be sure that what is considered and decided is robust in the face of these uncertainties.

Objectives

The effectiveness of this method will be shown through the following objectives:

1. Identify the factors that affect water reuse.
2. Determine which of these factors currently impact water reuse the most.

3. Project the state of water reuse into the future and determine which factors will be most influential over water reuse then.
4. Develop an index to measure the potential for successful water reuse implementation.
5. Use the hybridized computer-aided decision tool to combine this index with scenario analyses to determine which factors are most important for ensuring water reuse success.
6. Apply this tool toward determining key factors for a local utility, and show how it can be incorporated into their existing planning system.

1.2 Scope of Study

Because the factors that contribute to water reuse implementation success vary significantly from one location to the next, this study will focus on water reuse in the United States and Australia. These two countries have similar circumstances regarding water reuse, thus the results should complement each other well. Data was gathered from both countries, as well as from a few sources from western Europe, Singapore, and Israel.

It is important to note that much of the data and the results presented from this study are influenced by bias. Much of the statistics and information gathered in surveys and expert workshops, and from literature was attained from sources involved in the water reuse industry. Thus the views present in the industry are reflected in this study.

1.3 Arrangement of the Thesis

This dissertation is arranged to develop an understanding of the many factors that affect water reuse, to show the progression of determining key factors, and to demonstrate the effectiveness of the hybridized computer tool. Chapter 2 provides a literature review outlining the factors that affect water reuse and the complexities that they present to the industry. The progression of the determination of key factors is outlined in Chapter 3, showing how the multitude of factors discussed in Chapter 2 are reduced and combined into a format that is useful for the decision tool. Chapter 3 also discusses the views of water reuse practitioners and experts regarding factors that contribute to the success of water reuse. The method and configuration of the hybridized computer tool is outlined in Chapter 4. This chapter also validates the model by comparing results from the computer tool to the key drivers of past and present cases of water reuse implementation. Chapter 5 discusses a study conducted with the computer tool that uses a sensitivity study to determine both the key societal factors and the essential priorities that are generally the most important for water reuse success. Chapter 6 demonstrates how this hybridized computer tool can be used for long-range planning conducted by a utility. Data and information from a local utility are used to help determine key factors for their service area, and to help guide policy analysis.

Chapter 2

MAKING SENSE OF THE FACTORS THAT DRIVE WATER REUSE – A LITERATURE REVIEW

The lack of adequate fresh water resources coupled with population growth, regional drought, and impending climate change is one of the most significant environmental issues facing the world. Fresh surface and groundwater resources are finite in their ability to provide the clean water resources necessary to support the Earth's population. As the population grows and the general use of water increases, pressure is being placed on the balance between water supply and demand. Thus, there is widespread concern that the supply of freshwater will not be adequate to support future needs. In order to address this concern, many are turning to the practice of water reuse.

Current water reuse practices vary widely worldwide, involving different applications, technologies and standards. Each location has a unique set of characteristics that describe things such as its infrastructure, government, available water supply, demand, economy, culture, and climate. In addition, when considering water reuse, there are a number of technical, environmental, institutional, and socioeconomic issues that need to be considered. Some of these issues include determining how to best integrate water reuse into current water resources planning and management schemes, and ensuring that water reuse practices will not have ill effects on water quality and public and environmental health. It is also necessary to garner support for the practice, thus there are also concerns regarding gaining public acceptance, demonstrating that water reuse can be economically viable, and addressing water rights, water ethics, and cultural norms. Legally, there are questions regarding how future reuse schemes affect water rights and future allocations, and how to develop effective standards and regulations.

For entities that are considering water reuse, this multitude of considerations can make implementation difficult. They must consider all of these issues when devising water reuse strategies that also consider factors such as continually evolving technology and climate change. Some of the most perplexing questions that these entities consider include deciding whether to implement water reuse, which reuse methods are most applicable to their unique circumstances, which of these many factors are most important to focus on, and how their decisions will affect future business. This review aims to improve the understanding of the many factors and complexities that affect water reuse as well as their interactions. In addition, this paper will discuss research and development options that will best advance water reuse in the face of these complexities.

2.1 Overview of Water Reuse

The modern definition for water reuse is the use of degraded, or impaired, water sources for any beneficial purpose (Metcalf & Eddy, Metcalf & Eddy, 2007). Degraded, or impaired water is water that has suffered chemical (increased levels of salinity, nutrients, trace elements, organic chemicals), physical (increased suspended solids concentration, temperature), or microbiological (pathogens) degeneration in quality as a result of use (O'Connor et al., 2008). Despite the term "degraded," water may be treated, even to better than original quality, before reuse. Sources of degraded water include: municipal wastewater effluents, brackish groundwater, seawater, effluent from animal operations, irrigation return flow, industrial wastewater, stormwater, graywater, and thermoelectric cooling water (O'Connor et al., 2008). Water reuse may also be referred to as water reclamation or water recycling.

However, water reuse is not a new concept. Humans have been reusing water as it moves through the hydrological cycle for as long as humans have existed. Wastewaters (municipal, agricultural, industrial) have been applied to land for centuries (Rowe, 1985). Irrigation flows return to streams where the water is used for other purposes. Water from irrigated or waste-amended fields, and effluent from wastewater treatment plants routinely flow to surface and groundwater bodies, and are subsequently withdrawn as "fresh water" supplies by downstream users. Large scale water reuse began about 150 years ago when cities began reusing water by flushing toilets that was routed to sanitary sewer systems and for irrigation using sewage farms (Crook et al., 2005). With the widespread use of sewer systems and centralized wastewater facilities, reclaimed water has been increasingly used in agriculture for crop and pasture irrigation (Asano, 1998).

Today, increasing levels of urbanization, escalating costs, and increasing difficulties in efficiently managing scarcer and less reliable water resources have triggered a switch to reuse efforts driven by sustainability desires and integrated water management approaches (SWITCH, 2008). Some of the key elements of this paradigm shift are diversification of water portfolios, decentralized approaches promoting more localized reuse, and the integration of advanced water treatment technologies to provide higher quality reuse water. Water reuse is now seen as presenting many opportunities for addressing water needs. For example, moderately treated reuse water can be used where high quality potable water is not required and conserve high-quality supplies. Highly treated water can be used to augment potable water supplies, to help meet water needs, and improve the reliability of local water supplies during drought years. There are also environmental benefits, such as decreasing the diversion of freshwater from natural water bodies, reducing contaminant discharges, decreasing the need for water control structures, preventing saltwater intrusion into freshwater aquifers and improving groundwater reliability. For municipalities, water reuse can reduce energy, chemical, and material usage by reducing water treatment needs. It can also delay or reduce the need to upgrade and expand water and wastewater infrastructure.

Water scarcity and wastewater discharge requirements have been the main drivers for developing water reuse in the United States. Most sites that utilize reuse are located in the dryer western and southwestern states, where water supplies are limited. Recently, water reclamation has spread to the wetter more humid regions where there is rapid growth and urbanization. For example, Florida began utilizing water reclamation to protect against coastal eutrophication and other environmental effects. Rapid population growth spurred Florida to utilize water reclamation at a grander scale. St. Petersburg in Florida has faced water and wastewater problems for over a century, which were compounded by rapid population growth. As a result, it became the first major municipality in the U.S. to achieve zero discharge to surrounding surface waters through landscape irrigation.

Wastewater treatment standards have evolved to the point where there is great confidence in the processes to protect public health (Metcalf & Eddy, Metcalf & Eddy, 2007). As a result, water reclamation and reuse have grown significantly in the U.S. By 2006, there were over 1000 reuse projects in the United States (Bixio et al., 2006).

2.1.1 Water Reuse Applications

Water reuse is implemented in many ways. In general, applications can be categorized into potable and non-potable uses, with a further distinction in potable reuse being established as direct or indirect reuse. Table 2.1 summarizes the major applications of water reuse.

Table 2.1 - Common Water Reuse Applications

Reuse Application		Example Uses / Additional Information
Potable – Direct	Blended with municipal water supply	No use of an environmental buffer
Potable - Indirect		Augmentation of drinking water reservoirs; Augmentation of potable aquifers for later extraction via surface spreading, riverbank filtration or direct injection
Urban Restricted	Irrigation where public access is controlled	Golf courses, cemeteries, highway medians
Urban Unrestricted	Irrigation where public access is unrestricted	Parks, playgrounds, residences, fire protection water, construction, ornamental fountains, commercial toilet flushing
Agricultural-Restricted	Irrigation of non-food crops. Similar to restricted urban reuse.	Fodder, fiber, seed, pastures, nurseries, sod, aquaculture crops. Possible that crops can be irrigated by wastewater effluents, animal manure effluents, some stormwaters and graywater.
Agricultural Unrestricted	Watering of crops consumed or contacted by humans	Typically requires high-quality water, similar to unrestricted urban reuse.
Groundwater Recharge	Water directly injected or allowed to percolate into aquifer	Saltwater intrusion barriers, Provides further treatment, Augments potable and non-potable aquifers, Reclaimed water storage for future use, Prevent ground subsidence
Industrial	Internally or externally recycled water for industrial processes	Evaporative cooling water, Boiler feedwater, Process Water, Landscape irrigation, Fire protection, Dust control, Ornamental fountains, Construction, Laundry, Car washes, Textiles, etc
Elementary Body Contact Recreational	Waters used for bathing, swimming, waterskiing, etc	Waters must be aesthetically attractive, have acceptable physical attributes (taste, odor, temp, solids, turbidity), free of toxic substances and pathogens
Secondary Body Contact Recreational	Boating, canoeing, camping, landscape, fishing, golf courses	Less stringently regulated than elementary contact waters. People not allowed to physically be in the water.
Non-contact Recreational	Confined water bodies, fountains, aquaculture	Reasonable temp to sustain aquatic life, suitable conc. of DO, trace elements, pH, pesticides, etc. Reasonable microbiological quality. Elimination of nutrients that cause eutrophic conditions.
Environmental	Higher stream flows allow for less stringent regulation	Wetland enhancement and restoration, Wetlands for wildlife habitat and refuge, Flow augmentation for streams and rivers

(Adapted from Rowe, 1995; USEPA, 2004; WHO, 2006; Metcalf & Eddy, Metcalf & Eddy, 2007; and O'Connor et al., 2008)

2.2 Issues and Factors Affecting Water Reuse

In addition to considering the ways reclaimed water will be used, there are many other issues and factors that need to be considered when deciding whether to pursue water reuse. These issues include water supply and demand considerations, social factors, political and policy conditions, regulatory and legal issues, energy use, technology advancement, economic conditions, and environmental concerns. These are discussed in the following sections.

2.2.1 Water Related Issues

WATER DEMAND, STRESS, & SCARCITY

It has been estimated that conventional water resources represent less than 0.2% of the earth's supply of water (Speidel & Agnew, 1988). Of this small percentage, the water is not evenly distributed around the globe. It is estimated that as of 2007, collected there was 8,210 m^3 per capita per yr (m^3/capita-yr) of freshwater supply, but regionally this value can be as low as 1,398 m^3/capita-yr, as found in the Middle East and North Africa, and as high as 52,674 m^3/capita-yr (WRI, 2007). This geographic variation combined with natural differences in rainfall, areas of intense population growth, and widespread urbanization has led many areas of the world to be classified as "water stressed" or "water scarce." A region is said to be "water stressed" if the water supply is less than 1,700 m^3 per capita per year, and is "water scarce" if that figure drops below 1,000 m^3 (WRI, 2003). Presently, nearly 11% (700 million people) of the world's population live in water scarcity conditions. By 2025, 48% of the world's population (3.5 billion people) is projected to live in water-stressed areas, and at least 2.4 billion people will live under water stressed conditions (WRI, 2003). By 2050, nearly half of the population, in 149 countries are projected to live in water scarce areas (UN, 2006). The regions expected to be most affected by water scarcity are the west coast of the United States, much of Australia, North and South Africa, the Mediterranean, western Asia, the North China Plain, western and southern India, Pakistan, and central and southern Mexico (WRI, 2003).

It is important to note that water scarcity issues typically exist at smaller regional and local scales. Regions subject to water scarcity face hindered economic development, degradation of public welfare, inadequate food supplies, environmental degradation, and possibly even water-related conflicts. Areas with the greatest water scarcity often are areas with the greatest need for economic development, improvement in public welfare, and increased food supply to support a growing population (O'Connor et al., 2008). Interestingly, water scarcity might be expected to be greater for developing countries, but projections show that there will be growing water shortages in the developed world as well, such as in the southwestern United States and many regions of Australia (Metcalf & Eddy, Metcalf & Eddy, 2007). A study conducted by the United States General Accounting Office (GAO, 2003) found that most state water managers, given normal climatic conditions, anticipated either regional or local water shortages by the year 2013.

WATER QUALITY

There is a lot of controversy about the relationship between the quality of reclaimed water and public health (Bixio et al., 2006). There is concern that humans have an increased likelihood of coming into contact with pathogens in reuse water, thus special regulations are set regarding contact with these waters. Having water cycled through the population more times before release to the hydrologic cycle raises concerns about the accumulation of toxins such as heavy metals, pesticides, endocrine disrupting chemicals, hormones, pharmaceuticals, personal care products, and other emerging contaminants. This leads to concerns of antibiotic resistance, immune and endocrine system effects, cancers, and ecological effects on the environment (O'Connor et al., 2008).

AGRICULTURAL WATER REUSE ISSUES

Globally, approximately 70% of the water withdrawn from the earth's rivers, lakes, and aquifers (approximately 820 x 107 m^3/day) is used for irrigation (FAO, 2003). It has been suggested that improving irrigation efficiency by 10% would allow the amount of fresh water available for all other uses (domestic, industrial, etc.) to double (O'Connor et al., 2008). This could be accomplished through the use of reclaimed water. Using reclaimed water for agriculture involves some extra considerations.

Depending upon the level of treatment, reuse waters often have higher nutrient concentrations. While this is beneficial for agriculture, it can also cause problems such as eutrophication. When reclaimed water is used for irrigating, salinity, sodicity, and toxicity by specific ions and trace elements are a major concern. The largest of these concerns is salinity, which can be high in treated wastewater. In fact, according to the United States Environmental Protection Agency, salinity is the single most important parameter for determining the suitability of reuse water for agricultural irrigation (USEPA, 2004). Excessive salts can impact both plant growth and soil structure, which can permanently affect the productivity of a soil (O'Connor et al., 2008). There are some special procedures that can be utilized to help manage salinity. The proportion of sodium relative to other cations can be reduced by adding other cations such as calcium. The reclaimed water can also be blended with a higher quality water. Emerging contaminants can have ecological effects on aquatic organisms, plants, and soil microbes (O'Connor et al., 2008).

Conservation versus Reuse

It has been estimated that enacting water conservation measures could reduce water use by 50% (Rowe & Abdel-Magid, 1995). Domestic water use provides many opportunities for conservation. Shorter showers and low-flow toilets can reduce domestic use by 30%. Fifty percent of the domestic water supplied is used for lawn irrigation. Different plant choices and smarter irrigation could reduce the lawn irrigation demand by 33 to 50% (O'Connor et al., 2008).

In the United States, it is estimated that 53 x 10^7 m^3/day of water is used for agricultural irrigation (USGS, 2004). Globally, approximately 70% of the water withdrawn from the earth's rivers, lakes, and aquifers (approximately 820 x 10^7 m^3/day) is used for irrigation (FAO, 2003). Much of this irrigation water is applied using low efficiency methods. It has been suggested that improving irrigation efficiency by 10% would allow the amount of fresh water available for all other uses (domestic, industrial, etc.) to double (O'Connor et al., 2008).

Some have argued that water conservation is preferable to water reuse. One reason stated is the view that making more water available may support further growth in an area that is not sustainable for the surrounding ecosystem. Additionally, the construction of the treatment facilities and distribution networks, along with the ongoing operation consuming energy and chemical supplies can be much more intrusive upon the environment than enacting water conservation measures. There are also concerns that emerging contaminants such as pharmaceuticals and personal care products may accumulate and have impacts on sensitive waters and on organisms (Davis, 2008). It has been found that substances that remain in wastewater effluent do accumulate in lakes, rivers, sediments, and various test organisms such as zebrafish (Knacker et al., 2006).

Proponents of water reuse argue that conservation alone will not solve the water problems of the future. It must play a key role, but water reuse must also be part of future water use plans. They claim that many of the concerns that environmentalists have can be addressed proactively by water professionals. To address the concern of additional growth, it may be as easy as communicating with decision-makers, developers, and the public about how much development is actually possible with what is currently supplied and how that may change with enacting water reuse practices. It is key that they stress that often water reuse is used to remove some of the stresses that are currently being placed upon the environment. Minimizing the effects of construction and operation of new facilities can be accomplished by incorporating environmental analysis tools such as the Natural Step™ framework, Ecological Footprints, and the LEED™ (Leadership in Energy and Environmental Design) Green Building Rating System (Holmes et al., 2004). In countries where there is a high usage level of pharmaceuticals and personal care products, avoiding the implementation of water reuse will not solve these environmental issues, as these compounds are prolific in wastewater effluents that are also released to the environment.

2.2.2 Social Factors

POPULATION

As the world's population continues to grow, and economies in developing nations grow, the demand for new water supplies can also be expected to grow. This will place additional pressure on water supplies as industrial demand and energy use grows. This pressure has been notably observed during the last two decades in every state and territory of Australia, parts of the United States, Singapore, India, China, Japan, Spain, Portugal, Italy, and much of Africa and the Middle East. Water stress is also being induced due to rapid urbanization and the growth of megacities and the slums that surround them. With increasing population also comes the need to supply food, which is water intensive. It has been estimated that agriculture uses 70% of the water withdrawn from the earth's rivers, lakes, and aquifers for irrigation (FAO, 2003). Thus, supplying a growing population with adequate food will further stress the available water supply.

Populations in water stressed areas of the United States have been projected to grow between 30 and 50 percent between 2000 and 2025 (Campbell, 1997). Populations in some drought-affected areas of Australia, including parts of South East Queensland, are growing at annual rates of over 2.5% (ABS, 2008). Recent projections have estimated populations of 1.395 billion in India, and 1.441 billion in China by 2025 (WRI, 2008). As the world's population continues to grow, and economies in developing nations grow, the demand for new water supplies can also be expected to grow. This will place additional pressure on water supplies as industrial demand and energy use grows. This pressure has been notably observed during the last two decades in water-stressed areas of the United States, particularly California, Arizona, Texas, Florida, Georgia, Nevada and Colorado. Globally, the strain of population combined with water-stress has been seen in every state and territory of Australia, Singapore, India, China, Japan, Spain, Portugal, Italy, and much of Africa and the Middle East. Water stress is also being induced due to rapid urbanization and the growth of megacities and the slums that surround them. Historically in the United States, water use for domestic supply has increased proportionately with population (Hutson et al., 2004). However, with the implementation of water conservation measures, the rate of domestic use has slowed to about half the rate of population growth (GAO, 2003). With increasing population also comes the need to supply food. It has been estimated that agriculture uses 70% of the water withdrawn from the earth's rivers, lakes, and aquifers for irrigation (FAO, 2003). Thus, supplying a growing population with adequate food will further stress the available water supply.

PUBLIC ACCEPTANCE

A major barrier to water reuse, perhaps even its greatest challenge, is a lack of public acceptance and public support. Entire water reuse projects have been derailed due to problems with how the public viewed reuse practices. Some factors that affect how the public views water reuse include: the perception of risks from the water, disgust at the thought of reused water, how the recycled water will be used, what source water is being recycled, amount of trust in science and authorities, attitudes toward the environment, the cost of the recycled water, and other social and cultural factors (Po et al. 2005 & 2003; Marks et al. 2006; O'Connor et al. 2008). A synopsis of some of the factors that influence public acceptance of water reuse follows.

- **The "yuck" factor (disgust):** Most people have a psychological barrier that makes it difficult to reconcile the use recycled water. This can be a mental image, emotional discomfort, or the perception that a neutral object may acquire disgusting properties from some other object through brief contact and it cannot be fixed.

- **The specific uses of the reuse water:** The closer the recycled water use is to human contact or consumption, the higher the opposition is to using the water (Marks et al., 2006). Conversely, forms of reuse that are not ultimately consumed by the public are generally more readily accepted (Fletcher et al., 2008). For example, in San Francisco it was found that 90% of people viewed using reclaimed water for concrete production positively. However, only 30% were positive about irrigating crops directly consumed, and only 18% would feel comfortable with direct potable reuse (O'Connor et al. 2008). Studies (Melbourne Water, 1998; ARCWIS, 2002) have also found that acceptance of reclaimed water drops substantially as the uses move from public areas to uses within the home, and then also from non-potable household (toilet flushing, laundry, bathroom and kitchen) uses to drinking water.

- **Water sources to be recycled:** Water reused from sources other than wastewater are more easily accepted (Fletcher et al., 2008). In addition, reuse of greywater or wastewater from an individual's own household was more acceptable than that from other public or further removed sources. This may be tied in with the "yuck" factor and that people may find their own waste less revolting than that of others. In addition, the type of water (e.g. rainwater, greywater, wastewater) also affects public acceptance, with rainwater being preferred over greywater and greywater being preferred over wastewater. (ARCWIS, 2002; Nancarrow et al., 2002; Kaercher et al., 2003)

- **Choice:** In areas where there are water shortage issues, water reuse is much more readily accepted. If there are other possible water sources available, then the need for water reuse is questioned. There must be a genuine need for water reuse (Melbourne Water, 1998; Dishman et al., 1989)

- **Trust in authority and scientific knowledge:** Trust in authorities to provide safe water, and in the quality of scientific investigation and technology can be a key factor determining public acceptance of water reuse schemes.

- **Attitudes toward the environment:** Studies have found that people who strongly believe in the importance of environmental issues also tend to support water reuse (Sydney Water, 1999; Po et al., 2005)

- **Environmental justice issues:** Perceived injustices such as low and middle class citizens receiving the majority of recycled water (Recycled Water Task Force, 2003), unfairness in decision-making processes (Syme et al., 1999, 2000, & 2001), and aesthetic concerns over placement of treatment plants (Sydney Water, 2002) can influence public perception of water reuse projects.

- **Socio-demographic factors:** A less influential factor in determining public acceptance may be found in analyzing demographics. Studies have found some differences in acceptance levels based on age, gender, education level, place of residence, and language spoken (Hartley, 2003; Sydney Water, 1999). However, there are many inconsistencies across different studies as to the type and extent that demographic differences affect public perception, with some studies showing no influence of gender age or socio-economic status (Jeffrey, 2002).

- **Cost of recycled water:** In general, people expect to pay less for recycled water because it is perceived as being a lower quality product and its use is often restricted (Anderson et al., 2008b). In order to promote industrial reuse, it is often beneficial to show potential economic advantages that stem from utilizing reuse water (Gagliardo, 2003). However, economic benefit will not necessarily guarantee acceptance.

- **Cultural Reasons:** Customary practices involving water may not agree with the use of reclaimed water. Many people are averse to handling human waste, and reclaimed water seems to intimately close to that sort of contact. And finally, religious rules of purity may make the use of reclaimed water taboo. (Sheikh, 2004)

2.2.3 Public Health

There is a lot of controversy about the relationship between water reuse and public health (Bixio et al., 2006). There is concern that humans have an increased likelihood of coming into contact with pathogens in reuse water, thus special regulations are set regarding contact with these waters. Having water cycled through the population more times before release to the hydrologic cycle raises concerns about the accumulation of toxins such as heavy metals, pesticides, endocrine disrupting chemicals, hormones, pharmaceuticals, personal care products, and other emerging contaminants. This leads to concerns of antibiotic resistance, immune and endocrine system effects, cancers, and ecological effects on the environment. (O’Connor et al., 2008) Table 2.2 lists classes of reuse water constituents that may be of risk to human health.

Table 2.2 - Reclaimed Water Constituents That May Be of Risk To Human Health

Suspended Solids	Can develop sludge deposits and anaerobic conditions, may include pathogens. Can affect disinfection efficiency if not properly treated.
Organic Matter	Can cause odor and septic conditions. Some organics are priority pollutants with toxicity and health effects. Some refractory organics resist conventional wastewater treatment (surfactants, phenols, pesticides, etc).
Inorganic Matter	Greatly affects how reuse water can be used. Includes heavy metals, anions and cations. Some inorganics are priority pollutant
Pathogens	Bacteria, viruses, protozoa, and helminthes. Can survive in water and infect humans through ingestion, person-to-person contact, or contaminated food and surfaces.
Nutrients	Can be great for agricultural reuse. Excessive amounts can be harmful to infants, contaminate ground water and cause algae blooms and eutrophication in surface waters.
Dissolved Solids	Affects suitability of reclaimed water for agricultural, industrial and groundwater recharge applications.
Added Domestic, Commercial and Industrial compounds	Highly mineralized water from water softeners, groundwater infiltration, and industries. Can also be organic compounds such as proteins, carbohydrates, oils and fats, urea, and synthetic organic chemicals.
Stormwater Constituents	Problem substances include oils, grease, tars, metals, pesticides, herbicides, fertilizers, animal feces, and decayed humics. May also contribute saline water from infiltration of brackish groundwater.
Trace Constituents	There is potential for adverse health effects. Includes some metals, and low concentrations of pesticides, pharmaceuticals, hormonal agents, and personal care products.
Disinfection Byproducts (DBPs)	Caused by chemical oxidation processes, such as chlorination. They are usually dissolved organohalogens. Extent of formation depend on pH, temp, reaction time, and concentrations of precursor, ammonia, and chlorine.

Source: Crook, 1992; Metcalf & Eddy, Metcalf & Eddy, 2007

The potential spread of infectious disease pathogens through untreated or inadequately treated wastewater is a major concern people express about water reuse. There is no epidemiological evidence of an outbreak of disease due to the use of reclaimed water in the United States (Metcalf & Eddy 2007). However, there have been outbreaks around the world, especially in developing countries, particularly with helminthes, which cause approximately 4.5 billion illnesses per year (Tchnobanoglous et al. 2003 & Maya et al. 2006). Unintentional reuse of wastewater for human consumption was documented in Mexico and Peru where aquifers were recharged by irrigation waters (Jiminez & Asano, 2008). The reality is that any potable water supply that receives human or animal wastes could be contaminated by pathogens, and disease can also be spread through crops subject to soil application or irrigation, or through aerosols generated by sprinklers (O'Connor et al. 2008).

Another major health concern regarding reclaimed water has to do with Emerging Contaminants of Concern (ECOCs). ECOCs are substances that until recently were undetected in water or were not considered to be a risk (Daughton, 2001). They have been found to be harmful at trace levels of nanograms and micrograms per liter, causing antibiotic resistance, endocrine disruption, immune system effects, cancer, unknown effects from long-term exposure, and ecological effects on aquatic organisms, plants, and soil microbes (O'Connor et al. 2008). Removal of some of these constituents is proving to be a major challenge. Some can easily be removed or degraded during conventional wastewater treatment (Polar, 2007). Yet, others are effectively removed by advanced treatment processes (nano-filtration, activated carbon, reverse osmosis, ozonation, advanced oxidation) (O'Connor et al., 2008; Metcalf & Eddy, Metcalf & Eddy, 2007; Belgiorno, 2007). Activated sludge with a longer solids residence time, coupled with nitrification/denitrification is showing promise for removing natural and synthetic estrogens (Metcalf & Eddy, Metcalf &

Eddy, 2007). And it has been found that Soil Aquifer Treatment is effective for the removal or deactivation of many trace constituents (Crites, 2000).

2.2.4 Political & Policy Factors

INSTITUTIONAL ISSUES

Water reclamation and reuse projects are influenced by institutional agreements, policies regarding the development of reclaimed water rates, and rules affecting system construction and liability (USEPA, 2004). Many countries lack a national water plan, which leads to a lack of focused water-related governance, and if they do have one it is often difficult to incorporate water reuse into it. Additionally, in many countries, efficient governance of water reuse is hindered by institutional and policy complexities. Often, there is a myriad of agencies that are responsible for the many aspects of water reuse, such as health, environment, drinking water, wastewater, stormwater, water resources management, price regulation, etc. This division of responsibilities leads to great inefficiencies and conflicts regarding the implementation and promotion of water reuse, such as needing multiple permits and approvals from various authorities, and establishing areas of responsibility for each agency (SECITARC, 2002, Bixio et al., 2006). Traditionally, water reuse policy has largely focused on water quality. However, there are also economic, environmental, and social needs that must be addressed by these policies. Additionally, water pricing structures often shift as institutional structures, rules, and policies and regulations regarding the use of water resources change.

Currently, there are often multiple agencies that are responsible for the many aspects of water resources management, such as health, environment, drinking water, wastewater, stormwater, water reuse or recycling, rate regulations, etc. Although these aspects are interrelated, they are considered separately, which often leads to the mismanagement of water. Water management practices vary significantly between countries, regions, states and local municipalities, with different approaches to managing water reuse based on their depth of understanding, traditional management styles, and the economic situation in the area. Furthermore, different water resources such as surface waters, ground waters, stormwater, imported water, virtual water, wastewater, treated effluent, and recycled water are also considered separately. Thus, environmental impacts are difficult to fully predict. This also leads to many stakeholders being ignored in the decision-making process. These conditions make it very difficult for entities to plan for long-term sustainability through provision of clean water and sanitation services, to incorporate recycling and reuse, to ensure food security, to eliminate contaminants that are a concern, to plan for climate change, and to ensure water availability for future generations.

Alternatively, integrated water resources management is a paradigm that considers many of the interrelated aspects of water together in order to more effectively manage water resources. It incorporates all water resources including surface waters, ground waters, stormwater, imported water, virtual water, wastewater, treated effluent, and recycled water. It also accounts for environmental impacts, involves all stakeholders in decision-making, and incorporates plans for long-term sustainability through provision of clean water and sanitation services, planning for recycling and reuse, ensuring food security, eliminating contaminants that are a concern, planning for climate change, and ensuring water availability for future generations.

WATER RIGHTS

Water rights to reclaimed water are not clear in many regions. Furthermore, surface water rights and groundwater rights are often considered separately. This may either promote water reuse or create problems with implementing reuse applications. There may be water rights laws that prohibit the use of potable water for non-potable purposes, or uses of reclaimed water that would not be returned to the same water body from which it came may be illegal. Additionally, entitlement and allocation laws need to be developed regarding urban stormwater, which is beginning to be recognized as a water resource.

LEGAL ISSUES

Water reclamation and reuse planning is subject to water rights laws, water use and wastewater discharge regulations, land use restrictions, public health protection laws, and environmental protection laws (Metcalf & Eddy, Metcalf & Eddy, 2007). There are three legal issues that are key for water reclamation and reuse. These are standards for effluent quality, the regulation of effluent uses, and legal rights to the effluent.

In the United States, federal law governs water quality standards while water quantity management and water rights are governed by individual states. U.S. laws allocate water based on either the appropriative doctrine or the riparian doctrine. Appropriative water rights are prevalent in most western states, especially where water quantity is slight. Water is assigned based on a first-in-time, first-in-right basis. Senior users have a continued right to use the water. New water users may be granted a water allocation according to what is available after considering all previously approved users. Users may not divert more water than they can use, and what is not used is forfeited. Riparian water rights are commonly found in the East and other areas that are abundant in water. Water rights are given based upon the user's proximity to the water source, and they may be acquired with the purchase of land near the source. If the water is on a user's land, they may use it. However, a user may not withdraw amounts of water that would cause substantial depletion in stream flow or water quality, and the water can only be used for legal and beneficial purposes. Water granted under riparian rights can only be used on the riparian land and it can be held indefinitely (USEPA, 2004).

In the U.S., surface water rights and groundwater rights are considered separately (Getches 1990). This may either promote water reuse or create problems with implementing reuse applications. For example, there have been legal challenges regarding the ownership of water entitlements which have affected the use of reclaimed water. There may be water rights laws that prohibit the use of potable water for non-potable purposes, or uses of reclaimed water that would not be returned to the same water body from which it came may be illegal. Thus, the complexities of water law and water rights can make the utilization of water reuse challenging in the U.S. (USEPA, 2004).

In Arizona, there has been some advancement in this matter. A case ruled on by the Arizona Supreme Court (*Arizona Public Service Co. v. Long)* ruled that until this question was settled by the state legislature, the producers of effluent are entitled to put that effluent water to any beneficial use. They also ruled that effluent is neither surface nor ground water until it is returned to one of those states. It was also found that people may use, but not own effluent. Thus, entities could put their effluent to any use, including selling it to others. The effluent is not subject to appropriation until it was returned to a waterway, and the city utilities were not required to discharge the effluent to downstream waterways despite downstream appropriative rights (Chapman, 2005). Some states, such as California, Idaho, Nevada and New Mexico have enacted legislation that provides for artificial groundwater recharge (Chapman, 2005). In California, the legislature declared that using potable water for non-potable purposes (such as golf courses) is wasteful and an unreasonable use of water if there is reclaimed water available (Chapman, 2005).

STANDARDS, REGULATIONS & GUIDELINES

Due to the variety of applications of recycled water and the individual needs of specific localities, guidelines and regulations vary widely. There are many varied interpretations of what appropriate standards, regulations, and guidelines are. Typically they are based upon the following factors: protecting public health; controls (signage, purple pipes, fencing, etc) in reuse areas; water quality requirements to protect vegetation, soil, equipment, and industry and other specific reclaimed water users; environmental protection; economics of imposing the regulations; and, political realities such as public policy, public acceptance, enforceability, water quality monitoring, and technical and financial feasibility (Metcalf & Eddy, Metcalf & Eddy, 2007). Note that the protection of public health and the environment will not be compromised to make water reuse more economically feasible, though (NRC, 1998). Specific considerations, for specific applications of water reuse are outlined in Table 2.3 below.

Table 2.3 - Regulatory Considerations for Specific Water reuse Applications

Water Reuse Application	Special Regulatory Considerations
Agriculture	Crop contamination, pathogen survival time, hydraulic loading, buffer zones, gw monitoring, crop processing, trace constituents, salinity and sodicity. level of treatment
Landscape Irrigation	Public access, proximity to populated areas, trace constituents, use area controls
Dual Distribution and In-Building Uses	Color-coding and labeling, cross-connection control, physical separation of potable and non-potable lines, allowable pressures, surveillance, backflow prevention, distribution system features, reclaimed water quality for applied use
Impoundments	Type of use (body or non-body contact), water quality (pH, temperature, clarity, chemicals)
Industrial	Generation of aerosols, safety of manufactured products,
Groundwater Recharge	Aquifer characterization, soil aquifer treatment controls, additional treatment is necessary for direct injection and potable end uses
Indirect Potable	Water quality, barriers between discharge and drinking water system intake
Other Non-potable Uses	Use dependent. Suitability for use, extent of public contact. (These uses include flushing sewers, street cleaning, dust control, soil compaction, commercial laundries and car washes, fire protection, concrete making, snowmaking, decorative fountains, snow melting, etc.)

Source: (de Koning et al., 2008. O'Connor et al., 2008; USEPA 2004, Metcalf & Eddy, Metcalf & Eddy, 2007)

In the United States, there are no federal regulations that concern water reclamation and reuse. The lack of uniform regulations for the country is considered by some to be a barrier to widespread reuse implementation (Miller, 2006). Regulations are handled at the state government level, in the form of enforceable rules or as guidelines. As new states develop their own regulations, they are often based upon the enacted regulations of other states, particularly upon California Title 22, which has a long history of successful case studies in unrestricted irrigation (Bixio et al., 2006). All states can apply the USEPA guidelines (USEPA, 2004), and the lack of regulations in a certain state does not prohibit water reuse there. Often water reclamation and reuse schemes are evaluated on a case-by-case basis by governing entities. As of 2007, no single state had regulations that encompassed every reuse application (Metcalf & Eddy, Metcalf & Eddy, 2007). Often national laws conflict with state water policies. For example, the necessity for a National Pollutant Discharge Elimination System (NPDES) permit, or to comply with environmental regulations sometimes constrains water reclamation and reuse in the U.S., especially for agricultural and indirect potable applications (O'Connor et al., 2008; Metcalf & Eddy, Metcalf & Eddy, 2007).

The USEPA guidelines prescribe a combination of water treatment and water quality requirements that are certain to produce reclaimed water that is of acceptable standards. Thus the monitoring of the finished product for specific constituents would not be necessary. Pilot tests are recommended to fully characterize the reclaimed water that is to be produced and to compare it to other nearby water sources. Pilot tests also serve to select and validate treatment trains and to refine their design. There are also many requirements for reclamation plants that ensure the facility is reliable at protecting public health and even during power failures, flooding, peak loading, equipment failure, and maintenance operations. Fulfilling all the requirements often leads to redundant and oversized processes. Thus the financial burden of meeting these requirements often limits the implementation of reuse projects, especially the smaller ones (USEPA, 2004).

There are many varied interpretations of what appropriate standards are. Often these standards are based more on public perceptions, fears, and misconceptions rather than public health standards or scientific developments. At times, health related concerns regarding reclaimed water projects can result in the requirement for recycled water to be over-treated, resulting in expensive, over-engineered systems (Toze, 2006), which often leads to prohibitive costs for developing reuse schemes where they are needed most. New technologies and a body of water reuse that is growing rapidly can lead to the need to update guidelines and regulations frequently (Bistany, 2006) Thus, future standards must be developed that progress with technology advances, consider compliance and cost, protect public health, and make water reuse schemes less restrictive, and more realistic and realizable. An example of this can be found in The Australian Guidelines for Water Recycling, (NRMMC et al., 2006) which are notable for the innovate risk management approach, and the which has been adopted.

2.2.5 Energy & Technology Factors

THE ENERGY/WATER NEXUS

Water and energy are interdependent. Water is an integral element of generating electric power and for developing, extracting, refining, processing, and transporting energy resources. In return, significant energy is needed in water extraction, conveyance and treatment. For example, in 2000, thermoelectric power generation accounted for 39 percent of all freshwater withdrawals in the United States, which is roughly equal to the water used for agriculture (USGS, 2000). See Figure 2.1 for an illustration of these interdependencies.

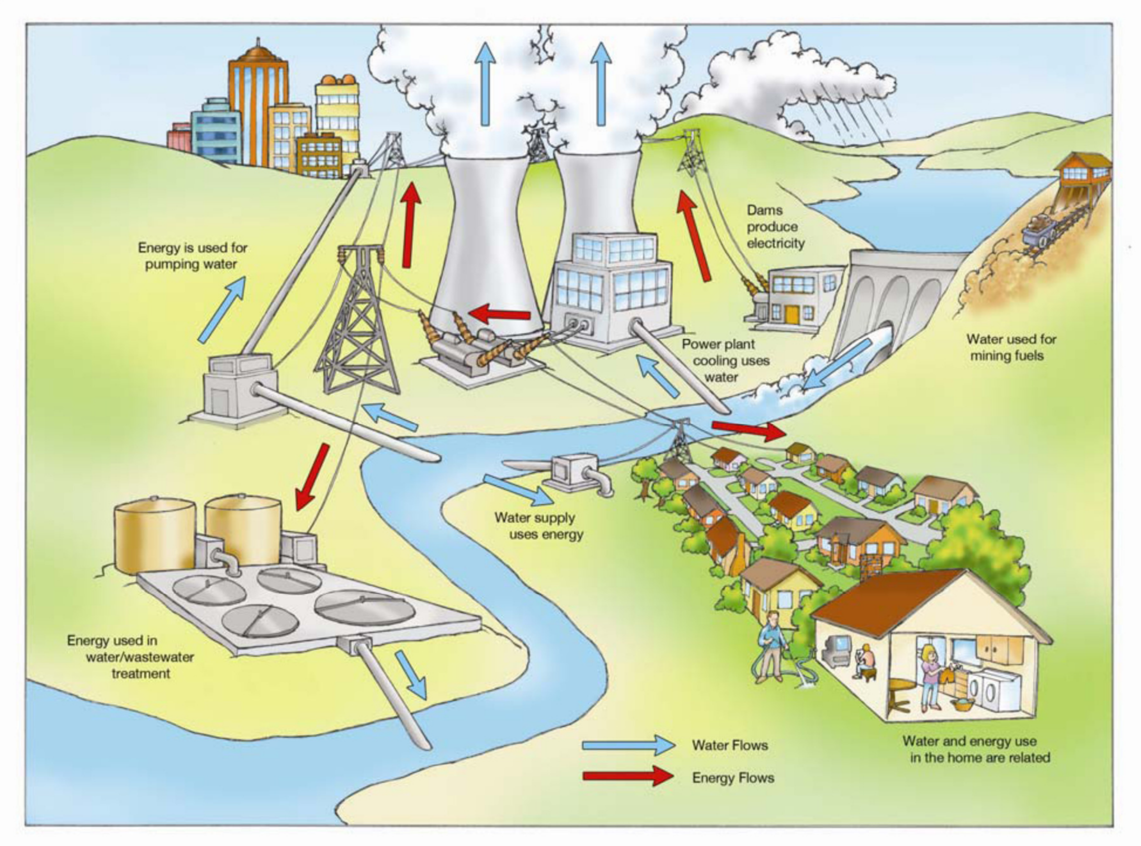


Figure 2.1 - The Interrelationship Between Water And Energy (Source: DOE, 2006)

The U.S. is currently striving to replace imported petroleum and natural gas with fuels from domestic sources, such as biofuels, synfuel from coal, hydrogen, and possibly oil shale (DOE, 2006). Due to the water-intensive nature of producing energy from these sources, this shift will result in a significant increase in pressure on available water resources. Utilization of impaired water from coproduced water from the extraction of non-conventional natural gas resources presents an opportunity to provide water for some of these energy generating uses. It is estimated that between 6.1 and 7.8 million m^3/day (1,600 – 2,100 mgd) of coproduced water is generated in the U.S. This amount is greater than the combined daily water consumption of New York City and Los Angeles (Benko & Drewes, 2007).

Additionally, supplying, purifying, distributing, and treating water and wastewater accounts for 4 percent of the energy produced in the United States (EPRI,2002). Regionally this amount varies depending on the water source, how far the water is conveyed, and topography. However, providing electricity accounts for approximately 75 percent of the cost of processing and distributing municipal water (Powicki, 2002). Supply and conveyance can be the most energy intensive part of the water delivery process, depending on the distance of conveyance and aquifer depth. The energy required to pump water from surface water can be negligible in gravity-fed systems or where users are located close to the source. Certain groundwaters can require little energy for purification. Surface waters generally need more extensive treatment, so they fall in the upper range of energy requirements. Interestingly, a study of the energy requirements of water use in California by the California Energy

Commission (CEC) found that the energy consumption associated with residential water use is greater than the energy consumed during supply and treatment. The energy used for water heating and clothes washing used 14 percent of the electricity and 31 percent of the natural gas consumed in California.

As populations continue to grow, the demand for water will increase, and freshwater supplies will become more limited. As this happens, the energy required to pump water greater distances or from greater depths will also increase. In addition, as water quality standards change and require greater removal of constituents, the energy required for water and wastewater treatment will increase. For agriculture, more efficient methods may replace gravity-fed irrigation, leading to more energy consumption in the agricultural sector as well. According to the Electric Power Research Institute (EPRI), by the year 2050, the energy needed for public and commercial water supply and treatment is expected to increase almost 50 percent. Energy use for industrial water supply is expected to triple (EPRI, 2002). If current trends in water use and energy efficiency continue, the demand for water is expected to increase by approximately 50 percent (EIA, 2006), placing additional pressure on the already stressed water supplies. If new power plants with evaporative cooling continue to be constructed, the consumption of water for electricity production could increase from 3.3 billion gallons per day in 1995, to 7.3 billion gallons per day in 2030 (Hoffmann et al., 2004).

TECHNOLOGY ADVANCEMENTS

Water reuse technology spans the gamut of complexity from centuries-old practices to state-of-the-art water treatment processes. There are many variations on actual reuse schemes and the technologies utilized, depending upon many factors such as local conditions, wastewater infrastructure, water quality desired, end use of the water, and regulations. Especially during the last 20 years, technological advancements have facilitated the rapid expansion of water reuse. These advancements have led to improved water quality and more efficient treatment, thus enabling reclaimed water to be utilized for higher value applications of water reuse.

WATER REUSE TECHNOLOGY

Water reuse technology spans the gamut of complexity from centuries-old practices to state-of-the-art water treatment processes. In developing countries and isolated locations, lagoons and stabilization ponds are used to treat wastewater, which is occasionally disinfected. The effluent from these ponds is often used for irrigation (restricted or unrestricted, depending on location and level of treatment). Many of the more traditional reuse schemes found in the more developed regions of the world start with secondary wastewater treatment and often include biological nutrient removal. Following secondary treatment, the water is treated in various ways depending on the final usage. Desalination is also practiced where it is viable, either from the ocean or from brackish groundwater. Water reuse schemes that deal with the reuse of rain-, storm-, gray- and black-water are also used. Stormwater harvesting for aquifer recharge is practiced in some regions.

During the last 20 years, technological advancements have facilitated the rapid expansion of water reuse. Low-pressure membranes (i.e. microfiltration and ultrafiltration), membrane bioreactors, and integrated membrane systems (IMS), in particular, have experienced rapid growth leading to significant cost reductions and consequently improved economic viability for many reuse applications. Another such technology is direct membrane filtration (DMF) of raw wastewater, which uses UF membrane filtration to create an effluent rich in dissolved nutrients and other components, making the water promising for agriculture (AQUAREC D17). Technological advancements have furthermore led to improved water quality, thus enabling reclaimed water to be utilized for higher value applications of water reuse. Further promising technology include advanced oxidation processes (AOPs) which are effective in removing residual pesticides, endocrine disrupters, and other emerging contaminants subsequent to membrane filtration. Finally, the production of more desalinated water has potential to help reduce the increase in quantity of water the earth needs as population rises (Metcalf & Eddy 2007).

There are many variations on actual reuse schemes and the technologies utilized. These vary depending upon many factors such as local conditions, water and wastewater infrastructure, water quality desired, end use of the water, and regulations. Table 2.4 below shows typical reuse technologies and which water quality contaminants they are capable of reducing.

Table 2.4 - Water Reuse Technologies and Water Quality Issues that they Address

Constituent Class

Unit Operation or Process	Suspended Solids	Colloidal Solids	Particulate Organic Matter	Dissolved Organic Matter	Nitrogen	Phosphorus	Trace Constituents	Total Dissolved Solids	Bacteria	Protozoan cysts and Oocysts	Viruses
Secondary treatment	X			X							
Secondary with nutrient removal				X	X	X					
Granular filtration	X								X	X	
Surface filtration	X		X						X	X	
Microfiltration	X	X	X						X	X	
Ultrafiltration	X	X	X						X	X	X
Dissolved air flotation	X	X	X							X	X
Nanofiltration			X	X			X	X	X	X	X
Reverse Osmosis				X	X	X	X	X	X	X	X
Electrodialysis		X						X			
Carbon adsorption				X			X				
Ion Exchange					X		X	X			
Advanced oxidation processes			X	X			X		X	X	X
UV											
Disinfection				X					X	X	X

Source: Metcalf & Eddy Metcalf & Eddy, 2007

While the improvement of technology has helped to advance water reuse, more development is still necessary. Of large concern, technologies need to be developed that can remove or neutralize the multitude of emerging organic contaminants. Also, solutions are needed that are more efficient, durable, energy efficient, and cost-effective. For example, membrane technologies need improvements that increase durability and performance, decrease operating pressures, enable energy recovery, control membrane fouling and cleaning, and are more cost-effective. Existing technologies also need to be re-evaluated for new applications (Metcalf & Eddy, Metcalf & Eddy, 2007). Work is also necessary to expand the flexibility of technologies in order that they can be used for both centralized and decentralized systems. Infrastructure needs to be designed to readily incorporate reuse, be more energy efficient, more robust for treatment, and more resistant to malicious attacks and natural disasters.

Operational improvements will also serve the future of water reuse well. These needs include improving process control for activated sludge systems, the ability to detect water constituents at very low levels, improved methods for monitoring disinfection performance, and develop concentrate processing and disposal systems that are applicable for centralized and decentralized systems.

2.2.6 Economic Factors

Even though recycled water can be a cost effective water source that is comparable to other sources such as new dams, reservoirs, and desalination, switching to reclaimed water sources is often hindered by cost constraints. The cost of recycled water projects is affected by multiple factors, including the types of reuse, the degree of treatment required, and the distance to deliver the recycled water. Water reuse typically requires large upfront capital investments while having limited demand during the initial years of a reuse project. Implementing water reuse is more cost-effective for new construction (i.e., greenfield applications) rather than retrofit situations (i.e., where separate underground pipe and pumping infrastructure needs to be installed for reuse water, apart from the potable supply and wastewater transmission systems).

Additionally, the costs associated with sourcing, supplying, treating, and disposing water and wastewater has been steadily escalating. And water has historically been heavily subsidized, so rarely do water or wastewater customers pay for the full cost of these services. However, as the cost of revitalizing aging water and wastewater infrastructure is starting to be incurred, and as water supply scarcity increases and increasingly stringent wastewater discharge requirements are implemented, the relative cost of reclaimed water may begin to approach (or even become less expensive) than some potential alternatives for potable water supply or wastewater management.

There are also inefficiencies because water and wastewater costs (and utility entities) are often compartmentalized, rather than being integrated into one. This often makes legitimizing water recycling difficult in financial (as well as institutional) terms. Thus, it is nearly impossible to encourage water reuse based on financial terms alone (i.e., revenues are rarely expected to cover reuse costs). Fortunately, analyses that put a value on the environmental and social benefits of water reuse, and try to accurately predict future economic benefits are making it easier to promote water reuse to the general public and government officials. (Raucher et al. 2006; Mullin 2004)

Additionally, the degree of debt often may require that any new reuse projects must establish water prices that reflect full cost recovery of associated costs, which could make acceptance by consumers difficult. Often, recycled water needs to be delivered to the consumer at a discount in order to encourage its use. In order to meet the burden of high initial cost, the majority of reuse projects are finaced through long-term bonds, or supplemented with grants and State Revolving Fund Programs. Occasionally, there are also special agreements reached with developers or industrial users to contribute either assets or money. (Exall et al., 2008) However, the ultimate success of water reuse projects is dependent upon recognizing the full value of water and finding an appropriate pricing structure for reclaimed water (Bixo et al. 2006). The appropriate cost structure for a reuse project is highly dependent upon policy objectives, the extent to which water reuse is considered a measure of pollution control, water conservation, and water supply, and the structure of how the urban water cycle is managed (Bixio et al. 2006).

Due to the patterns of financing infrastructure projects, the economies of scale of existing systems, and external environmental costs, the cost of recycled water can often be higher than the price of first use potable water (MacDonald & Proctor, 2008). Additionally, water pricing structures often shift as institutional structures change. These include formal and informal rules, policies and regulations regarding the use of water resources. For example, in Australia water use, and management has changed due to extreme drought, resulting in higher prices for urban water and rural irrigation water. This combined with decreasing costs for reclaiming water is making water reuse more feasible there.

2.2.7 Environmental Factors and Climate Change

In addition to pressures from growing populations, future water supplies are also threatened by the effects of climate change. Water is considered to be the primary medium through which climate change will impact people, economies, and ecosystems. Climate change is expected to greatly alter the global hydrologic cycle and have serious impacts on regional water resources, which will affect both the quantity and quality of water supplies (IPCC, 2000; USEPA, 2008a). It is predicted that there will be an increased occurrence of extreme weather events such as storms, floods and droughts. Accordingly, it is likely that there will be changes in the global quantity and distribution of precipitation and runoff. Groundwater-to-surface water interactions and water quality characteristics could also be significantly affected.

According to the Intergovernmental Panel on Climate Change (IPCC, 2000), the nations that will be hardest hit by climate change include the least developed countries, which are often located in already food- and water-stressed and drought-prone areas; and small island developing states, where populations are highly exposed to rising sea levels and extreme weather. The IPCC has predicted that by 2020 between 75 and 250 million people will be exposed to increased water stress and rain-fed agricultural yields could be reduced by up to 50% in some countries. In many already food-stressed countries, such as those in Africa and Australia, agricultural production is projected to be severely reduced. The disappearance of glacial ice and changes in precipitation patterns may significantly affect fresh water availability for consumption, energy, and agriculture. Decreased snowpack and increased rainfall in mountainous regions will lead to decreased summer flows and increased competition for water.

Potential water related impacts of climate change include increases in water pollution problems, more extreme water-related events, changes to the availability of drinking water supplies, water body boundary movement and displacement, and changing aquatic biology (USEPA, 2008a). These impacts can be summarized as follows (IPCC, 2000; USEPA, 2008a):

1. **Increases in Water Pollution Problems –** Increased temperatures from global warming will in turn increase water temperatures. Warmer waters hold less dissolved oxygen which can lead to some aquatic species no longer surviving. Warmer water temperatures can also foster algal blooms and alter the toxicity level of some pollutants.

2. **More Extreme Water-Related Events** – Higher rainfall amounts will increase the risks of flooding, increase the variability of stream flows, widen floodplains, and increase erosion due to higher velocity storm flows. All of these changes can result in diminished water quality and aquatic system health.

3. **Changes to the Availability of Water Supplies** – Water supplies (potable, agricultural, industrial) available will change due to changing precipitation and snowmelt patterns, droughts, and increased evapotranspiration. Glacial ice may disappear, affecting fresh water supplies. Supply will also be affected by rising sea level and the resulting salt water intrusion. Higher temperatures may also increase the use of water to fulfill agricultural, industrial and energy production needs.

4. **Movement and Displacement of Water Body Boundaries –** Rising sea levels will relocate estuary and ocean shorelines due to the displacing of wetlands, inundation of lowlands, and the changing of tidal ranges in rivers and bays. Changing precipitation patterns, altered water flow, and increased evaporation will affect the size of lakes and wetlands.

5. **Changes in Aquatic Biology –** Warmer water temperatures will cause a shift in aquatic biological species. This shift is likely to occur at an uneven pace, which will allow non-indigenous and invasive species to establish. Thus significant deterioration of aquatic ecosystems may result in some areas. These conditions may be exacerbated by changing water flows.

As more regulations and treaties are passed to help counteract climate change, sources of greenhouse gas emissions are likely to be targeted. Water and wastewater treatment emits a substantial amount of greenhouse gasses. In 2006, wastewater treatment in the United States contributed 24 million metric tons (tonnes) of CO_2 equivalent of methane and 8 million metric tons (tonnes) of CO_2 equivalent of nitrous oxide (USEPA, 2008b). Thus, water and wastewater treatment and supply facilities are likely to come under any policy regime to combat climate change, potentially increasing the cost of treating and providing water.

2.2.8 Other Issues

In addition to those discussed above, there are other issues that must be considered regarding water reclamation and reuse. Finding accurate predictions of future supply and demand is difficult. Quantities vary greatly from study to study, thus it is difficult to plan future integration into water management plans. Achieving water efficiency and balance may be difficult. For example, reuse during wet seasons may create an excess water supply that needs to be dealt with, or environmental discharges may have to be increased to counteract environmental effects of decreased effluent releases into streams. Culturally, reuse practices must fit into cultural norms, which may bring additional difficulties to developing reuse projects. And finally, when considering reuse in developing countries, there is an additional set of considerations including water management in megacities, appropriate technological solutions, small and decentralized systems and other applicable strategies that may be needed.

2.3 Conclusion

As can be inferred from the above discussion, the future of water reuse and reclamation depends upon numerous complex issues, and their interactions. Additionally, current water reuse practices are widely varied worldwide, having been developed with different objectives and using different schemes, technologies and standards. Each location has a unique set of characteristics that describe its infrastructure, government, available water supply, demand, and climate. Additionally, there is a large set of needs to be met in order to make the implementation of water reclamation widespread, including technological innovation, public acceptance, environmental and public health projection, increased funding, and media, regulatory and political support (Miller 2006; Metcalf & Eddy, Metcalf & Eddy, 2007). The drive to incorporate water reuse will continue to grow as wastewater discharge requirements become more stringent, potable water shortages are exacerbated and more entities have the desire to manage their water resources sustainably. The ability of water reuse to grow and meet this future demand will be tested by how well future challenges can be met. Knowing which of these factors to focus planning and research efforts on will help to meet these challenges.

Chapter 3

DETERMINATION OF KEY FACTORS – A PROGRESSION THROUGH MULTIPLE METHODS

It is not practical to attempt to include all of the factors and issues that affect water reuse when analyzing future conditions and plans with analytical methods. Therefore, multiple methods were used during this study to determine which of the factors are most influential and thus most important to include in a computer model. These methods include surveys, expert workshops, qualitative scenario studies, statistical analysis, and computer analysis with a hybridized tool. The philosophy behind using multiple methods was to start broadly, including as many factors as possible, and using the subsequent methods to reduce the number of key factors that must be considered in order to attain a small subset of factors with the most influence over water reuse. It was hoped that multiple methods will provide some agreement as to which factors are most important.

Survey participants identified critical drivers and factors affecting water reuse from a list that was compiled from the literature review. This list of factors and drivers was further analyzed and refined over the course of the expert workshops. Scenario studies and group discussions were used to analyze these factors to determine which of them are most critical to focus upon over the next 20 years. Those determined to be most important became the key factors in illustrative scenarios. The illustrative scenarios were used to further refine the list of key factors and identify some key challenges that the water reuse industry needs to focus on during the next twenty years. Statistical analysis of survey data was the final process utilized to determine which of the refined list of factors is most influential. This chapter outlines the methods and results for each of these investigations, except for the computer tool, which is discussed in Chapters 4 and 5.

3.1 Key Factors as Identified in the Literature

Through literature review, it quickly becomes apparent that the future of water reuse and reclamation depends upon numerous complex, and interrelated factors. Every time reuse implementation is considered there is a unique set of characteristics that describe that location's infrastructure, technology, social structure, government, available water supply, demand, climate, needs and objectives. When this many considerations are considered over time for planning purposes, it can be overwhelming to determine which of these factors is most important to focus on. There are some authors, though, who did identify some factors and issues as being the most important to address to help advance water reuse, which are summarized in Table 3.1.

Table 3.1 - Considerations and Factors Important for the Future of Water Reuse

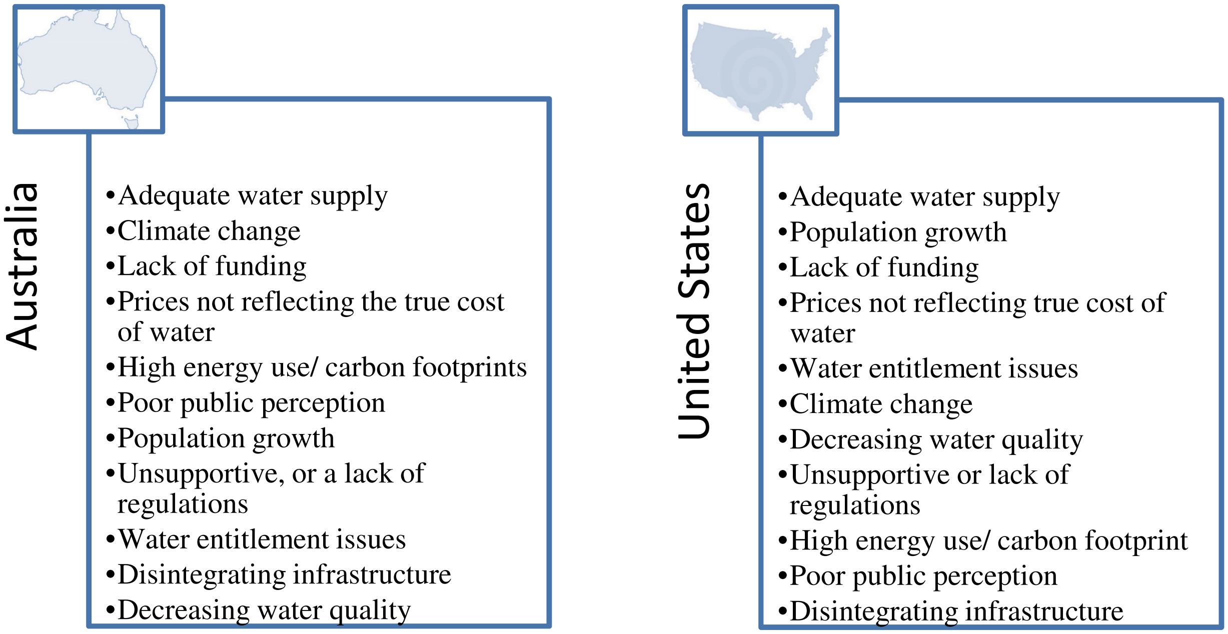
Knowledge Base	Better understanding of issues and complex interactions; tools and assistance for communities to implement successful reuse projects; Scientifically developed educational systems to help improve public perception,
Economics	Better understanding of economic impacts; effective pricing schemes
Infrastructure	Designed to incorporate reuse; Energy efficiency; Increased durability to resist natural disasters and malicious acts
Regulatory Support	Consistent regulations and guidelines are needed for desalination and reuse. Uniform regulations are needed that govern concentrated residuals streams from membranes. (Currently, they are state mandated and extremely variable.) This will make long term planning for concentrate disposal easier.
Environmental and Public Health	Evaluate effects of water constituents and reuse processes; Evaluate levels at which emerging contaminants are considered harmless; Sustainability of long-term reuse; Discover indicator organisms that are accurate predictors of reuse-related health threats
Emerging Constituents Considerations	Cost effective detection, Develop processes capable of removing them, Improve monitoring techniques, Identify and eliminate sources of these contaminants, Investigate behavior in the environment, risk to human health, fate and transport, and risk;
Membranes	Improved durability; Energy recovery devices; Cost-effectiveness; Control of fouling; Reduce cleaning requirements
Decentralized Systems	Innovative uses; Applicable technology development; Concentrate processing and disposal system for brine processing,
Technological Advancement	Need the capability to reliably meet current and future regulations; Improved methods for monitoring disinfection performance; Reuse infrastructure should be easy to integrate into existing plants; Compact treatment technologies to squeeze into available space.
Technological Advancement, Continued	Ballasted flocculation; High-rate clarification; Cloth-media filters; Membrane filtration; Optimize activated sludge process for emerging contaminant removal; Integrated fixed-film activated sludge process for enhanced nitrification in small space; Oxygen-based membrane biofilm reactors; UV disinfection; Advanced oxidation; Innovative uses for non-potable reclaimed water
Public Perception	Better understand how judgment strategies, risk perceptions, trust in water authorities influence public perception. Examine how factors of health, environment, treatment, distribution, different water sources, different treatment processes, perceived economic advantages, and conservation issues impact willingness of public to use reclaimed water.

Source: Miller, 2006; Metcalf & Eddy, 2007; NRC, 1996; USEPA, 2004; O'Connor et al., 2008; Hightower & Keyes, 2005; Lynch et al., 2005; Po et al., 2003

3.2 Key Factors Determined by Surveys

A survey was developed to provide a view of the current and future state of water reuse according to the viewpoints of member utilities of the WateReuse Research Association, water reuse providers in the Water Services Association of Australia (WSAA), and utility participants in the expert workshops. It sought to determine where and how water reuse is being implemented and what plans and concerns there may be regarding water reuse in the future. Surveys were sent to over 180 United States participants, with 108 completed from 78 different entities. Of these 78, 69 of them produce reclaimed water. Participants included municipalities, utilities, consultants, government, regulating agencies, researchers, wholesalers, and industrial representatives. In Australia, surveys were sent to all 35 members of WSAA, with nine replies received, each from separate entities.

In these surveys, participants were asked to rank how critical certain factors and issues may be water reuse over the next 20 years. These issues are listed below, from the most to least critical, in Figure 3.1. Participants in both nations felt that maintaining an adequate water supply will be the largest challenge faced. Other issues such as lack of funding, pricing structures of water services, and unsupportive regulations were ranked the same in both countries. The order of ranking of the other issues reflects the conditions in those countries at the time of the surveys. For example, poor public perception is predicted to be more critical in Australia, which is likely due to several water recycling projects there that recently have not been implemented due to public perception issues derived from opportunistic political and press comments. Climate change is also an important issue in Australia, which explains why it was ranked to be second in importance. On the other hand, water entitlement issues are much more of an issue in the United States, especially in the West, which explains why it is toward the top of the list for that country, whereas, entitlements and allocations are more clearly defined and differentiated in Australia. Additionally, participants were given the opportunity to list any other specific issues they felt were important for the future of water reuse. Nearly 100 specific issues were added to those listed above in the categories of Energy; Technology; Institutional, Legal & Regulatory; Economics; Public Perception, Agriculture; Water Resources Planning; and Water Treatment.



Australia

- Adequate water supply
- Climate change
- Lack of funding
- Prices not reflecting the true cost of water
- High energy use/ carbon footprints
- Poor public perception
- Population growth
- Unsupportive, or a lack of regulations
- Water entitlement issues
- Disintegrating infrastructure
- Decreasing water quality

United States

- Adequate water supply
- Population growth
- Lack of funding
- Prices not reflecting true cost of water
- Water entitlement issues
- Climate change
- Decreasing water quality
- Unsupportive or lack of regulations
- High energy use/ carbon footprint
- Poor public perception
- Disintegrating infrastructure

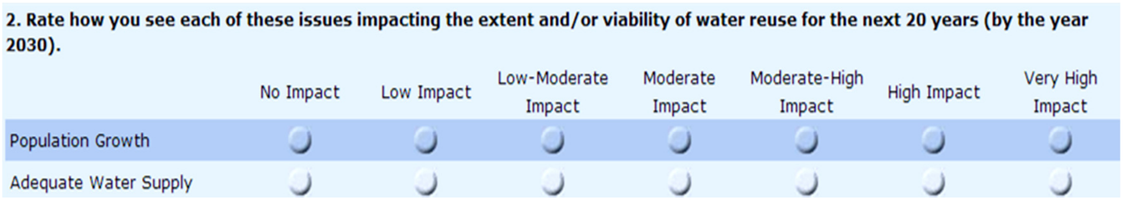
Figure 3.1 - Critical Issues That the Water Reuse Industry Will Face in the Next 20 Years: The issues were identified in the surveys administered in each country. They are listed in the order of their rankings received, from the most critical to the least critical

3.3 Key Factors from the Expert Workshops

There were two methods used during the expert workshops to try to ascertain which factors have the most impact upon water reuse. Participants in Australia were asked to provide ratings for a series of factors, and both workshops focused upon scenario studies. The results of both activities are explained below.

FACTOR RATINGS

Participants in the Australia expert workshop were asked to rate factors for how much they impact water reuse practices. The ratings were done on a seven point scale ranging from no impact to "very high" impact. (See an example question below in Figure 3.1)



2. Rate how you see each of these issues impacting the extent and/or viability of water reuse for the next 20 years (by the year 2030).

	No Impact	Low Impact	Low-Moderate Impact	Moderate Impact	Moderate-High Impact	High Impact	Very High Impact
Population Growth	○	○	○	○	○	○	○
Adequate Water Supply	○	○	○	○	○	○	○

Figure 3.2 - Sample Rating Question

The average ratings for each of the factors as rated by the Australia Workshop participants are shown in Figure 3.3. The factors that received the highest ratings include water availability and demand, along with environmental factors such as climate change. Note that the average ratings for every factor is at or above moderate. This is due to a bias that was implicit because all participants in the workshops had some current involvement in water reuse, and that all of the factors rated were initially included because they were deemed important.

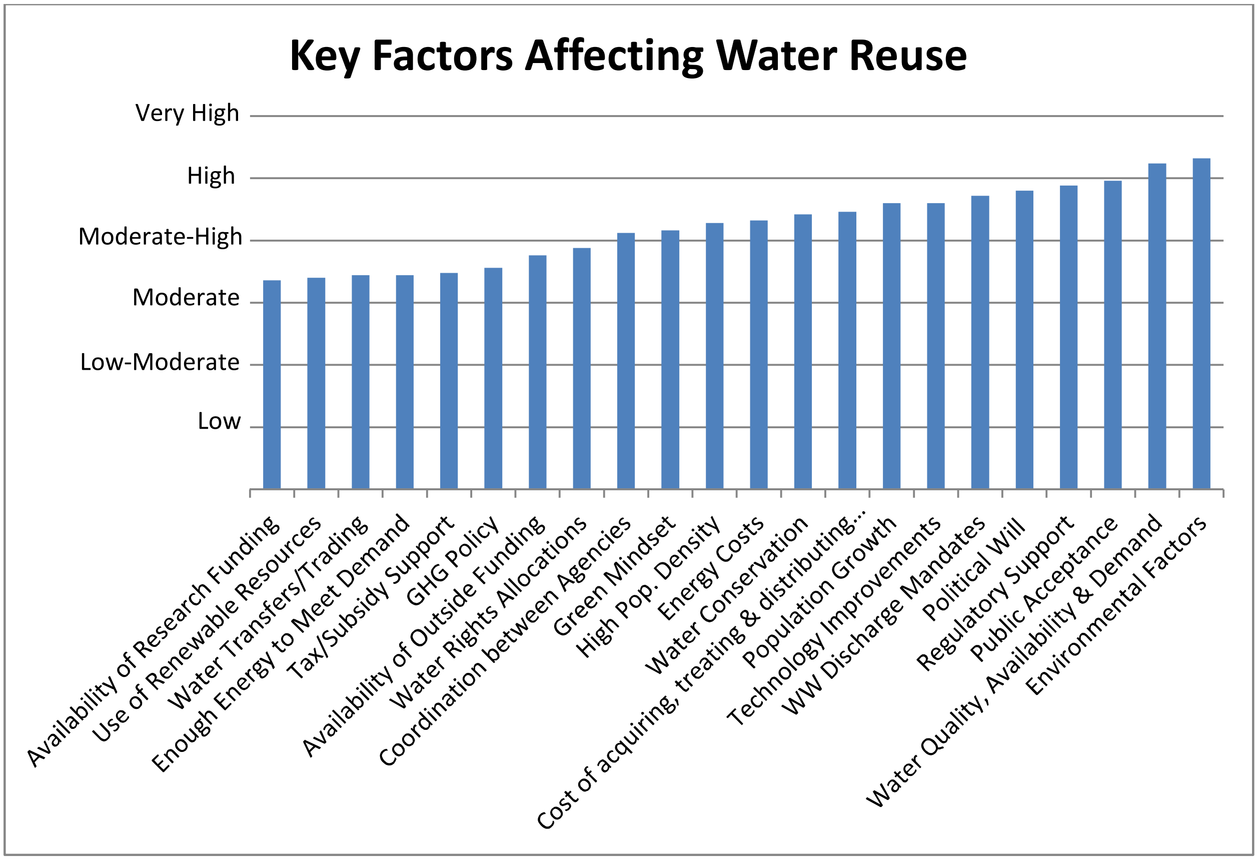


Figure 3.3 – Key Factors Affecting Water Reuse as Rated by Participants in the Australia Workshop.

SCENARIO STUDIES

The factors driving water reuse were investigated during a series of two expert workshops. During these workshops, group discussions and scenario analysis was used to consider the factors that influence water reuse. The scenario analyses were used to help consider the socio-economic uncertainties of the future and their impact on these factors and on water reuse. Extensive discussions were focused upon various factors and issues that drive water reuse, and how future scenarios may affect them. As a result, the key challenges that affected water reuse across all the futures scenarios were identified. This enabled the determination of a set of factors which will have the most effect upon water reuse now and in the future, regardless of which socio-economic conditions are prevalent.

The scenarios used in the workshops were based on the Intergovernmental Panel on Climate Change (IPCC 2000) emissions scenarios served as a foundation for the storylines used. These scenarios follow the general IPCC storylines for the A1b, A2, B1, and B2 scenarios with additional downscaled GDP and Population data from Columbia University (CIESIN 2002), water withdrawal information from Shen et al. (2008), and U.S. population growth trends from the U.S. Census Bureau (2008). The major variables considered include population, GDP growth and per capita distribution, energy use, land use changes, resource availability, degree of technological change and innovation, cultural and social interaction, favored energy sources, and water use practices. An overview of these scenarios can be found in Appendix A.

Through the course of the workshops, some factors were deemed to be influential across many of the scenarios, indicating that the workshop participants determined these factors will have more impact upon water reuse in the future than they do currently. Each of the factors listed below in Table 3.2 was rated for how extensively they influence water reuse in the present day and for each scenario. The factors in the first column were predicted to be more influential in the year 2030 than they are today regardless of which scenario was being considered. The factors listed under "Mixed Change in Importance" were rated in some scenarios to be a greater influence in 2030, and in others to not change or be of less influence. There was agreement across all the scenarios that the factors listed as “Less Important” are of greater influence today than they will be in the year 2030.

Table 3.2 - The Relative Importance of Water Reuse Factors Across all Workshop Scenarios

More Important	Mixed Change in Importance		Less Important
- Population growth - Pop. density - Water rights allocations - Use of renewable resources - Water availability & demand	- Green mindset - GHG policy - Political will - Coordination between agencies - Wastewater discharge mandates - Enough energy to meet demand - Energy costs	- Water quality - Cost of acquiring, treating and distributing water - Environmental factors - Taxes and subsidies - Regulatory support - Water transfers & trading - Technology improvements	- Public acceptance - Water conservation - Availability of research funding - Availability of Outside funding

Of these factors, the following were indicated as being more influential in the future than they are now for at least two of the four scenarios considered in the expert workshops:

- Water rights allocations
- Coordination between agencies
- Political will
- Use of renewable resources
- High population density
- Greenhouse gas policy
- Enough energy to meet demand
- Technology improvements
- Population growth
- Energy costs
- The cost of acquiring, treating & distributing water

In addition to scenario studies, there were also several opportunities for discussion of the factors during the expert workshops. From these discussions, which were separate from the scenario studies, a few key factors emerged as more important for water reuse, regardless of what the future may bring. These are as follows.

1. Regulatory Support - More supportive regulations that are directly applicable or attuned to water reuse, rather than those that address it as an afterthought.

2. Public Acceptance - Thoughtful, careful use of language and images that represent water, wastewater, and water reuse in a favorable way need to be used when educating and communicating with the public, both formally and informally. Water professionals and other champions for water reuse need to be utilized to educate about water, the water cycle, possible crises, and the importance of watersheds. It is interesting to note that the participants felt this issue was very important, even though the scenario studies indicated that it will be less important in the future than it is today.

3. Economics - More accurate (true market economy) pricing. Also need economic analyses inclusive of externalities, that will help show the long term economic benefit of water reuse, and support operations.

4. Water Resources Management - Integrated management of water and other resources in which reuse is an essential element.

5. Institutional Support - Institutions solely dedicated to water reuse including professional associations, representatives and lobbyists, and research organizations are needed. These institutions can serve as “champions” for water reuse, assist in government planning and policy, push for dedicated regulations, and assist in other industrial needs.

The factors that were deemed to be most important informed the selection of the factors used for the qualitative scenario study, which is discussed in the next section.

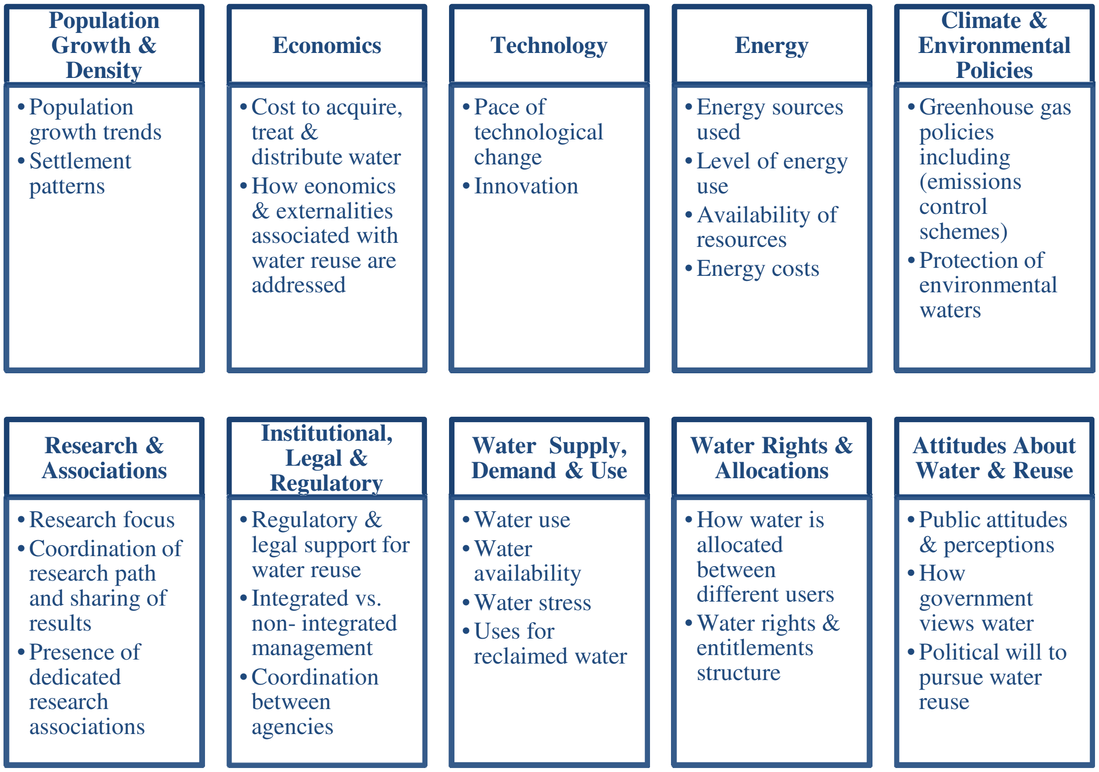
3.4 Key Factors from the Qualitative Scenario Study

The qualitative scenario study was the culmination of the surveys and the expert workshops. It was used to further contemplate the outcomes of the surveys and the expert workshops, consider the uncertainty involved in the industry, and look a bit closer at the factors that were found to be important in the workshops and surveys. For this study, the scenarios used during the expert workshops were further adapted to illustrate two divergent worlds that are based upon the same studies as the expert workshop scenarios, but also include consideration of deliberations and results of the workshops. These adapted scenarios were created to help illustrate the span of possible challenges and opportunities that practitioners may face over the next 20 years. The challenges and opportunities presented by both of the worlds portrayed in the illustrative scenarios were used to develop a clearer picture of what the future may hold for water reuse, what factors will have the most impact, and how to best plan for research and development.

FOUNDATION OF THE SCENARIOS

The foundation of the scenarios is based on a set of ten key factors/focus areas for the qualitative scenario study were determined based on those found to be most important in the expert workshops. These focus areas are summarized in Figure 3.4.

The scenarios used for the qualitative study are a compilation of a number of scenario studies combined with the results of the expert workshops. They are loosely based upon several sources. The Intergovernmental Panel on Climate Change (IPCC) A1b, A2, B1 and B2 emissions scenarios served as a foundation for the scenarios used (IPCC 2000). Downscaled GDP (Gross Domestic Product) and population data from Columbia University (CIESIN 2002) was also incorporated. Water withdrawal information is from a study by Shen et al. (2008) that used global climate models and the IPCC storylines to create water use scenarios that correspond with the A1b, A2, B1, and B2 IPCC scenarios. Some of the future water reuse and resource management trends are derived from a scenario study by Makropoulos et al. (2004). Another scenario study performed by the International Food Policy Research Institute and the International Water Management Institute is used as a basis for determining the outlook of future water and food issues (Rosegrant, Cai & Cline 2002). The state of water reuse and related challenges and opportunities are derived from workshop discussions.



Population Growth & Density
- Population growth trends
- Settlement patterns

Economics
- Cost to acquire, treat & distribute water
- How economics & externalities associated with water reuse are addressed

Technology
- Pace of technological change
- Innovation

Energy
- Energy sources used
- Level of energy use
- Availability of resources
- Energy costs

Climate & Environmental Policies
- Greenhouse gas policies including (emissions control schemes)
- Protection of environmental waters

Research & Associations
- Research focus
- Coordination of research path and sharing of results
- Presence of dedicated research associations

Institutional, Legal & Regulatory
- Regulatory & legal support for water reuse
- Integrated vs. non- integrated management
- Coordination between agencies

Water Supply, Demand & Use
- Water use
- Water availability
- Water stress
- Uses for reclaimed water

Water Rights & Allocations
- How water is allocated between different users
- Water rights & entitlements structure

Attitudes About Water & Reuse
- Public attitudes & perceptions
- How government views water
- Political will to pursue water reuse

Figure 3.4 - Key Factors and Considerations for the Illustrative Scenarios

THE SCENARIOS

The first scenario (Scenario One) is based on the assertion from the discussion of Copenhagen that we are on a path toward a global, market driven economy that focuses on local needs, with moderate population growth. The aim of this scenario is to illustrate what water reuse may look like within a variant of a world that progresses according to what some see as the current trends.

The mass global interest shown in the COP15 UNFCCC and the initial progress toward a global climate change policy form the basis for the second scenario (Scenario Two). This scenario investigates a "green" world, with the aim of investigating a world that has found the momentum to work toward a more sustainable path. Further information about this qualitative scenario study can be found in a report entitled, "Water Reuse 2030 - Identifying Future Challenges and Opportunities." (Linden et al., in press)

This study focused on determining how best to develop water reuse in a manner that will be flexible, diverse, and robust enough to ensure that water reuse is a feasible solution in any region, and in any uncertain future. To accomplish this, the study focused on determining challenges for water reuse that were common in both scenarios. By focusing on the common challenges, it was possible to determine key factors to focus on and to discover opportunities for advancement of water reuse. The challenges and opportunities identified in this study include:

- Determining how to best advance technology and related knowledge,
- Addressing the need for more decentralized water reuse methods,
- Finding effective ways to govern water reuse,
- Innovating more effective resource management schemes,

- Proving economic viability,
- Being prepared for water scarcity and climate change, and
- Encouraging public knowledge and support.

From these challenges, the following key factors can be concluded.

Technology Advancement

Some specific advancements that are necessary include treatment methods that are water, energy, and cost efficient need to be developed. In addition, natural treatment processes need to be studied further and optimized. It is also very important to ensure a broad focus on technology improvement that will ensure that a diverse range of source waters, a wide selection of end-uses for reclaimed water, uses for treatment by-products, and other improvements are ensured. Additionally, agricultural reuse may key in ensuring that there is enough food to support growing populations.

Operating schemes also would benefit from some specific improvements. Developing operating schemes (and the supporting technology) that are rapidly adaptable to flow and quality variations will help treatment plants adjust for unforeseen circumstances. In addition, the development of equipment and methods for online water quality testing will allow for rapid adjustments in operations when necessary and offer confidence that operating schemes are safe and effective.

One key technology that will help to attain the flexibility that will be needed in the future is decentralized water reuse. Decentralized systems offer the possibility of providing treatment that is widely applicable and can function in extreme situations such as rapid growth and high population density. Energy efficiency and energy neutrality of these systems also need to be investigated. There also needs to be economic analysis of the feasibility of decentralization, educational programs for operators, training for those responsible for upkeep of the systems, and a strong set of guidelines to direct decentralized water reuse regulations.

Regulatory and Legal Support

Effective regulation of water reuse is essential for ensuring that it plays a robust, feasible and widespread role in the future. National water plans and guidelines for water reuse that offer the flexibility to address local constraints and priorities such as economics, governance, and attitudes, will be beneficial for every locality, region, or country that practices water reuse. Robust guidelines will help to develop regulations that are supportive of water reuse while still ensuring the protection of public and environmental health.

There are other regulatory needs as well. Source control requirements will help to maintain public and environmental health, while keeping water treatment processes and requirements manageable. Further research on the human and ecological effects of emerging contaminants such as pharmaceuticals and personal care products will help to ensure that public and environmental health are maintained, while keeping removal requirements achievable by treatment processes. Also it is essential to find appropriate indicators and surrogates of contaminants for regulatory applications in order to make monitoring and enforcement effective.

Legally, it is vital to gain understanding of how laws need to be revised to support water reuse. Areas to focus on include water rights laws, laws governing water quality, and laws specifying when and how recycled water can be used.

Resource Management

Because practicing water reuse affects so many facets of society and the earth, managing it within an agency that only focuses on one or two resources is very inefficient and detrimental to progress. Managing water reuse within a more holistic scheme, through integrated resource management and resource recovery, can help ensure that water and other resources are being sustainably used to their greatest potential. It can also lead to flexibility that will be necessary to manage water when supply and demand fluctuates, and help achieve greater operational and economic efficiency.

Economics

There needs to be an expansion of the previous economic research to further investigate the unique costs and benefits that evolve over time by reusing water, as well as by implementing other water supply options. The true costs and externalities related to water reuse need to be quantified. Doing so will enable more accurate comparisons of proposed water supply, treatment, and reuse schemes. These sorts of comparisons also need to be conducted in order to optimize how water reuse is provided. In order to ensure water is used efficiently in the future, it is necessary to identify where water reuse will be economically viable and which options exist for the use of reclaimed water. The effects of subsidizing water reuse also need to be analyzed in order to determine whether they provide economic benefit or whether they lead to economic inefficiency.

Energy Use and Emissions Reduction

In response to climate change fears, it is very likely that policies aiming to limit greenhouse gas footprints will affect the water reuse industry by mandating lower emissions during water treatment. Therefore, the greenhouse gas footprints of water, wastewater, and reuse plants need to be analyzed and optimized. Methods to achieve an energy balance at these plants also need to be devised. In addition, green infrastructure approaches that will decrease greenhouse gas emissions, such as natural treatment and sustainable drainage practices, need to be investigated further and given more consideration for meeting the demands of communities. It would also be useful to investigate the viability of using reclaimed water for urban agricultural practices, which would not only help to feed growing urban populations, but also have a cooling effect due to irrigation and the presence of vegetation.

Public Acceptance

It is essential that more effort and research is devoted toward ensuring that everyone is aware of water, how it has several different qualities, how it ties into the global water cycle, and how humans affect it, with the aim of a future public that is more involved with and supportive of water reuse.

3.5 Key Factors from Statistical Analysis

A statistical analysis was conducted to gain an idea of which factors water reuse practitioners in the United States find to be most influential. This analysis allowed for quantitative results to be calculated that can then be compared to the qualitative results from the surveys, expert workshops, and the qualitative scenario study. The questions were formulated to also allow for direct comparison to the output derived from the computer tool.

As a result of a series of surveys, expert workshops, and a literature review, factors were identified and analyzed for how they interact and affect each other and how they affect water reuse practices (Linden et al., in press). A final set of eight key factor categories were determined to have the most effect upon the successful implementation of water reuse, and thus were used for the statistical analysis and the computer aided tool. These include:

1. **Water use intensity (Water)** – The percentage of consumptive water use versus renewable supply. Renewable water supply is defined as the sum of precipitation and water imports minus the water that is unavailable for use due to exports, evapotranspiration, minimum required stream flows and other losses. The effects of climate variability and population changes can be reflected by this factor.
2. **Public Acceptance (Pub Accept)** - How favorable the public finds water reuse and the extent and uses of recycled water that they are comfortable with
3. **Regulatory & Legal Support (Reg & Legal)** – Indicated by policy positions and priorities, legislation, and regulations regarding water reuse. Water rights also factor into this category.
4. **Technology Effectiveness & Adaptability (Tech)** – The capability of technology to meet regulatory requirements, to be energetically and economically efficient, and to adapt to changes that may occur due to climate change or other conditions.
5. **Costs of Acquiring, Treating, & Distributing Water (Costs)** – The costs incurred to collect water, make it suitable for use, and to deliver it to users

6. **Institutional Structure (Inst)** – Indication of how water, wastewater, and other resource entities work together. These structures can range from completely separate management of each resource, to water and wastewater being managed by the same entity, to the management of water, wastewater, and other resources (minerals, oil and gas, etc.) in a holistic manner.
7. **Social Attitudes Toward Sustainability (Soc Att)** – How open society is toward sustainability and environmentally conscious actions.
8. **Energy Sources, Costs, & Availability (Energy)** – This category helps to incorporate the water demands of energy and the effects of energy costs and availability will have upon technology choices and water reuse in general.

METHODS

A survey was administered to water reuse practitioners in the U.S. The survey participants were asked to rate how influential factors were upon water reuse when they were first implementing water reuse and also how they impact it now. The survey also asked the participants to rate how much of a priority their organization attributes to each of these factors in their water reuse operations. Expert workshop participants were also asked to rate the impact that certain factors have upon water reuse. These data sets were used for this analysis.

The ratings for the influence each factor has upon water reuse were conducted as a Likert item (Likert 1932), which is a statement that the participant evaluates according to either subjective or objective criteria. The criteria were arranged on an eleven-point scale from 0 to 10. A zero corresponds to the factor affecting water reuse "extremely negatively." A 5 means that there was no positive or negative effect, and a 10 indicates that the factor affects water reuse "extremely positively." The rating for each participant is treated as ordinal data, allowing for statistical analysis.

The priorities that the participants have are determined through two separate rating steps. First the respondent rates each factor as a 7-point Likert item rating how much priority their organization places on the factor regarding their water reuse practices. A rating of 1 indicates "very little priority", a 4 indicates a "moderate" priority, and a 7 rating indicates a "very high priority." The second rating step is a forced ranking. Participants rank each factor in order from most to least important, with no duplicate rankings allowed. The scores from each step are then used to calculate a weighted ranking. A weighted ranking allows for establishing an order of priority, even for factors that receive the same score in the first rating step. The ranks are weighted as follows:

$$If\ i > \frac{r}{\left(\frac{8}{7}\right)} + 1, \quad then\ Wt_{add} = 0.5 * \frac{i-r}{\frac{8}{7}}; \tag{3.1}$$

$$If\ i < \frac{r}{\left(\frac{8}{7}\right)} - 1, \quad then\ Wt_{sub} = 0.5 * \frac{i-r}{\frac{8}{7}} \tag{3.2}$$

$$r_{wtd} = r + Wt_{add} + Wt_{sub} \tag{3.3}$$

where i = the influence rating, r = the original rank score, Wt_{add} = added rank weight, Wt_{sub} = subtracted rank weight, and r_{rtd} = the weighted rank. These ranks are also treated as ordinal data, and thus can be used for statistical analysis.

The priorities and influences were analyzed separately using principal component analysis (PCA), which is a statistical method developed in 1901 by Karl Pearson that is used as an exploratory tool and to identify trends in multi-dimensional data sets that are difficult to find (Wilks 2006). PCA is performed by applying a singular value decomposition (SVD) on the covariance matrix calculated for a data set. SVD is a process for factorizing a matrix (Trefethen et al. 1997). It decomposes the covariance matrix into three matrices. These matrices contain the eigenvalues and the left and right eigenvectors of the data. When the eigenvectors are multiplied with the data set, after it has been centered about zero by subtracting the mean, the vectors of data are rotated and shifted so that the data is expressed as linear combinations expressed in the direction where the variability of the original data is maximized, creating principle components of the data. The principle components are used to determine ways to most efficiently express the data and to identify relationships that may exist (Wilks 2006).

The data gathered in the survey are decomposed into the three matrices, which are then used to identify the key contributing factors and explore any possible interrelationships. The covariance matrix of the data, **A**, is decomposed into the **U**, **S**, and $\mathbf{V}^T$ matrices.

$$\mathbf{A} = \mathbf{USV}^T \tag{3.4}$$

The U and V matrices are eigen vector matrices, and the S matrix is a diagonal matrix containing eigen values. The sum of all the eigen values represents the total variance of the data. Therefore, a normalized eigen value represents the fraction or percentage of the variance exhibited by that component of the data.

The **V** matrix is used to identify the magnitude of contribution from each factor. The higher the magnitude of the value of each cell in the first column of the matrix, the greater the contribution (Wilks, 2006b). An Example of this matrix is presented in Figure 3.5. For this example, the factor that has the most impact upon water reuse for this data is Technology, followed by Water, Costs, and Institutional

Structure. The “Water”, “Costs”, and “Inst.” categories are close enough in magnitude that it can be concluded that their impacts are similar.

V Matrix	**Effects of Societal Factors on Reuse in the US at Time of Implementation**							
Water	-0.364	-0.348	-0.396	-0.224	-0.437	-0.480	-0.186	-0.288
Pub Accept	0.106	-0.199	-0.368	-0.278	0.690	-0.329	-0.083	0.382
Reg & Legal	-0.289	-0.009	-0.603	0.150	0.256	0.531	0.251	-0.346
Tech	0.718	-0.032	-0.150	-0.029	-0.033	-0.255	0.440	-0.448
Costs	-0.350	0.751	-0.037	-0.079	0.072	-0.412	0.363	-0.011
Inst.	0.313	0.340	-0.545	0.394	-0.326	-0.015	-0.313	0.359
Soc. Att.	-0.181	-0.398	0.028	0.558	-0.085	-0.215	0.556	0.366
Energy	-0.060	0.024	0.148	0.614	0.384	-0.314	-0.404	-0.434

Figure 3.5 - Example V Matrix for a PCA Analysis

When the **V** matrix is multiplied with the original data, after it is centered about zero, which will be called **Y,** the resulting matrix expresses the principle components (PC’s). Plotting the values for individual PC’s or plotting one PC versus another is used to extract relationships in the data. While the PC’s were plotted for the data sets in this study, none of them resulted in uncovering any relationships. Therefore, there will be no further discussion of the PC plots.

RESULTS

The key factors affecting water reuse were extracted from the V matrix for four combinations of the data gathered in the follow-up survey. These combinations include:

1. Respondent priorities (called Utility Priorities for this study) – survey participants ranked each factor for how much of a priority it is upon their water reuse practices.
2. The effect of each factor during implementation – Each factor, as it existed in society, was ranked for how it affected water reuse when it was being considered and/or implemented by the participant’s organization.

3. The effect of each factor at the present time – Each factor, as it exists in society, was ranked for how it affects water reuse at the present time.

4. The combination of the effects for each factor – The data for combinations 2 and 3 was combined to gain understanding of how the factors affect water reuse in a more general sense.

The results for each combination are presented below.

Utility Priorities for Water Reuse

The PCA analysis for this data set, as shown in Table 3.3, indicates that it is essential for entities practicing water reuse to ensure that there is regulatory and legal support of water the top priority. It is also very important that the organization is focused on attaining and maintaining public acceptance of water reuse. With the exception of striving to influence social attitudes, the other factors are of some importance to keep as a priority.

Table 3.3 - Results for PCA analysis of priority data

Priorities	
US	
Reg & Legal	0.62296
Pub Accept	0.44783
Costs	0.36445
Energy	0.32828
Tech	0.2718
Water	0.22028
Inst.	0.21568
Soc. Att.	0.04301

Effects of Factors in Society upon Water Reuse

The key factors in society were analyzed for how much they influence water reuse practices. The results of the PCA for the second, third, and fourth data combination described above are shown in Table 3.4.

Table 3.4 - Results of PCA Analysis of Key Factors in Society that Affect Water Reuse

Impact of Water Reuse by these Factors in Society					
Australia		All US		All US and Australia	
Energy	0.774	Tech	0.687	Costs	0.516
Soc. Att.	0.443	Pub Accept	0.434	Tech	0.449
Inst.	0.338	Costs	0.367	Inst.	0.414
Reg & Legal	0.214	Water	0.338	Pub Accept	0.402
Water	0.146	Soc. Att.	0.231	Water	0.348
Tech	0.112	Reg & Legal	0.153	Soc. Att.	0.265
Costs	0.095	Inst.	0.101	Energy	0.074
Pub Accept	0.054	Energy	0.061	Reg & Legal	0.056

The analysis shows that the factors most with the most influence on water reuse are quite different in the US than in Australia. It is important to note that the Australia data was collected in 2009, when there was a severe drought driving the viewpoint. The US data was collected in 2011 when drought was not so much of an issue. The combination of the two data sets provides a more balanced collection of values. Thus, overall, it can be determined from this study that costs are most important for water reuse. Technology, institutional organization, public acceptance, and water supply and demand are also very important. Energy issues and regulatory and legal support do not have much influence at all.

3.6 Conclusion

Key factors that affect water reuse were determined through a series of methods, with each one building on the results of the last. These results will be compared to the factors that are found to be most important using the computer-aided tool that is described and discussed in the next chapters.

Chapter 4

HYBRIDIZED DECISION TOOL METHODOLOGY

4.1 Introduction

With the pressures of increasing populations, maintaining water quality, and combating water stress, utilities worldwide are considering implementing water reuse into their portfolio of water supplies. Incorporating water reuse is very complex, dealing with aspects that encompass multiple disciplines of engineering (environmental, water treatment, wastewater treatment, and water resources management), as well as issues that stretch beyond the technical and into the socio-economic, sociological, legal and regulatory realm. Therefore, long range planning involving water reuse is also very complex. Key considerations include the following: Should a specific utility implement water reuse practices or not? Which societal factors affect water reuse the most? How do the priorities of the utility or planning entity affect the potential for water reuse to be successful?

In order to help consider questions like these and to assist with utility planning and water resources management, planners and governments have developed and used decision tools and performed scenario analyses. Some examples include predicting the feasibility of water reuse in European countries (Hochstrat 2006), determining the best way to integrate reuse into existing treatment trains through hydraulic and process evaluation (Jaksimovic et al. 2006), and others (Hidalgo et al.

2007; Makropoulos et al. 2008; Rozos et al. 2010; Zarghami et al. 2008). Typically, these decision tools and scenario analyses are developed for a single problem or entity, utilizing only a small number of variables and/or qualitative scenarios. Probability distributions and relationships are used to estimate what each policy option will look like for each scenario. The resulting policy and planning decisions are based upon these views.

Often these analyses are difficult to develop and quite complex to think through. Typically, the number of variables considered is limited due to uncertainties related to their nature and the complexity of their interactions with other variables. In addition, complexities and uncertainties regarding some determining factors can make assigning probability distributions of outcomes very difficult. It can also be very difficult to incorporate the effect of factors which are hard to quantify, such as public acceptance and other social issues. It is not very effective to attempt to incorporate a wide range of possible futures, as well as "surprises" that may arise, when only considering a small number of scenarios. And finally, the views and priorities of multiple stakeholders are often not easily included.

To address these needs and the deficiencies of traditional decision-making methods, a decision aid tool was developed. This decision tool hybridizes decision modelling techniques and scenario analysis into an application that is flexible and useful for utilities. Rather than using computer models to predict the future using fixed probabilities, exploratory analysis is utilized to run "experiments" of how conditions may evolve over time and how different policy options may perform under a wide range of possible future conditions (Bankes 1993, 2002). This tool creates a large number of scenarios, analyzes the potential for successful implementation of water reuse under each scenario, and evaluates the contribution of each societal factor and user priority. The results of these analyses will help to ensure that future plans are robust to the uncertainties of the future, and assist users in evaluating policy alternatives, with the goal of arriving at decisions that lead to successful water reuse implementation that is resilient to future events.

4.2 Methods

FACTOR CATEGORIES

Through a series of literature review, surveys, and expert workshops, factors were identified and analyzed for how they interact and affect each other and how they affect water reuse practices (Linden et al. in press). As a result, eight key factor categories were determined to have the most effect upon the successful implementation of water reuse. These factors will be used as the main categories for the utility priorities and the state of society in the computer simulations. They include:

1. **Water use intensity (Water)** – The percentage of consumptive water use versus renewable supply. Renewable water supply is defined as the sum of precipitation and water imports minus the water that is unavailable for use due to exports, evapotranspiration, minimum required stream flows and other losses.
2. **Public Acceptance (Pub Accept)** - How favorable the public finds water reuse and the extent and uses of recycled water that they are comfortable with

3. **Regulatory & Legal Support (Reg & Legal Support)** – Indicated by policy positions and priorities, legislation, and regulations regarding water reuse. Water rights also factor into this category.

4. **Technology Effectiveness & Adaptability (Technology)** – The capability of technology to meet regulatory requirements, to be energetically and economically efficient, and to adapt to changes that may occur due to climate change or other conditions.

5. **Costs of Acquiring, Treating, & Distributing Water (Costs)** – The costs incurred to collect water, make it suitable for use, and to deliver it to users

6. **Institutional Structure (Inst Str)** – Indication of how water, wastewater, and other resource entities work together. These structures can range from completely separate management of each resource, to water and wastewater being managed by the same entity, to the management of water, wastewater, and other resources (minerals, oil and gas, etc.) in a holistic manner.

7. **Social Attitudes Toward Sustainability (Soc Attitudes)** – How open society is toward sustainability and environmentally conscious actions.

8. **Energy Sources, Costs, & Availability (Energy)** – This category helps to incorporate the water demands of energy and the effects of energy costs and availability will have upon technology choices and water reuse in general.

DECISION TOOL

This decision tool has three main modules. The first module identifies the priorities of the user (p) through the use of rating and ranking exercises, and determines the indices that describe the state of society (f). The second module generates scenarios of the future. The third module identifies where sensitivities exist, and determines which factors and priorities will be most influential. The decision tool can be used on its own or incorporated into decision making processes that the user may already use. This process is illustrated in Figure 4.1 and discussed further below.

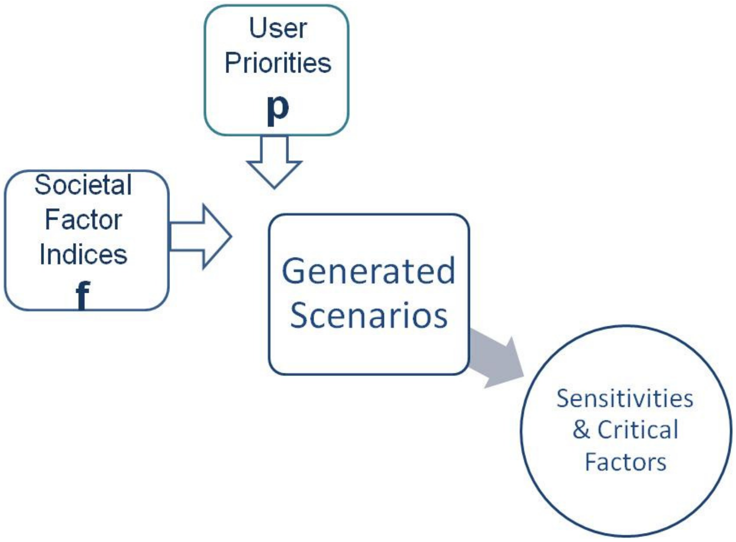


Figure 4.1 - Overview of the decision tool process

MODULE ONE – USER PRIORITIZATION AND SOCIETAL FACTOR DETERMINATION

The first module allows the user to incorporate their priorities and the unique attributes of their system, region, and entity into the evaluation of the potential for water reuse success. The user priorities and societal factor indices are determined and used for further analysis in the third module.

User Prioritization

The user rates each of the factor categories for how important they are to them. Each factor category is then ranked in order from most to least important. Performing dual weighting exercises allows for subtleties in priorities to be discovered, and allows for any bias in one weighting method to be dampened by the second. (Hajakowicz et al. 2000) The results of these user inputs are used to develop a weighted ranking (User Priorities), ranging from 0 to 1, with 0 indicating that there is no priority and 1 indicating extremely high priority being given to that factor category. The user priorities are used to calculate the potential of water reuse success in the second module.

Societal Factor Indices Determination

Societal Factor Indices are a measure of the state of each of the eight key factor categories in society. Each factor category is ranked according to how it contributes to water reuse success. The index values range from 0 to 1, with the following meaning:

0.0 – The factor category affects water reuse extremely negatively
0.5 – Water reuse is not affected either positively or negatively
1.0 – The factor category affects water reuse extremely positively

The values for each index can be used in two different ways – to determine the current state of society or to generate scenarios of future conditions. Determining the current state of society through these indices is a subjective judgement by the user. The subjectivity will be analyzed in this study to determine if a more guidance is necessary for the user. Index values used in scenario generation, which represent future states of society, are assigned by computer simulation.

MODULE TWO - EXPLORATORY SCENARIO ANALYSIS

The User Priority Weights and Societal Factor Indices developed in Module One are used to investigate how future uncertainties may affect water reuse potential. The goal of this module is to look holistically at water reuse as it relates to user priorities, and identify which of these priorities and societal factors are most sensitive to the success of water reuse. This module helps to explore which conditions lead to difficulties in the implementation of reuse schemes, and which circumstances may lead to successful implementation of water reuse.

Module Two centers upon calculating an index that measures the applicability of water reuse given varying levels of influence from each of the key factors. This index is described as a weighted additive utility, with the weights being the User Priority Weights calculated in module one, and Societal Factor Indices generated by Monte Carlo Simulation (Clemen & Reilly 2001). For each simulation of one possible future state of society, a measure of the potential for water reuse success is calculated as follows:

1. Random values for each Societal Factor Index is generated from a uniform distribution from 0 to 1 in the model.
2. The Societal Factor Indices are correlated to each other through a Cholesky Decomposition (Wilks, 2006) of interrelationship ratings provided as a result of a survey sent to water reuse practitioners in the United States. Multiplying the factors by the Cholesky Decomposition allows for the interrelationships between each factor category as they were present in the survey data to be carried over into the factor indices generated in the Monte Carlo Simulation.
3. The random generated values are used to calculate a Reuse Potential Value:

   $$Reuse\ Potential\ Value\ (RPV) = \sum_{i=1}^{8} p_i * f_i \qquad (4.1)$$

   where, p = the User Priority Weight and f = the Societal Factor Index for each factor category. Higher RPV values indicate a higher potential for successful implementation of water reuse. Without the Cholesky factorization of each index, the RPV values would range from 0 to 8. However, with the factorization, f can be slightly negative or greater than 1. Therefore, in this model RPV can be less than zero and greater than 8, with the actual values depending upon how the values for f are correlated.

4. Using Excel with the ModelRisk plug-in (Vose Software 2010), this procedure is repeated to generate thousands of scenarios for the societal factor index and/or utility priority values, which are then used to calculate the RPV. Generating thousands of scenarios allows for the user to capture uncertainty without developing probability distributions for each factor (Groves 2006; Lempert et al. 2003).

MODULE THREE - SENSITIVITIES & EXPLORATORY ANALYSIS

The third module uses the ensemble of RPV values generated for each scenario to analyze the sensitivity of the RPV to the User Priority Weights and the Societal Factor Indices. Using statistical analyses and the ModelRisk plug-in for Excel, the magnitude of contribution of each priority and factor toward the RPV can be determined. Further analysis of the scenarios in Module Two that have the most impact upon RPV (positive or negative) can serve as the key scenarios used for future comparison when evaluating policy options. The policies that perform well across many of the key scenarios can be consiedered robust under future uncertainty (Lempert et al. 2006).

4.3 Threshhold values for the Reuse Potential Value

Using the model, one thousand scenarios were generated using random values for both the User Priorities and the Societal Factor Indicies. The resulting histogram, which is shown in Figure 4.2, indicates the range of values possible.

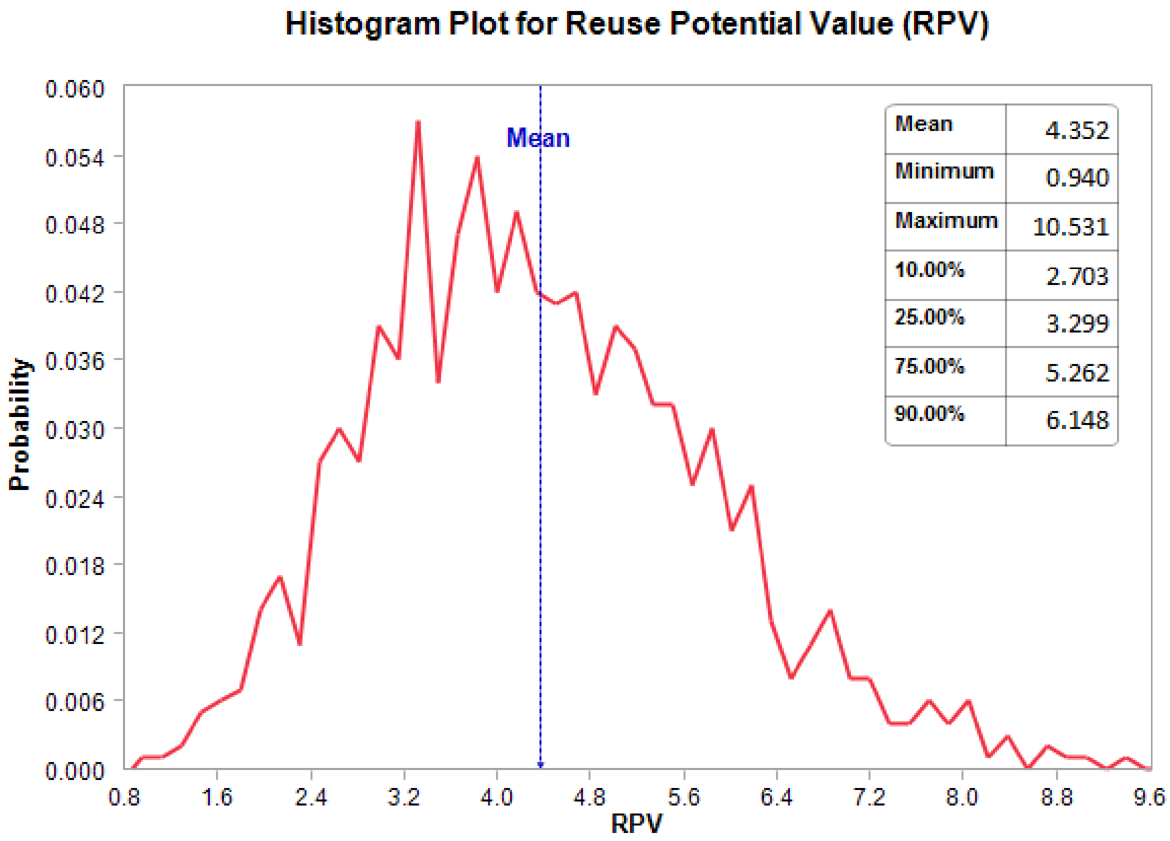


Figure 4.2 - Span of values for Reuse Potential Values (RPV) attained by varying User Priorities and Societal Factors through scenario generation. One Thousand scenarios were generated with the resulting RPV calculated. Statistical information for the histogram

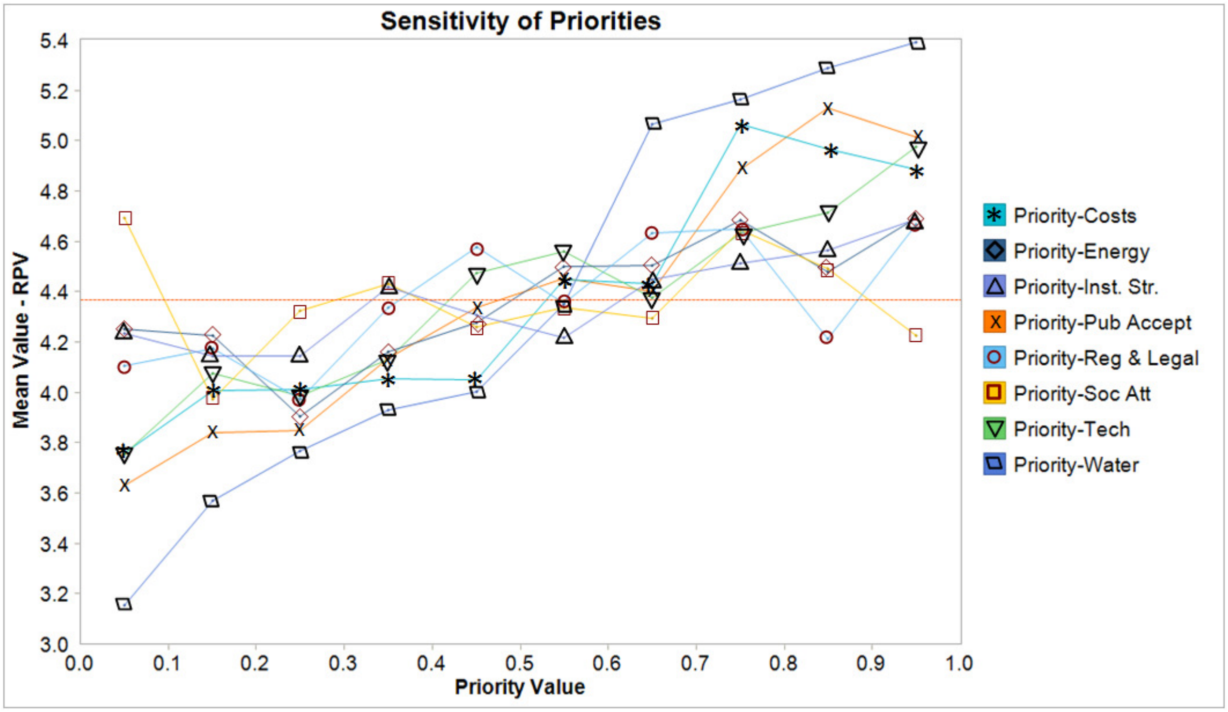
Because this simulation spans all possible values for the User Priorities and the Societal Factor Indices, it can be inferred that this histogram represents the range of RPV that are possible in any scenario. The mean of all RPV equals 4.4. It can therefore be generally concluded that for any scenario that is generated, a RPV greater than 4.4 indicates a potential for successful water reuse implementation, with higher values representing a higher chance for success. Whereas a value less than 4.4 indicates a potential for unsuccessful schemes, and lower values represent a greater chance for failure. Looking at the statistics, any value surrounding the mean between the values for the 25th (3.3) and 75th (5.3) percentile indicates a slight potential for either reuse success or failure, dependent on the value. It can be further determined that a RPV greater than 5.3 (75th percentile) is very likely to be successful and a value less than 3.3 (25th percentile) is very likely to not be a success. Furthermore, any RPV falling below the 10th or above the 90th percentiles (2.7 and 6.1, respectively) can be concluded to be an extreme situation where either success or failure (depending upon the value) is almost certain. To summarize, the following RPV values can be interpreted as follows:

- RPV = 0 – 2.7: Almost Certain Failure
- RPV = 2.7 – 3.3: Very Likely to Fail
- RPV = 3.3 – 4.4: Likely to Fail
- RPV = 4.4 – 5.3: Likely to Succeed
- RPV = 5.3 – 6.1: Very Likely to Succeed
- RPV = 6.1 or Above: Almost Certain Success

4.4 Observation of the Sensitivity of the RPV to the Subjectivity present in the Rating Scales

One aspect of this method that some may find disconcerting is the subjective nature of the rating and ranking exercises that lead to the User Priority and Societal Factor Index values. One user's idea of what a "4" means is not necessarily the same as another. Without thousands of participants and multiple studies, there is not a rigorous method for ensuring the accuracy of the priority and index value selection. Therefore, it is beneficial to look at how RPV values change as the priority and index values change. Doing so can help to affirm that a narrow fluctuation in the prioriy and judgement scoring will not lead to wide swings in RPV, giving confidence that the model is valid. Additional operational validation for the model is performed in Section 4.4. To ensure that the subjectivity present in determining the priorities and indices does not impair the tool, a sensitivity analysis was performed comparing how a change in priority or index value affects the final outcome of the RPV calculation. Figure 4.3 shows spider plots illustrating how the mean RPV value changes as each priority or index is varied from zero to one.

The spider plots are constructed as follows. For each input variable, the model data are sorted and filtered into groups pertaining to that variable's percentile groups: 0-10%, 10-20%, 20-30%, …, 90-100%. Within each of these percentile groups, the mean RPV value for the simulation is calculated. This analysis is repeated for each percentile group, for each variable. In the graph for the sensitivity of priorities, it can be read that the mean RPV value calculated in the simulation when the value for the priority accorded to water was in the 0-10th percentile range is approximately 3.15. The steeper the slope of the spider line, the more sensitive RVP is to that variable. For the priorities, RPV is most sensitive to "Water."



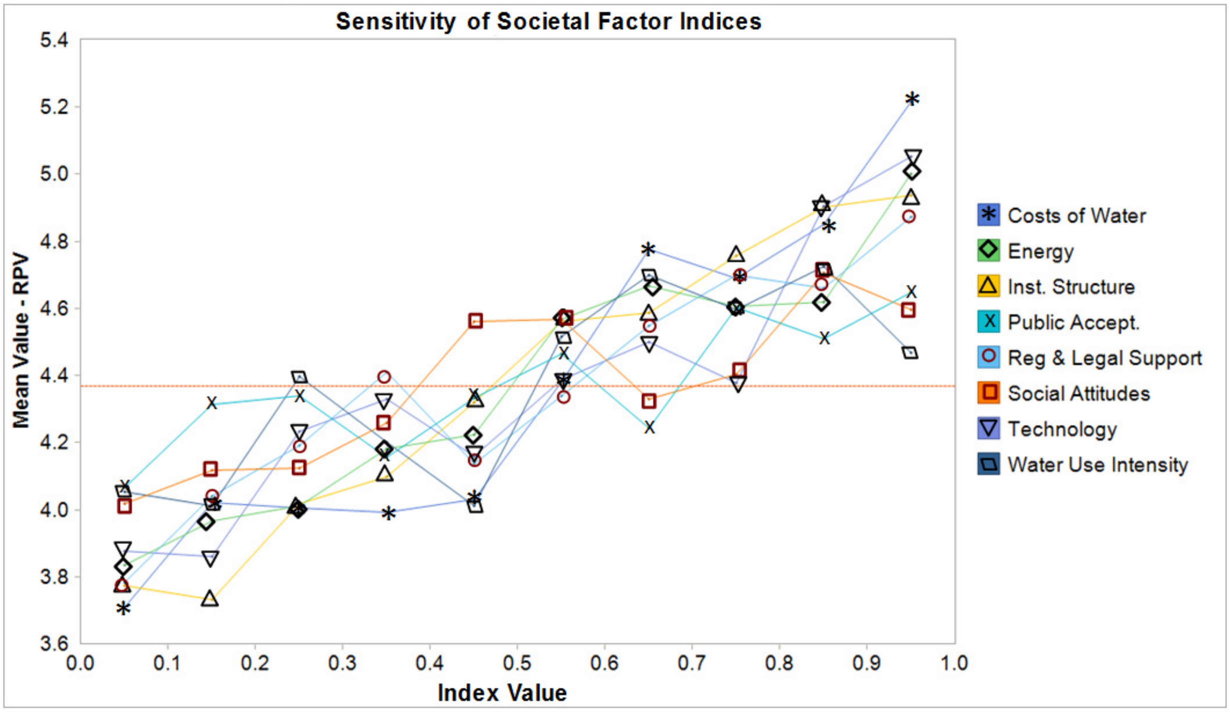


Figure 4.3 - Spider plots illustrating mean changes in RPV, versus changes in User Priority and Societal Factor Indices. The horizontal orange lines indicate the overall mean RPV.

By evaluating the difference in RPV as the priority and societal factors change, the relative sensitivity of the model to subjectivity can be evaluated. On the graphs, the most dramatic change occurs for "Priority-Water." For a 1% change in the value, there is a 7% change in RPV. More typically, a 20% change in the priority and factor values results in a 2-5% change in RPV. The one variable where subjectivity may present a problem is "Priority-Water." Future iterations of this model can help to address this issue by including one more method for ranking and rating the priorities, such as pair-wise comparisons, to provide more dampening of any implicit bias and help to further elicit subleties (Hajakowicz et al. 2000).

4.5 Operational Validation of the Model

Operational validation is the process of "determining that a model's output behavior has sufficient accuracy for the model's intended purpose…" (Sargent 1994). To test for operational validity, a comparison is made between data from the model and data from the entity that the problem stems from (Sargent, 1996). For this model, comparisons were made from the RPV values determined in Section 4.3 with historical cases of water reuse implementation to determine if the model can predict the outcome. In the past, water reuse was usually a fix for an emergency situation. Today, many entities are looking to water reuse to help maintain a secure local water portfolio, long before there is an emergency.

In order to keep the subjectivity to a minimum, only cases with documentation were used. Cases were found that represent a wide variety of circumstances. Each of these circumstances are described in the sections below. The values for the User

Priority and Societal Factor Indices used for validation were determined based upon the information from each source. Descriptions of each case were used in combination with the author's judgment to determine the value of each priority and factor index. If information was not available for certain factors or priorities, the values were assumed to be 0.5, indicating moderate priority or no positive or negative impact upon water reuse. Table 4.1 shows the criteria used for attributing values.

Table 4.1 - General criteria for attributing values for Societal Factor Indices and User Priorities

Value	Reasoning for Societal Factors	Reasoning for Utility Priorities
0.9	Extremely supportive of water reuse	Expressed as major challenge or priority
0.8	Highly favorable for water reuse	
0.7	General positive effect upon reuse	Concern or priority is evident
0.6	Favorable for reuse, but no strong effect	
0.5	Neutral or not specifically mentioned	Some Priority stated, but not very strong
0.4	Mildly unsupportive of reuse	
0.3	General negative effect upon water reuse	Not a big priority
0.2	Highly unfavorable for water reuse	
0.1	Extremely negative effect upon reuse	Not a priority
0	Disastrous for water reuse	

ORANGE COUNTY

In the 1950's, Orange County began to realize that they had problems with seawater intrusion into the aquifer being used for drinking water. Therefore, in the 1970's, Water Factory 21 was built in order to produce high quality water for recharging the aquifer to prevent seawater intrusion (OCWD 2008). Orange County relies on rainfall, the Santa Anna River, the Colorado River, Lake Oroville and water diverted from the Sacremento-San Joaquin River Delta through the State Water Project (GWRS 2003-04b). As the population of the county grew, and water available from decreased rainfall and Santa Anna River flows decreased, it became apparent that a new solution would be necessary. In addition, new environmental regulations mandated that more water remain in the Delta. Thus, in order to ensure that a reliable water supply could be maintained, the Groundwater Replenishment System (GWRS) was developed and implemented. Today, it is a successful scheme that is considered by some to be a showcase project. (GWRS 2003-04a). Table 4.2 outlines the values determined for the priorites and factor indices for Orange County.

Table 4.2 - Values used for Operational Validation with Orange County Water District

Category/ Factor	Priority Value	Reasoning	Societal Index Value	Reasoning
Water Use Intensity	0.9	Concern about dwindling supply. High quality needed for injection.	0.7	Concern about future problems
Public Acceptance	0.8	Lots of publicity. Dedicated Website	0.7	Not the first project. Generally positive. No publicity about problems
Reg. & Legal Suport	0.6	Regs making other sources dwindle. No apparent regs against.	0.6	No real barriers, yet no real incentives.
Costs	0.5	Not directly stated. Set at 0.5.	0.5	Not directly stated.
Institutional Structure	0.4	Structure already established. Cooperation necessary with Orange County Water District	0.7	Cooperation exists between different entities to support project.
Social Attitudes	0.1	Doesn't seem to be applicable in this case.	0.5	Unknown. Doesn't seem to be an issue either way.
Energy	0.4	It's available. Large quantity necessary for treatment.	0.6	Stated that this process saves energy over other pumping or desalination.
Technology	0.8	Wanted to ensure water quality requirements	0.8	Technology available to treat water to required standards

Attributed values based upon GWRS, 2003-04; OCWD, 2008 and author judgment

MONTEBELLO FOREBAY

The Montebello Forebay was originally built in the 1930's to attenuate flood flows. In 1954, imported water was added to the spreading ponds as well to help recharge the aquifer below it. In 1962, tertiary treated recycled water was added to the mix of sources feeding the ponds (Gasca et al., 2011). The system currently meets 40% of the demand for 3 million people. Table 4.3 outlines the values for priorities and indices.

Table 4.3 - Values used for Operational Validation with Montebello Forebay Groundwater Recharge Program

Category/ Factor	Priority Value	Reasoning	Societal Index Value	Reasoning
Water Use Intensity	0.8	Maximizing local water availability and water quality are key concerns.	0.8	Drought is an issue in the area
Public Acceptance	0.6	Aware that it is a focus need. Planning for future outreach.	0.5	Not specifically mentioned.
Reg. & Legal Suport	0.9	Regulatory changes have created challenges.	0.6	Support is there. Regulations can cause operational challenges.
Costs	0.7	Keeping costs low is a concern.	0.5	Not specifically mentioned.
Institutional Structure	0.7	Coordination between three agencies	0.7	Three agencies appear to cooperate well.
Social Attitudes	0.1	Not mentioned. Not a concern	0.5	Unknown
Energy	0.4	Mostly gravity fed. Not a big priority	0.6	Energy is available if needed but expensive.
Technology	0.5	Conducted research to confirm that Soil Aquifer Treatment is effective.	0.8	Technology is available to meet requirements of demand and government.

Attributed values based upon Gasca et al. 2011 and author judgment

TOOWOOMBA, AUSTRALIA

Drought had been so persistent in Queensland that in 2003, the residents of Toowoomba were faced with water restrictions that got progressively more stringent. The Toowoomba City Council launched a “Water Futures Initiative” in 2005, which included an indirect potable scheme (Hurlimann & Dolnicar 2010). Although an extensive 3-year community engagement program was planned, the organization called Citizens Against Drinking Sewage (CADS) was more efficient in spreading their views among the public. As a result of mixed information and political woes, a referendum election in 2006, regarding whether to implement the indirect potable reuse scheme, defeated the Water Futures Initiative. Despite many conditions being favorable for reuse, this project ultimately resulted in failure. The values used from Toowoomba for the validation of the model are shown in Table 4.4.

Table 4.4 - Values used for Operational Validation with the Toowoomba Water Futures Initiative

Category/ Factor	Priority Value	Reasoning	Societal Index Value	Reasoning
Water Use Intensity	0.9	Drought and limited water supply existed	0.8	Long running drought threatened supply.
Public Acceptance	0.7	It was a priority, however it was initiated too late.	0.05	Referrendum defeated the project.
Reg. & Legal Suport	0.3	This was not a key concern.	0.4	There were guidelines, but none published for potable use at that time.
Costs	0.6	They were aware of the need for funding for the project.	0.8	Town Council had promised funding with a match from the Australia Government promised.
Institutional Structure	0.4	This was an emergency measure, but some coordination was necessary.	0.5	Not stated in the document
Social Attitudes	0.1	Not a large concern.	0.5	Rainwater collection and other measures had been implemented-but maybe under duress.
Energy	0.2	The energy resources were present. They were in the midst of a drought.	0.5	Not stated in the document.
Technology	0.6	Wanted to ensure high water quality.	0.8	The technology necessary to meet water quality and other needs available.

Attributed values based upon (Hurlimann & Dolnicar 2010) and author judgment

WESTERN CORRIDOR, QUEENSLAND AUSTRALIA

Queensland, Australia was facing a long term drought, nearly diminished water supplies, and uncertainty where future water would be provided from. As a result, the Australian government created the Western Corridor Project, which included desalination and recycled water components. This project was fast-tracked to address a water crisis situation, commencing in 2005 and completed in 2008 (Traves et al. 2008). Validation values for the Western Corridor project are shown in Table 4.5.

Table 4.5 - Values used for Operational Validation for the Western Corridor Project during the drought

Category/ Factor	Priority Value	Reasoning	Societal Index Value	Reasoning
Water Use Intensity	0.9	Very concerned at gaining reliable supply.	0.9	Drought was creating a large need.
Public Acceptance	0.7	A priority having come right after Toowoomba.	0.7	Fairly accepting-running out of water.
Reg. & Legal Suport	0.5	Not a large concern as the support was present	0.7	Guidelines for potable reuse released for comment.
Costs	0.5	Not mentioned	0.6	Funded by government
Institutional Structure	0.8	Very large project. This was essential.	0.8	Necessary coordination occurred.
Social Attitudes	0.1	Unknown. Doubtful that is was a priority	0.5	Not mentioned.
Energy	0.5	Not mentioned	0.5	Not mentioned. But energy available for energy intensive processes.
Technology	0.6	Water Quality and goals relied on technology choice.	0.7	Technology available.

Attributed values based upon Traves et al. 2008 and author judgment

As the project neared completion in 2008, Queenland received record rainfall, releasing it from the drought crisis. As a result, even though three state-of-the-art water reclamation facilities had been constructed, the government changed its policy. Instead of continuously providing water by indirect potable reuse (IPR), IPR would only be used in cases of water scarcity, when the supplies in the reservoirs dropped below 40% of capacity (Rodriguez et al., 2009). Values for priorities and societal indices that reflect this change are shown in Table 4.6.

Table 4.6 - Values used for Operational Validation for the Western Corridor Project After the Rains

Category/ Factor	Priority Value	Reasoning	Societal Index Value	Reasoning
Water Use Intensity	0.6	Not a crisis anymore	0.5	Old supply sources were replenished.
Public Acceptance	0.6	Still a priority. Lots of press, flyers, etc.	0.3	Not so sure the reuse water is needed
Reg. & Legal Suport	0.5	Not a large concern as the support was present	0.2	Government changed rules for use of reuse water.
Costs	0.5	Not mentioned	0.6	Funded by government
Institutional Structure	0.8	Very large project. This was essential.	0.8	Necessary coordination occurred.
Social Attitudes	0.1	Unknown. Doubtful that is was a priority	0.5	Not mentioned.
Energy	0.5	Not mentioned	0.5	Not mentioned. But energy available for energy intensive processes.
Technology	0.3	Technology Choices had been made and installed.	0.7	Technology available.

Attributed values based upon Traves et al. 2008; Rodriguez et al. 2009 and author judgment

The values for the User Priorities and Societal Factor Indices were entered in the model in order to calculate a RPV for each case. The results of the model calculation along with a description of what the RPV Value indicates are tabulated in

Table 4.7.

Table 4.7 - Results of Objective Validation of the Model versus Case Studies

Case Study	**Orange County**	**Montebello Forebay**	**Toowoomba**	**Western Corridor - Drought**	**Western Corridor - After Rains**
RPV	7.73	7.47	6.17	7.96	4.97
	Almost Certain to be successful	Almost Certain to be successful	Very Likely to Succeed	Almost Certain to be successful	Likely to Succeed

Overall, the model does an adequate job of predicting the success of the various schemes, with the exception of Toowoomba. Orange County and Montebello Forebay are established, successful programs. Therefore, a high RPV should be expected. The Western Corridor Project, during the drought, was touted as a great solution that was going to be a solution to water supply problems. Therefore, the high RPV (likely due to the high "Water" values from the drought) is appropriate. After the rains came to Queensland, there were changes in multiple priority and societal factor values. These changes affected the RPV and indicated a result that is in the range surrounding the mean, which points to no difinitive determination of success.

The failure of Toowoomba to adequately be represented can be attributed to the "surprise" involved in this case. Everything seemed in order for a successful implementation of water reuse, until an outside group and political jockeying changed everything. This dramatic change, however, only resulted in the low value for one of the factors. All the other values pointed to a fairly well-designed scheme. Therefore, the model is not sensitive enough to "surprises." A near zero rating for one value is not enough to tip the measure of success to failure if the other values are supportive of water reuse.

SENSITIVITY TO SUBJECTIVITY

According to Section 4.3, a 20% difference (either plus or minus 0.2) in a priority or factor index value results in a maximum change in RPV of 15%. To address subjectivity for these results, a table illustrating the changes in results for a 20% variation in RPV, following the RPV interpretation of values from Section 4.4, is shown in Table 4.8.

Table 4.8 - Illustration of 20% variation in RPV results for each Case Study

Case Study	**Orange County**	**Montebello Forebay**	**Toowoomba**	**Western Corridor - Drought**	**Western Corridor - After Rains**
RPV	**7.73**	**7.47**	**6.04**	**7.96**	**4.97**
RPV +20%	9.276	8.964	7.248	9.552	5.964
RPV -20%	6.184	5.976	4.832	6.368	3.976
Original Indication	Almost Certain to be successful	Almost Certain to be successful	Very Likely to Succeed	Almost Certain to be successful	Likely to Succeed
Possible Change	No Change	-20% change: "Very likely to Succeed"	+20%: "Almost Certain Success."	No Change	+20% change: "Very Likely

			-20%: "Likely to Succeed"		to Succeed"

Except for Toowoomba, a 20% change in RPV only slightly changes the end interpretation. It can be argued that the result of the Western Corridor after the rains could lead to an incorrect result if the priority and societal factor values are judged so high that the RPV increases by 20%. Therefore, for circumstances that have an aspect of "surprise" to them, the results from the model may not reflect the true situation.

Chapter 5

KEY FACTORS AND PRIORITIES IN THE FACE OF FUTURE UNCERTAINTIES

5.1 Introduction

When entities consider water reuse as a water supply option, there are a number of technical, environmental, institutional, legal, and socioeconomic issues that need to be addressed. These include determining how to integrate water reuse into existing institutional structures, ensuring that reclaimed water does not negatively affect public or environmental health, reducing the energy intensity required for some treatment techniques, encouraging public acceptance of water reuse, and addressing water rights and other legalities.

In addition, effective water reuse practices vary widely from one location to the next. This is because each location has unique characteristics, such as its geography, climate, infrastructure, government, available water supply, and water demand. Also, each installation involves different water reuse applications, technologies and standards. This diversity makes planning for water reuse very challenging. Therefore, to help utilities in the initial water reuse planning stages, a study was conducted to determine the key Societal Factors and User Priorities for water reuse, in general.

5.2 Methods

This study used the model framework explained in Chapter 4. In order to determine the RPV values that indicate high and low reuse potential and to determine the most influential User Priorities and Societal Factors, a sensitivity model was created. The sensitivity model is a scenario study completed by varying the values of all User Priority Weights and Societal Factor Indices from 0 to 1 through Monte Carlo simulation. Five thousand scenarios were generated and used to calculate RPV. Through analysis of the results, the following things were determined:

1. The User Priorities that contribute most toward determining RPV values; and,
2. The Societal Factors that have the most weight in determining RPV values.

5.3 Results and Discussion

KEY FACTORS WITH THE GREATEST CONTRIBUTIONS TOWARD RPV

It is also useful to look at which societal factors and user priorities support and detract most from water reuse practices given different values of the Reuse Potential Value. Table 5.1 below shows the order of the magnitude of contribution to RPV for subsets of scenarios organized by percentile values.

Table 5.1- Contribution of Societal Factor Indices and User Priorities to RPV for various scenario subsets. Factors and priorities are listed with the greatest contributor listed at the top, and the least contributing categories at the bottom. Shaded cells indicate User Priorities, and white cells indicate Societal Factors.

Overall	Very Low RPV=2.7	Low RPV=3.3	Moderate RPV=4.4	High RPV=5.3	Very High RPV=6.1
Priority: Water	Priority: Water	Priority: Water	Priority: Water	Priority: Water	Priority: Water
Priority: Pub. Accept	Priority: Pub. Accept	Costs	Costs	Costs	Priority: Pub. Accept
Costs	Costs	Priority: Public Accept	Priority: Pub. Accept	Energy	Costs
Energy	Inst. Structure	Inst. Structure	Inst. Structure	Priority: Public Accept	Priority: Technology
Institutional Structure	Priority: Technology	Technology	Technology	Priority: Costs	Priority: Reg & Legal
Priority: Costs	Priority: Costs	Priority: Costs	Priority: Costs	Technology	Priority: Costs
Priority: Technology	Technology	Reg & Legal Support	Reg. & Legal Support	Priority: Technology	Technology
Technology	Social Attitudes	Energy	Energy	Reg & Legal Support	Energy
Reg & Legal Support	Priority: Reg & Legal	Priority: Technology	Priority: Technology	Inst. Structure	Priority: Energy
Social Attitudes	Reg & Legal Support	Water Use Intensity	Water Use Intensity	Priority: Energy	Inst. Structure
Priority: Reg & Legal	Priority: Energy	Priority: Inst Structure	Priority: Inst Structure	Priority: Reg & Legal	Priority: Soc. Attitudes
Public Acceptance	Energy	Priority: Energy	Priority: Energy	Water Use Intensity	Priority: Inst Structure
Water Use Intensity	Public Acceptance	Priority: Soc. Attitudes	Priority: Soc. Attitudes	Priority: Soc. Attitudes	Reg & Legal Support
Priority: Soc Attitudes	Priority: Soc Attitudes	Social Attitudes	Social Attitudes	Public Acceptance	Water Use Intensity
Priority: Energy	Water Use Intensity	Public Acceptance	Public Acceptance	Social Attitudes	Public Acceptance
Priority: Inst Structure	Priority: Inst Structure	Priority: Reg & Legal	Priority: Reg & Legal	Priority: Inst Structure	Social Attitudes

Considering all of the scenarios generated for the sensitivity study, the key overall societal factors and user preferences that contribute to RPV values include the costs required to acquire, treat and distribute water, the level of integration of the agencies and departments that manage water, and the availability and cost of energy (which affects technology choice). The societal factors that contribute the least are the water use intensity, how accepting the public is of water reuse, and how open society is to sustainability.

The user priorities that contribute most to the RPV include the priorities that users place on maintaining water use intensity at a sustainable level, encouraging public acceptance, and working to maintain an economic implementation. The priorities that contribute the least to RPV are the cost and sources of energy, being concerned about institutional structure, and encouraging social attitudes that support sustainability.

When initially considering Table 5.1, the results for the key contributing societal factors and user priorities may appear to be contradictory. For example, the societal factor public acceptance is a low contributor to RPV, but the priority placed upon public acceptance by the user is one of the highest contributors. Upon reflecting on the subtle differences between societal factors and user priorities, it becomes clear that this is not a contradiction. When implementing water reuse, it is not important that the public is initially supportive. However, it is extremely important that the user/provider is open about water reuse practices and focuses upon ensuring that the public is supportive. Similar conclusions can be reached regarding water use intensity. What exists in society is not nearly as influential upon water reuse success as is how the water reuse practitioner approaches these issues. The opposite is true for social acceptance of pursuing sustainability. If the acceptance is present in society it helps to increase RPV, however if the user places priority on this issue, it will not impact RPV much at all.

It is useful to look at subsets of the generated scenarios to determine the key societal factors and user priorities when the potential for water reuse success is either extremely high or extremely low. Table 5.2 summarizes how the factors and priorities change with extreme RPV. When RPV is extremely low, the costs involved and the institutional structure become much less important and other societal factors have more weight in determining the potential for success. Water use intesity is the key societal factor that leads to an extremely low RPV. This may occur when there is not sufficient water that is legally available to reuse, a surplus of available water, or a water rights structure that takes water available for reuse away during times of drought. Other societal factors leading to extremely low RPV include low regulatory and legal support, negative societal attitudes toward sustainability, and an institutional structure that separates resources and makes water reuse more difficult. The effects of user priorities further contribute to an extremely low RPV. The user priorities that contribute most to an extremely low RPV include when a user does not put adequate effort into balancing water supply with demands, encouraging public acceptance, or integrating water and wastewater.

Table 5.2 - Contribution of Societal Factor Indices and User Priorities to RPV for extreme values of RPV. Factors and priorities are listed with the greatest contributor listed at the top, and the least contributing categories at the bottom. Shaded cells indicate User Priorities, and white cells indicate Societal Factors

Overall	Extreme Low RPV=1.75	Extreme High RPV=8.3
Priority: Water	Priority: Water	Priority: Water
Priority: Public Accept	Water Use Intensity	Priority: Public Accept
Costs	Reg & Legal Support	Technology
Energy	Priority: Public Accept	Priority: Reg & Legal
Institutional Structure	Priority: Technology	Priority: Costs
Priority: Costs	Social Attitudes	Costs
Priority: Technology	Institutional Structure	Energy
Technology	Priority: Costs	Priority: Energy
Reg & Legal Support	Priority: Reg & Legal	Social Attitudes
Social Attitudes	Energy	Inst. Structure
Priority: Reg & Legal	Costs	Priority: Soc. Attitudes
Public Acceptance	Priority: Soc Attitudes	Priority: Inst Structure
Water Use Intensity	Technology	Water Use Intensity
Priority: Soc Attitudes	Priority: Inst Structure	Public Acceptance
Priority: Energy	Priority: Energy	Reg & Legal Support
Priority: Inst Structure	Public Acceptance	Priority: Technology

When the potential for successful implementation is very high, the priority of maintaining a balance on water use is still the most important. Technology choice and adaptability rises significantly in importance from cases with lower RPV, while the costs of water are still important yet drop in the amount of impact they have on RPV. User priorities have a lot of influence over a very high RPV. As with the overall average, the priority that the users place upon ensuring public acceptance and upon balancing available supply with demands are very influential. Other priorities though become more important than they are in the overall average results. In order to ensure a very high RPV, it is necessary to focus on ensuring that there is regulatory and legal support for water reuse.

Chapter 6

APPLICATION OF THE HYBRIDIZED DECISION TOOL

6.1 Introduction

This chapter demonstrates how the hybridized decision tool methodology described in Chapter 4 can be applied to assist a utility in their efforts of planning for water reuse. As many utilities do, the utility involved in this study faces unique circumstances. It is located in a semi-arid area at the base of the Rocky Mountains. Water supplies depend greatly upon snowfall in the mountains, and vary from year to year and season to season. Because it serves a high population, water resources are stressed. As a result, agreements have been made to pipe water over the mountains from less populated watersheds across the continental divide. Due to water rights laws, only water that is transported from other watersheds is available for reuse. Additionally, much of this trans-basin water can be redirected to its original basin in times of drought. Therefore, water reuse may not be feasible in times of drought.

In order to ponder and help plan for the future, the planning department has developed five “Futures” that are based on their key concerns. The current purpose for using these scenarios is to help the utility figure out what they should focus on in the near term in order to be prepared for whichever of these scenarios will become a reality in the future (Wagge 2011). The scenarios are described below.

1. **Traditional Future**: This future is extrapolated from past trends, few other unanticipated major changes occur. This scenario was developed using tree-ring growth data from 1634 to 2007 to predict future conditions.
2. **Water Quality Rules**: In this scenario, the public demands the highest practical quality of drinking water. Contaminant removal and other drinking water requirements are extremely stringent. This future assumes that regulations would require them to avoid using lower-quality water supplies, taking some of their key reservoirs out of their water portfolio, unless investment is made in new treatment technologies.
3. **Hot Water**: This future is characterized by a warmer climate accompanied by more frequent and more severe droughts. This change in climate will result in an overall reduction in streamflows, with higher and earlier spring runoff with lower flows the rest of the year. This scenario would cause a loss in water quantity.
4. **Economic Woes**: An ongoing energy crisis accompanied by a prolonged, deep economic downturn causes challenges in this scenario. It assumes that the utility will lose some of its water rights because of the difficulty in financing new supply projects, which would lead to increased water rights litigation between water providers and the loss of existing water supplies. Because water transfers may be stopped, water reuse may become infeasible with this Future.
5. **Green Revolution**: Environmental values and sustainable living become dominant social norms. Regulations to enhance the aquatic environment would require the utility to increase bypass flows at some of its diversions and reservoirs, reducing the water available for the city. Ironically, the demands of “green” living, such as living in the city center with a high population density, results in this scenario having the highest water demand of all the Futures proposed.

6. **Big Whammy:** This Future was not provided by the utility, but was added in order to examine what may happen if all of these Futures were to occur simultaneously.

6.2 Methods

As part of a survey provided to utilities to gather data for the model described in Chapter 4, the involved utility provided values for the User Priorities and Societal Factor Indices. These values provide the basis for exploring the future under the five scenarios developed by the utility planning department.

In order to help the utility determine what to focus on now, two key analyses are completed for this study. The first focuses on determining which societal factors in the future will be most influential for the utility's reuse practices, given they keep the same priorities that they have today. To examine this, the priorities in the hybiridized model were set to the values provided by the utility in the survey. One thousand scenarios were then generated to reflect different states of society in the future. The most influential priorities were then determined using sensitivity analysis and Spearman's rank coefficients.

The second aspect of the study centers on determining which utility priorities will be most influential under each of the utility's developed scenarios. Utility personnel correlated changes in the societal factor values to reflect each of the scenarios. The computer tool was then used to generate 1000 scenarios for each future. The key priorities were determined for each future using Spearman's Rank coefficients and sensitivity studies.

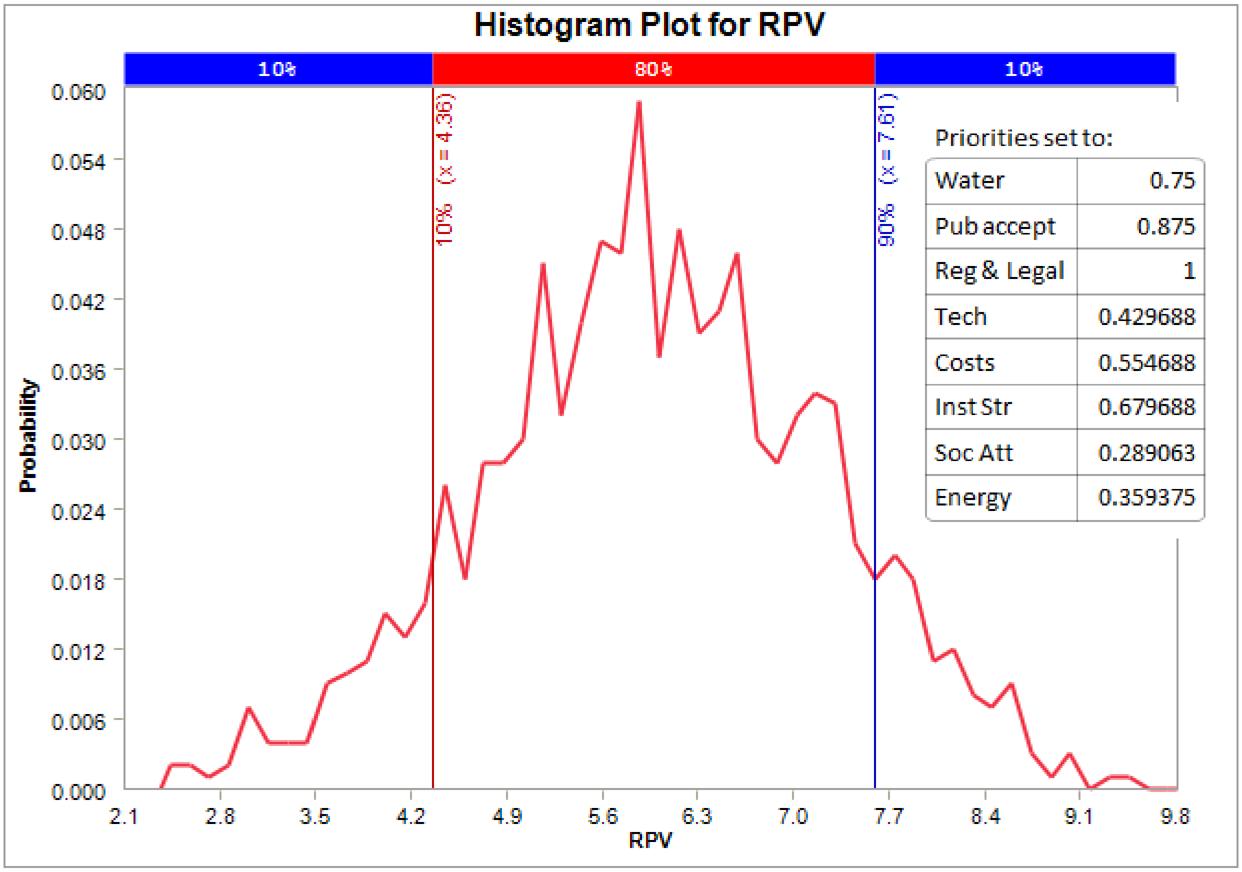
The model used for these analyses is explained in Chapter 4. For any scenario that is generated, a Reuse Potential Value (RPV) greater than 4.4 indicates a potential for successful water reuse implementation, whereas a value less than 4.4 indicates a potential for unsuccessful schemes. The RPV values can be interpreted as follows:

- RPV = 0 – 2.7: Almost Certain Failure
- RPV = 2.7 – 3.3: Very Likely to Fail
- RPV = 3.3 – 4.4: Likely to Fail
- RPV = 4.4 – 5.3: Likely to Succeed
- RPV = 5.3 – 6.1: Very Likely to Succeed
- RPV = 6.1 or Above: Almost Certain Success

6.3 Analysis One – Outlook for Water Reuse with the Current Priorities

The computer model was used to analyze which societal factors are most influential upon water reuse given the priorities are equal those supplied by the utility. One thousand different scenarios were generated to reflect different states of society that may occur in the future. A histogram of the RPV is shown in Figure 6.1.

It is notable that the mojority of the RPV values calculated are above 4.4, the RPV threshold indicating a chance for water reuse success. Only the scenarios below the 10th percentile, those that are highly unlikely, have RPV that indicate a chance for failure. Therfore, the priorities held by the utility now are very likely to serve them well in the future.



Priorities set to:

Water	0.75
Pub accept	0.875
Reg & Legal	1
Tech	0.429688
Costs	0.554688
Inst Str	0.679688
Soc Att	0.289063
Energy	0.359375

Figure 6.1 - Histogram of possible RPV values for 1000 scenarios with varied Societal Factor Indices and User Priorities set to those provided by the utility. The User Priority values used for the scenario generation are also tabulated.

Table 6.1 below shows the importance that each Societal Factor Index has for the RPV. The overall rank was determined by calculating the Spearman's Rank Coefficient for each factor index. The higher the value of Spearman's Rank, the higher the contribution of that factor toward the RPV. The ranks for each percentile were determined by analyzing the sensitivity of the factor indices, filtered to reflect each percentile, to the RPV.

Table 6.1 - Relative importance of societal factors for 1000 future scenarios, sorted according to percentile

Overall	1%	5%	10%	25%	50%	75%	90%	95%	99%
RPV= 5.97	RPV= 3.16	RPV= 4.01	RPV= 4.36	RPV= 5.05	RPV= 5.93	RPV= 6.87	RPV= 7.57	RPV= 8.20	RPV= 8.86
Reg & Legal	Reg & Legal	Tech	Costs	Costs	Costs	Reg & Legal	Reg & Legal	Reg & Legal	Inst Str
Costs	Inst Str	Reg & Legal	Reg & Legal	Inst Str	Reg & Legal	Inst Str	Inst Str	Inst Str	Reg & Legal
Inst Str	Costs	Costs	Tech	Reg & Legal	Energy	Energy	Costs	Costs	Costs
Tech	Water	Inst Str	Inst Str	Tech	Inst Str	Costs	Energy	Energy	Energy
Energy	Tech	Energy	Energy	Energy	Pub Accept	Tech	Pub Accept	Pub Accept	Tech
Pub Accept	Social Att	Pub Accept	Pub Accept	Pub Accept	Tech	Social Att	Tech	Tech	Social Att
Social Att	Energy	Social Att	Social Att	Social Att	Water	Pub Accept	Water	Water	Water
Water	Pub Accept	Water	Water	Water	Social Att	Water	Social Att	Social Att	Public Accept

If the utility were to maintain their priorities, in general, regulations and laws, and the costs of acquiring, treating, and distributing water, will be the aspects of society that most affect the success of water reuse. It will also be important that water management is integrated among the many sectors that are affected by it, such as energy, wastewater, and fresh water. Energy costs and availability, along with availability and adaptability of technology are important factors for some percitile ranges. When the scenarios resulted in a RPV indicating a potential for failure, most of the societal factors maintained the same relative importance. However, for the extrememly low RPV, either a severe problem with maintaining a balance between supply and demand, or finding technology that meets reuse needs played a key role.

Interestingly, for most cases, public acceptance, social attitudes toward sustainability, and the balance between supply and demand did not have a key role in determining RPV. While at first, this may seem like a cause for concern, it is important to remember the difference between the user priorities and the societal factors. This utility placed a high priority upon public acceptance and water use intensity. Therefore, no matter what issues regarding these factors are present in society, the utility is prepared to address them. Therefore, the issues of water and public acceptance, as they are occurring in society are not necessarily a concern.

6.4 Analysis two - Outlook for Water Reuse under the Utility "Futures"

For this analysis, the computer model was used to help the involved utility determine what their priorities should be in the near term, to ensure that they are prepared for any of their developed scenarios, or "Futures", should they occur in the future. For each Future, the model was set with Societal Factor Indices that reflected the Future, and scenarios were developed for the User Priorities. The priorities that are most influential when the RPV indicates a chance for success were determined to be most important for the utility to focus upon. Figure 6.2 compares the histograms for each Future.

The Big Whammy, Economic Woes, and Water Quality Rules Futures result in RPV distributions that have a large percentage of RPV in the range where water reuse has a potential for failure. Overall, the Hot Water, Green Revolution, and Traditional Futures offer the most opportunities for water reuse to be a success, as more of these distributions lie above the RPV success threshold of 4.4.

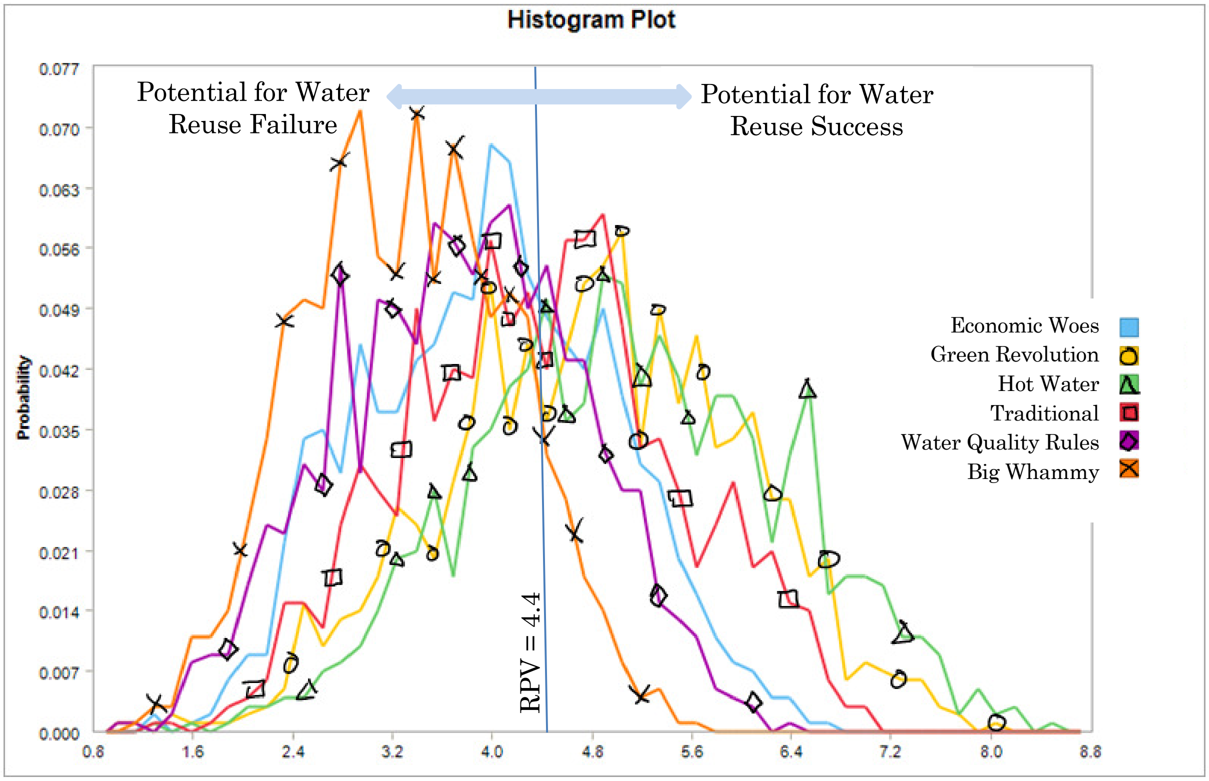


Figure 6.2 – Comparison of Histograms for each Future. The vertical line through the center of the chart indicates an RPV of 4.4, the threshold value separating the potential for water reuse success or failure.

Table 6.2 summarizes the findings for each Future. The mean, minimum and maximum values are shown, followed by the percentile values where each distribution attains RPV that indicate a chance for reuse success. Below these, there is a list of the priorities in order from the most to least important that affect water reuse when the chance for success is very likely. The ranking order for the priorities was determined by sensitivity studies for data sets filtered to only include RPV above 5.3, the threshold for “very likely success” of water reuse. The priorities are listed in order of importance, with the most important at the top.

Table 6.2 – Summary of Analysis for each Future. The mean, minimum and maximum values of RPV calculated are listed, followed by the percentile values at which each analysis attains RPV corresponding to a chance for reuse success. At the bottom, the key priorities, for when reuse success is very likely, are listed for each future.

Future	**Traditional**	**Water Quality Rules**	**Hot Water**	**Economic Woes**	**Green Revolution**	**Big Whammy**
Mean	4.38	3.77	5.07	3.98	4.75	3.35
Minimum	1.08	1.10	1.41	1.07	1.39	1.02
Maximum	7.50	6.33	8.82	6.44	8.45	5.66
Chance of Success	50th Percentile	75th Percentile	30th Percentile	65th Percentile	40th Percentile	90th Percentile
Success is Very Likely	80th Percentile	95th Percentile	60th Percentile	90th Percentile	65th Percentile	99th Percentile
Almost Certain Success	95th Percentile	Never	80th Percentile	99th Percentile	85th Percentile	Never
Key Priorities	***For cases when RPV Indicates very likely success***					
Most Important	Water	Water	Water	Water	Water	Water
	Public Accept	Technology	Public Accept	Public Accept	Public Accept	Public Accept
	Technology	Public Accept	Technology	Inst. Structure	Costs	Technology
	Costs	Costs	Inst. Structure	Reg & Legal	Inst. Structure	Costs
	Reg & Legal	Reg & Legal	Costs	Costs	Technology	Inst. Structure
	Inst. Structure	Social Attitudes	Social Attitudes	Technology	Social Attitudes	Social Attitudes
	Social Attitudes	Inst. Structure	Reg & Legal	Social Attitudes	Energy	Energy
Least Important	Energy	Energy	Energy	Energy	Reg & Legal	Reg & Legal

For all of these possible futures, the most important prioritiy is water use intensity. Public acceptance is also very important. Energy and Social Attitudes are consistently the least important priorities. The others lay between these values and vary according to the Future being considered.

6.5 Conclusions

ANALYSIS ONE - OUTLOOK FOR WATER REUSE WITH THE CURRENT PRIORITIES

The priorities that this utility is currently focusing upon will serve them well in the future. The computer tool and generated scenarios for possible states of society showed that this combination of priorities served well under all scenarios except for those that resulted in the lowest 10% of the RPV. The societal factors that this utility needs to be most concerned about include the following four items. The regulatory and legal support given to water reuse is very influential on the level of water reuse success. The costs of acquiring, treating and distributing water also affects the level of success. In addition, the ability of technology to treat water to required levels, and to adapt to changing inflow quantities and water quality states is important. Finally, there needs to be a focus upon ensuring that water resource management is coordinated between different sectors and agencies that are affected by water, such as fresh water supply, wastewater treatment, water reuse, agriculture, and energy. The analysis showed that when these four factor indices were high, water reuse had a good potential for success. When these four factors were not as supportive of water reuse, in addition to there being water use intensity issues such as a drought, the chance for water reuse success disappeared.

ANALYSIS TWO - OUTLOOK FOR WATER REUSE UNDER THE UTILITY "FUTURES"

The Big Whammy, Economic Woes, and Water Quality Rules Futures have the most potential to threaten water reuse practices for this utility. Whereas, the Hot Water, Green Revolution, and Traditional Futures offer the most opportunities for water reuse to be a success. When all the Futures are considered together, it is most important to make maintaining a balance between supply and demand a priority. Public acceptance is also very important to focus upon. Energy and Social Attitudes are consistently the least important priorities. Considerations for each Future are summarized below. Comparisons are also made between the key priorities as they are currently for this utility, and how they may need to change for each Future. To aid in this comparison, the current utility priorities are listed again, from most to least important:

- Water Use Intensity (balance between supply and demand)
- Public Acceptance of Water Reuse
- Regulatory and Legal Support for Water Reuse
- Technology Choice and Adaptability
- Costs to Acquire, Treat, and Supply Water
- Institutional Structure (how integrated water management is)
- Social Attitudes Toward Sustainability
- Energy Costs and Availability

The Traditional Future

The analysis for the Traditional Future returns a distribution of RPV that has a mean of 4.4, which is the overall threshold value that separates scenarios into those with the potential for success and those with the potential for failure. Therefore, half of the generated scenarios have potential for water reuse success. In order to increase the likelihood for water reuse success, technology and the costs of water need to become higher priorities than they currently are.

The Water Quality Rules Future

This Future has the most pessimistic outcome of all of the Futures provided by the utility. The only Future that had an even greater overall chance for water reuse failure was the Big Whammy Future, which was created for this study for illustrative purposes, not by the utility. A RPV indicating a very likely chance of success (RPV=5.3) only exists for the most extreme cases (95th percentile and above), and RPV never exceeds 6.1, where success becomes almost certain. With the high importance placed upon water quality in this Future, technology choice and adaptability are more important for this Future than it is for all of the others. In order to create the highest possibility for water reuse success, the utility must make balancing water supply and demand, and finding appropriate and adaptable technology, and maintaining pubic acceptance their key priorities. The priorities of managing the costs of water and working to attain regulatory and legal support are also quite important.

Hot Water Future

This Future illustrates a community challenged by decreased available supply and frequent and severe droughts. Surprisingly this Future has the highest mean RPV and the widest range of scenarios where there is a possibility for water reuse success. It is important to consider that this high potential for success holds for this community as long as they maintain their supply of trans-basin water. This water from outside their watershed is the only water that is legally available to reuse. It is also subject to being taken away from the utility and given back to the area it was diverted from in times of drought.

Because this is likely to be a time of crisis, the key priorities center around managing the difficulties of the time. Therefore, regulatory and legal concerns become less important, and an integrated water management structure becomes more important than it currently is.

Economic Woes Future

This is another Future where it is more difficult to attain water reuse success. Scenarios with an RPV indicating a very likely chance for success only exist for extreme cases beyond the 90th percentile. According to this study, during times of economic difficulty, the utility needs to put more priority on integrating the management of water between agencies than it currently does. Technology choice becomes less important.

Green Revolution Future

Increased demand by the public for sustainable action leads to this Future. Therefore, it is one of the most promising scenarios regarding water reuse success. The focus on sustainablity increases the need to integrate resource management, therefore institutional structure needs to increase in priority from where it stands today. Less of a priority will need to be placed on securing regulatory and legal support, likely because the public will be demanding it.

Big Whammy Future

This Future paints a bleak picture for water reuse. It is a combination of all the other Futures developed by the utility, therefore there are many challenging circumstances that are considered. From the analysis, a chance for success is found only in scenarios that are in the 90th percentile or higher. If a dire situation such as this were to occur, the utility would need to change some of its priorities. Balancing supply and demand and assuring public acceptance are still the most important. However, striving for regulatory and legal support becomes the least important of all the priorities, which is currently the third most important. The other priorities all become slightly more important than they currently are, sliding up one level of importance on the list.

Overall Impressions

According to this study, the current priorities that this utility has are robust and will serve them well. It is important to focus on keeping the balance of supply and demand and public acceptance the key priorities of the organization. Energy costs are not likely to ever need to be of a high priority, and social attitudes will only become important if the public moves in a direction to become more sustainable. The other priorities shift in importance depending on what is happening in society. Maintaining a moderate amount of priority for regulatory and legal support, technology, the costs of water, and institutional structure will allow for the level of importance attributed to these priorities to shift as needed.

Chapter 7

DISCUSSION AND CONCLUSIONS

The purpose of this dissertation was to ascertain whether a computer model coupled with scenario analysis can effectively determine key factors that influence water reuse. To determine this, multiple methods were used to determine key factors, including qualitative surveys and ratings, quantitative statistical analysis, and computer-aided modeling. In addition, the hybridized decition tool was validated operationally with the use of retrospective case studies. This chapter will evaluate the results of these approaches and discuss how they affect each hypothesis for this study.

7.1 Conclusions for Hypothesis 1: Comparison of Key Factors as Found by Various Approaches

Hypothesis 1: Using multiple methods to analyze the key factors that affect water reuse will lead to agreement upon which factors are most important

Each approach of determining key factors built from the original literature search. First, factors and issues that were important were gleaned from the literature. Surveys and expert workshops had water reuse professionals determine which of the factors from the literature they thought to be important, and they added their own. The multitude of factors were condensed and combined to create eight categories, which were used to describe User Priorities and Societal Factor Indices. These categories were then used for quantitative ranking of these factors through evaluation of data from the Australia expert workshop, statistical analysis of survey data, and use of the hybridized decision tool. Figure 7.1 compares the quantitative ranking results found from each approach.

For the User Priorities, there is some correlation between the general order of results for the model and for the expert workshop rankings. The statistical analysis showed some agreement on the importance of some of the priorities and factors, but not with the general order for either the user priorities or the societal factors. This lack of agreement with the statistical analysis is likely due to the differences in how the priorites and factors were treated for each approach. The User Priorities and Societal Factors were analyzed separately for the statistical analysis, yet the model analysis combined them together to arrive at the results. Therefore, using multiple approaches as presented in this study is not likely to lead to finding agreement upon which factors are most important for the success of water reuse.

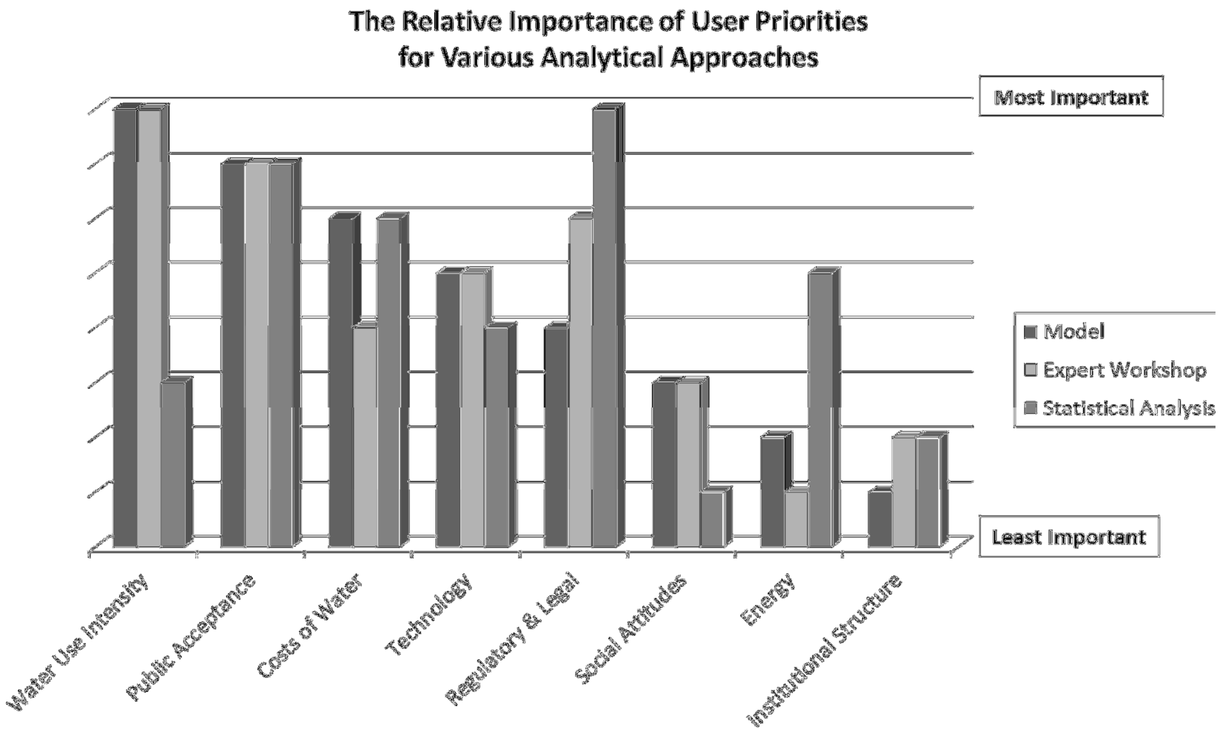


Figure 7. 1 - The Relative Importance of User Priorities and Societal Factors According to Various Analytical Approaches as Compared to the Model Results. The User Priorities and Societal Factors are shown from left to right in the order of importance, as found by the model analysis.

7.2 Conclusions for Hypothesis 2: Determining the Key Societal Factors and Utility Priorities Affecting Water Reuse

Hypothesis 2: Water supply needs and economics are the key factors in society that affect water reuse. Maintaining public acceptance is the factor most important for water reuse providers to have as a priority in their operations.

The societal factors and user preferences that contribute to RPV values and thus the success of water reuse) are reiterated in Table 7.1.

Table 7.1 - Contribution of Societal Factor Indices and User Priorities to RPV. Factors and priorities are listed with the greatest contributor listed at the top, and the least contributing categories at the bottom. Shaded cells indicate User Priorities, and white cells indicate Societal Factors

Overall	Extreme Low RPV=1.75	Extreme High RPV=8.3
Priority: Water	Priority: Water	Priority: Water
Priority: Public Accept	Water Use Intensity	Priority: Public Accept
Costs	Reg & Legal Support	Technology
Energy	Priority: Public Accept	Priority: Reg & Legal
Institutional Structure	Priority: Technology	Priority: Costs
Priority: Costs	Social Attitudes	Costs
Priority: Technology	Institutional Structure	Energy
Technology	Priority: Costs	Priority: Energy
Reg & Legal Support	Priority: Reg & Legal	Social Attitudes
Social Attitudes	Energy	Inst. Structure
Priority: Reg & Legal	Costs	Priority: Soc. Attitudes
Public Acceptance	Priority: Soc Attitudes	Priority: Inst Structure
Water Use Intensity	Technology	Water Use Intensity
Priority: Soc Attitudes	Priority: Inst Structure	Public Acceptance
Priority: Energy	Priority: Energy	Reg & Legal Support
Priority: Inst Structure	Public Acceptance	Priority: Technology

Overall, the societal factor that influences water reuse success the most is the cost required to acquire, treat and distribute water. Thus economics do play a key role in water reuse implementations. It also plays a key role in circumstances when water reuse is a highly favorable water supply option (RPV is very high). However, when circumstances dictate that water reuse may not be a good solution (RPV is very low), costs decrease in importance.

Water supply needs, which are described as water use intensity for this study, are the least important overall societal factor for determining water reuse success. However, water use intensity is the most important factor for utilities and water reuse providers to maintain as a priority. Therefore, the balance between supply and demand that exists in a service area is not a key determinant of water reuse success. However, under special circumstances when RPV is extremely low, water use intesity is the key societal factor. This may be due to insufficient water quantity that is legally available to reuse, a surplus of available water, or a water rights structure that takes water available for reuse away during times of drought.

The results of the sensitivity study for user priorities show that the the way in which the utility or water reuse provider addresses and considers water use intensity is most important. After water use intensity, the user priority that contributes most to the RPV is encouraging public acceptance. Therfore, it is extremely important that the user/provider is open about water reuse practices and focuses upon ensuring that the public is supportive. This was true in this study for the overall consideration of RPV as well as for extreme cases.

Thus, economic conditions in society are very important determinants of water reuse success. The influence of water supply and demand however is not as important as initially thought, unless there are extenuating circumstances. The hypothesis correctly determines the importance of having public acceptance as a priority for the utility providing reuse water, but it is not as important as ensuring that the balance between supply and demand is maintained in a sustainable manner.

7.3 Conclusions for Hypothesis 3: Effectiveness of the Hybridized Decision Tool

Hypothesis 3: The method of using a computer-aided model coupled with scenario analysis can effectively determine key factors that influence water reuse.

Overall, this decision tool provides a flexible platform for the analysis of water reuse opportunities now and in the future. It incorporates user preferences, includes softer qualitative issues along with quantitative values, and accounts for future uncertainties. The results allow for the user to gain understanding of the overall feasibility of water reuse in the future and of which factors to focus efforts on in order to ensure success. However, the only two methods that have somewhat comparable results are the expert workshop factor ratings and the priorities derived from the model.

Because there is no consistency between the factor analysis approaches, as seen in the comparison of the results from the various procedures, it could be claimed that there is not conclusive evidence that this hydridized decision tool method will effectively determine the key user priorities and societal factors. This may be due to the subjectivity involved, or because water reuse is driven by factors and priorities that are unique for each and every implementation. In addition, all of the approaches used were derived from or included some subjective judgements. While the subjectivity is a reality of trying to plan for water reuse implementation, it makes applying science to those efforts very difficult.

Despite the inability to correlate the rankings of priorities and factors between different analytical approaches, it was demonstrated through operational validation that the hybridized decision tool methodology can be effective at determining the RPV in a wide range of situations. Aside from circumstances where a “surprise” caused water reuse implementation to fail, the hybridized model did a satisfactory job of determining the potential for success in several retrospective case studies. Therefore, this methodology shows promise.

7.4 Future Improvements

As this is the first iteration of this model, there are a two key areas that need improvement or further investigation. These areas are addressing subjectivity and better incorporating the impact of “surprises” and factors with impacts upon water reuse that vary over time. These are both discussed below.

The effects of subjectivity may be able to be reduced with improved methods for determining values for the User Priorities and Societal Factor Indices. For the User Priorities, a method that allows for feedback to the user to check their consistency in rating along with several rating and ranking exercises will help to improve these values. For the Societal Factor Indices, many of them can be incorporated into a quantitative module that will inform the index. For example, a water balance module that incorporates quanitites for supply and various demands will allow the calculation of a water intensity value which can be compared to indices used to measure water stress. Economic modules can compare project costs to budgets. Eventually, interfaces that allow for the user to easily use the hybridized model will also be beneficial.

Further investigation is needed regarding how the impact of societal factors change with time, and how one factor can cause failure, even if every other one strongly supports water reuse. There are certain factors, such as public perception and water rights, that are time and event sensitive that can trump other more steady factors. As the model exists now, it is not currently incorporating the impacts of the destructive effects of "surprises." Even if one of these factors approaches an index value of zero, meaning it affects water reuse extremely negatively, it does not carry enough weight to result in a RPV indicating water reuse failure if other factors support water reuse. This was demonstrated in the operational validation of Toowoomba. This could be addressed by incorporating a scaling factor for the societal factor indicies. This factor would increases the weight of certain factors as they approach zero, allowing for surprise events to carry enough weight to make RPV drop to the point where water reuse fails.

7.5 Conclusions

This dissertation analyzed factors and priorities that affect water reuse and tested a methodology designed to help water reuse planners develop robust plans for future water reuse implementations that are robust to uncertainty. It was shown that the methodology shows promise of helping planners sort through the complexities of considering multiple factors and priorities when planning for water reuse. Improvements are needed to address the subjectivity inherent in the process and to help the model more accurately represent “surprises” when a single factor causes a water reuse plan to fail. With future work, this methodology may help many entities.

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Appendix

OVERVIEW OF SCENARIOS USED FOR THE EXPERT WORKSHOP

Scenario analysis is based on pondering alternative futures that may or may not be likely, focusing on sensitivity analysis rather than simulation or modeling. Scenario use is not intended to predict the future, but instead to be used as a tool to think about it. They are considered to be a realistic tool for considering a distant uncertain socio-economic future, its impact on specific sectors, and the translation of this thinking into action and policy. They also provide a tool to consider issues that do not necessarily have numerical data associated with them, which are abundant in water reuse.

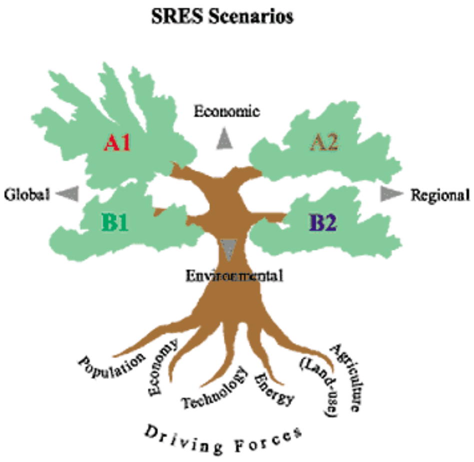
A.1 Water Reuse 2030 Scenarios

The scenarios used in the expert workshops follow the general IPCC storylines for the A1b, A2, B1, and B2 SRES with additional downscaled GDP and Population data from Columbia University (CIESIN 2002), water withdrawal information from Shen et al. (2008), and population growth trends from the U.S. Census Bureau (2008). The resulting scenarios are outlined below in Table 1.

A.2 Overview of the IPCC Scenarios and other Supporting Information

For this study, the IPCC SRES scenarios served as a foundation for the storylines used. An overview of these scenarios and additional studies that help to elaborate the water situation are discussed below.

A.2.1 IPCC SRES Scenarios



The Intergovernmental Panel on Climate Change (IPCC) created the IPCC Special Report on Emissions Scenarios (SRES), which are based upon four storylines (A1, B1, A2, B2) which became "families" of scenarios (IPCC 2000). Six different models were used to create 40 scenarios that can be roughly categorized into six scenario groups: A1C, A1G, A1B, A1T, A2, B1, and B2. Each storyline encompasses a distinctly different direction of future development. While focusing on climate change impacts and adaptations, they also cover aspects such as demographic, economic, and technological change. The major factors considered include population, GDP growth and per capita distribution, energy use, land use changes, resource availability, degree of technological change and innovation, cultural and social interaction, and favored energy sources. The four storylines can be described briefly as follows (IPCC, 2002; Arnell, 2004):

(A1) This storyline tells of a world with rapid economic growth, rapid globalization, low population growth (peaking in 2050 and declining thereafter), and rapid innovation of more efficient and new technologies. Generally, wealth increases with reduced differences in regional per capita incomes. Social values tend toward materialism and consumerism, with regional convergence, capacity building and increased social and cultural interactions. This storyline has variants that with different assumptions about energy sources. A1C focuses on "clean coal" technologies that are generally environmentally friendly with the exception of GHG emissions. A1G projects an "oil- and gas-rich" future, with a swift transition from conventional resources to abundant unconventional resources including sub-sea methane hydrates. The A1T is a "non-fossil" future, with rapid development of solar and nuclear technologies on the supply side and mini-turbines and fuel cells used in energy end-use applications. And the A1B “balanced” is a blend of all the A1 alternatives.

Table 1-Overview of the Water Reuse 2030 Scenarios

Factors	A1b	A2	B1	B2
Population Growth	(U.S. Population in 2000 was 281,400,000)			
Population Growth Rate	Low	High	Low	Medium
Global Population Projection for 2030	~7.9 Billion	~8.6 Billion	~7.9 Billion	~8.1 Billion
U.S. Population Projection for 2030	347,400,000	362,700,000	347,400,000	337,300,000
Northeast Regional Growth Rate	Low (5-10% Cumulative from 2000-2030)	Low (5-10% Cumulative from 2000-2030)	Low (5-10% Cumulative from 2000-2030)	Low (5-10% Cumulative from 2000-2030)
Midwest Regional Growth Rate	Low (5-10% Cumulative from 2000-2030)	Moderate (10-20% Cumulative from 2000-2030)	Low (5-10% Cumulative from 2000-2030)	Moderate (10-20% Cumulative from 2000-2030)
South Regional Growth Rate	High (30-40% Cumulative from 2000-2030)	Very High (>40% Cumulative from 2000-2030)	High (30-40% Cumulative from 2000-2030)	High (30-40% Cumulative from 2000-2030)
West Regional Growth Rate	High (30-40% Cumulative from 2000-2030)	Very High (>40% Cumulative from 2000-2030)	High (30-40% Cumulative from 2000-2030)	High (30-40% Cumulative from 2000-2030)
Economics (2000 GDP = $6.7 Trillion in 1990US$)	Rapid Growth, Rapid Globalization, Regional Convergence of GDP	Market Driven, Heterogeneous, growth varies regionally	Global Economic Solutions	Local and Regional Solutions with and Environmental Focus
GDP (1990US$)	14.8 Trillion	12.6 Trillion	14.0 Trillion	13.2 Trillion
GDP per capita (1990US$) (=$23,950 in 2000)	US1990$42,460	34,830	40,430	39,190
Land-use Changes	Low	Med-High to High	High	Medium
Technology	Rapid innovation	Innovation varies regionally	Sustainability Driven	Less Rapid and more Diverse Change
Technological Change Favors	Efficiency and development of new technologies	Focuses on what is needed to support regional growth	Clean and Efficient Development. Service and Information Sectors. Production of material quantities are reduced.	Changes are based on local and regional needs, leading to diversity. Environmentally conscious development
Pace of	Rapid	Slower-Varies from region to	Medium	Medium

Technological Change		region		
Factors	A1b	A2	B1	B2
Energy	Balanced	Regional	Clean and Green	Local and Regional
Sources	A mix of fossil, renewable, and unconventional sources.	Regional Sources	Clean Energy Sources	Whatever is easily available
Energy Use	Very High	High	Low	Medium
Resource Availability	Medium	Low	Low	Medium
Social	Materialistic & Consumerist, International	Heterogeneous	Environmental Sustainability and Cooperation	Local and Regional cooperation
Social Values	Regional convergence, capacity building, increased social and cultural interactions	Self-reliance, Local Identity preservation	Environment is very important, Cooperation, Global solutions sought for social issues	Social Equity and Environmental Protection
Institutional, Legal & Regulatory	Globally focused, Regional Convergence	Regional	Global Cooperation	Locally and Regionally Focused
Governance structure	Loose, globalized	Regional, Heterogeneous, Favors Regional Needs	Regulation and Cooperation occur on a global scale with the aim of finding global solutions	Economic, social and environmental issues are solved locally
Water Use in 2030	Steadily increasing use	Rapid Increase in all water sectors dominated by population growth	Peaks in 2025 and decreases thereafter, eventually approaching year 2000 usage levels.	Slow convergence of regions makes sustainability efforts take longer than the B1 scenario.
Total Water Use Intensity	Lower than A2 and steadily increasing. Growth rate of the water use trend slows after 2055. Use per capita is steadily increasing	Similar in Intensity to B2 Scenario and steadily increasing	Increase in use beginning to level off in 2030. Use will decrease thereafter.	Exceeds all other scenarios in 2030 but will eventually be surpassed by all scenarios except B1.
Industrial Use	Rapidly Increasing. Rapid technological change causes a steady increase in the amount of water needed.	Similar level to A1b in 2030. Will eventually exceed all other scenarios due to fragmented development and	Push for efficient and sustainable technology, water treatment improvements, water recycling technology	Exceeds all other scenarios in 2030 and will continue to increase due to fragmented technological development

		high pop.	and causes use to peak in the early 2020's.	among regions, even though there is an environmental focus within development. Will eventually be surpassed by A2.

Factors	A1b	A2	B1	B2
Agricultural	Higher than B2 scenario. Increases to a peak in the 2050's	Rapidly increasing. Exceeds all other scenarios due to high population..	Steadily increasing, following a trend similar to A1b.	Less than other scenarios, but still increasing. Will eventually surpass use in A1b and B1 scenarios after 2030.
Domestic	Increases steadily.	Rapidly increasing due to high population growth. Levels exceed all other scenarios	2030 Levels similar to A1b. After 2025, regional convergence social and economic issues cause a reduction in withdrawals.	Less than other scenarios in 2030 due to environmental focus.
W/C				
Water Stress in the U.S.	Widespread stress in west. Local and regional pockets in all regions, especially in areas with high population. As water efficiency and recycling and the associated technology is accepted worldwide, stress in some areas may be addressed.	Water stress will be prevalent across the U.S. as populations rise. Regional developments in technology and approaches to water management may help to decrease the level of stress felt in some areas.	As withdrawals decrease, the stress placed on watersheds will also decrease. Due to scarcity issues, there will still be water stress experienced, especially in the west and in highly populated or water scarce areas.	Water stress will be prevalent across the U.S. as populations rise. Regional developments in technology, social pressure for environmental sustainability, and approaches to water management may help to decrease the level of stress felt in some areas.

(A2) This paints the picture of a heterogeneous, market-driven world where self-reliance and local identity preservation dominate. This results in high population growth and fragmented, slower economic and technological growth. Economic growth occurs regionally, making income growth and technological change vary from region to region.

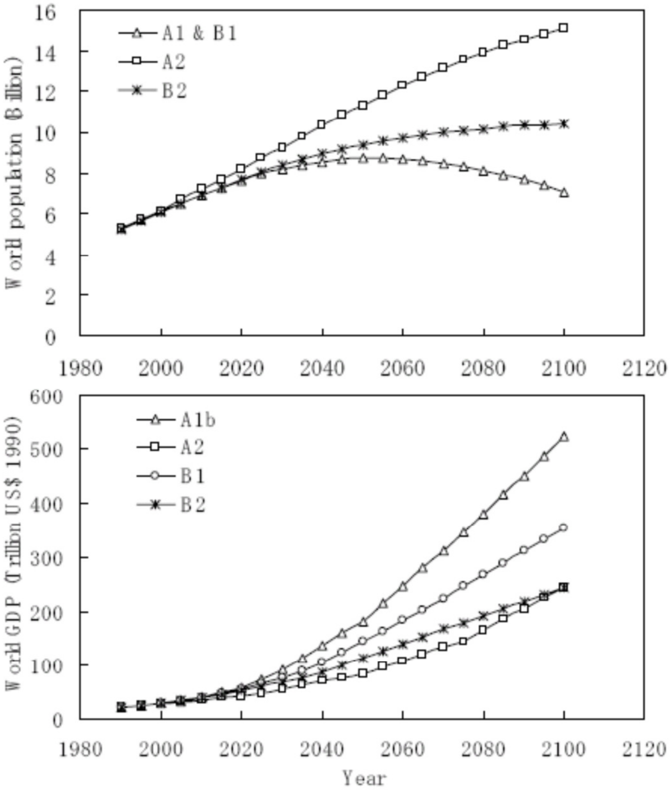


Figure 1 - Projected Population and GDP Under SRES Scenarios

(B1) The B1 storyline describes a sustainable, globally focused world with low population growth, clean energy, and heavy economic development in the service and information sectors, with a reduction in the material quantities produced. Development is much more focused on environmental sustainability, and regulation and cooperation occurs on a global scale, with the aim of global solutions for achieving economic, social and environmental issues. Technological growth focuses on clean and efficient developments.

(B2) The final storyline, B2, pictures more moderate conditions where there is a focus on social equity and environmental protection at the local and regional, rather global levels. Economic, social and environmental issues are solved locally. Population and economic growth is moderate, and technological change is less rapid and more diverse than the A1 and B1 storylines.

Note that the IPCC intentionally avoided "catastrophic" scenarios. Table 2 below summarizes each scenario group. The categorizations as given from the IPCC are for the projections for the year 2100. For the year 2030, many of these categories have not had adequate time to diverge, especially those that deal climate change effects.

Table 2 - Overview of Major SRES Scenario Groups

Family	A1				A2	B1	B2
Scenario Group	A1C	A1G	A1B	A1T	A2	B1	B2
Population Growth[1]	Low ~8 billion	Low ~8 billion	Low ~8 billion	Low ~8 billion	High ~9.3 billion	Low ~8 billion	Medium ~8.5 billion
GDP Growth[2]	Very High 95	Very High 95	Very High 95	Very High 95	Medium 50	High 75	Medium 65
GDP per capita[2]	11,000	11,000	11,000	11,000	5,000	10,000	7,500
Energy Use	Very High	Very High	Very High	High	High	Low	Medium
Land Use Changes	Low-Medium	Low-Medium	Low	Low	Med-High to High	High	Medium
Resource Availability	High	High	Medium	Medium	Low	Low	Medium
Technological Change Pace	Rapid	Rapid	Rapid	Rapid	Slow	Medium	Medium
Technological Change Favoring	Coal	Oil & Gas	Balanced	Non-Fossil Fuels	Regional Sources	Efficiency and Demateriali-zation	Dynamics as Usual

Population and GDP estimates for 2030. GDP estimates are in trillion 1990 US$ for the year 2030. Estimates for the A1 scenarios are an average of the variants. Adapted from IPCC (2000) and Arnell et al. (2004)

A.2.2 Downscaling

Numerous studies have been performed in order to make the globally related results of the IPCC studies relevant for their region. Typically, they involve "downscaling" of the IPCC data, which provides numbers that can be used for models and studies at a local, state, national, or regional scale. The Center for International Earth Science Information Network (CIESIN) at Columbia University in New York downscaled the IPCC data so that it can be used for national studies (CIESIN 2002). The population and GDP data for the United States from CIESIN will be used for the Water Resue 2030 scenarios. This data is summarized as follows:

	Year 2000 Value	**A1 (2030)**	**A2 (2030)**	**B1 (2030)**	**B2 (2030)**
Population	281,421,906	347,409,187	362,694,378	337,409,187	337,277,000
GDP (1990US$)	6.738 Trillion	14.752 Trillion	12.631 Trillion	14.045 Trillion	13.218 Trillion

A.2.3 Shen et al.: Water Resources under IPCC SRES Scenarios

Projections of total world future renewable freshwater resources are shown to increase due to global warming. However, socio-economic factors heavily influence water resource management, and they will still cause an increase in the number of people who live in water-stressed areas (Arnell 2004; Oki & Kanae 2006; Alcomo et al., 2007). Thus it is not sufficient to rely only on climate change projections. The amount of water that the world will withdraw also is affected by factors such as population growth, economic growth, water use practices, amount of irrigated farmland, environmental requirements, and technological change. The IPCC SRES did not specifically develop water resources data. However, a study by Shen et al. (2008) considered both socio-economic factors and climate change, and evaluated future water withdrawals using six climate simulating models and the SRES scenarios A1b, A2, B1, and B2. The results of this study will be used to provide water withdrawal information for the Water Reuse 2030 scenarios.

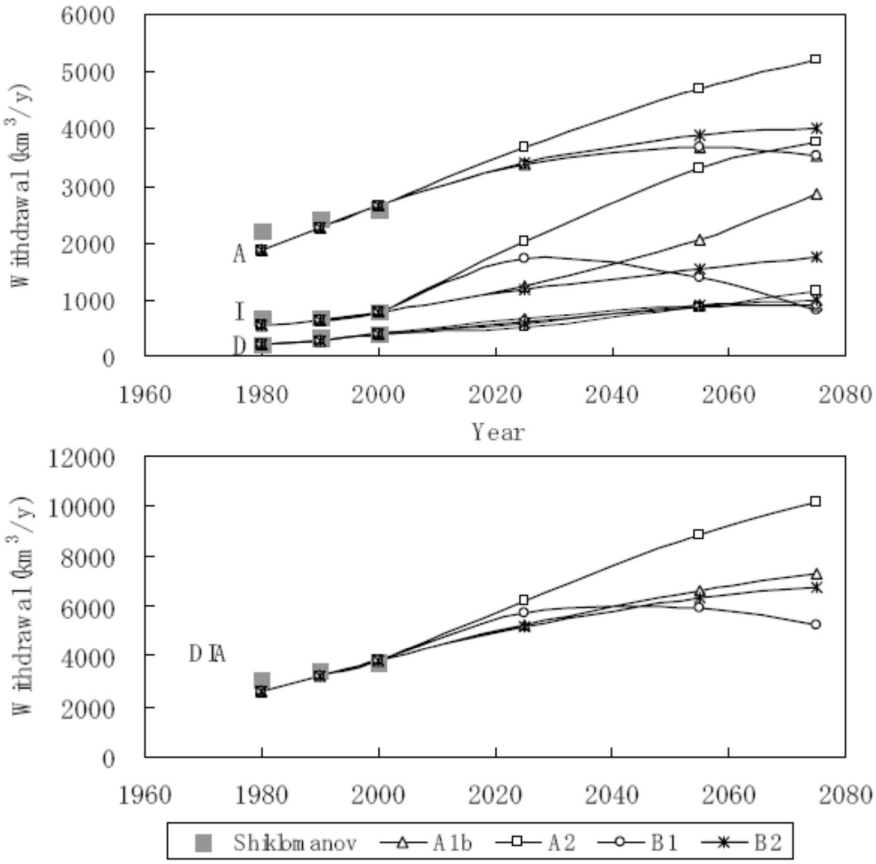


Figure 2 -- Water Withdrawal Predictions for the IPCC SRES Scenarios. D=Domestic, I=Industrial, A=Agricultural, & DIA=Total withdrawals

As of the year 2000, the world withdraws approximately 3800 km^3/yr of water, comprised of 70% agricultural, 20% industrial, and 10% domestic use (Shen et al., 2008). This amount is projected by Shen to exceed 6000 km^3/yr by 2055 for all four scenarios evaluated, with the amount that is used highly dependent on socio-economic issues. Each scenario produces varying degrees of increase in water withdrawal. The A2 scenario represents an extreme case where they are continuously increasing. The other scenarios also show increasing trends in water withdrawal, but the growth rate slows down after 2055 and even decreases in scenario B1. The results of the water withdrawal projections can be summarized as follows:

A1b: For this scenario, the industrial water withdrawal in 2075 will amount to four times the current demand; agricultural withdrawal will peak in 2055 and slightly decrease thereafter due to urbanization and a decrease in population, resulting in some irrigated farmland being turned back to natural land. Domestic water use will also increase to about two times the present use by 2075.

A2: For the A2 scenario, fast population increase dominates the change in water demand. All of the three sectors of water demand in 2075 will greatly increase. The industrial water demand will increase to five times that of the present, and the total withdrawal will exceed an astounding 10,000 km3/year (7200 Billion Gallons per day (BGD)).

B1: The growth in world agricultural and domestic water withdrawals is almost the same as for the A1b scenario. However, industrial water withdrawal is likely to increase rapidly in the coming two decades. Then, due to rapid globalization and technology transfer (including improvement of process water use and water recycling technology), industrial water withdrawal is likely to decrease quickly and reach 801 km3/year (580 BGD) in 2075, which is slightly higher than the present level. Societal actions involving global cooperation on social, environmental and economic issues in this scenario, such as convergence among regions in fertility patterns and social and economic development, lead to a reduction in water withdrawal after 2025.

B2: The growth of world water withdrawals for domestic and agricultural uses is likely to be higher than that for A1b, but lower than that for A2. However, the growth of industrial water withdrawal will likely be lower than that for A1b and A2, due to environmentally conscious development. However, slow convergence amongst regions leads to the slow improvement of wateruse efficiency, so that the industrial water withdrawal is likely to continuously increase.

The Shen et al. study provided calculations of water withdrawals for the world and for selected regions. The results for North America are listed in the table below. It is assumed that the U.S. withdrawals will follow the same general trends as listed for North America. Therefore, the growth trends were applied to the Water Reuse 2030 scenarios

Table 3 - Projected Water Withdrawals (BGD and % of total) and Population in North America for the SRES scenarios (Shen et al. 2008)

	A1b Scenario					**A2 Scenario**				
	Domestic	Industrial	Agricultural	Total	Population	Domestic	Industrial	Agricultural	Total	Population
2000	48.2 (13%)	180.8 (48%)	148.6 (39%)	377.6	308,300,000	48.2 (13%)	180.8 (48%)	148.6 (39%)	377.6	308,300,000
2025	52.9 (11%)	259.2 (53%)	179.6 (37%)	491.7	372,700,000	54.4 (11%)	262.8 (52%)	185.7 (37%)	502.8	384,400,000
2055	62.1 (10%)	324.9 (55%)	208.3 (35%)	595.3	432,300,000	67.9 (11%)	297.5 (50%)	228.6 (38%)	594.0	474,200,000
2075	66.7 (9%)	424.8 (60%)	222.2 (31%)	713.7	463,100,000	79.5 (11%)	361.0 (51%)	264.4 (38%)	704.9	553,900,000

	B1 Scenario					**B2 Scenario**				
	Domestic	Industrial	Agricultural	Total	Population	Domestic	Industrial	Agricultural	Total	Population
2000	48.2 (13%)	180.8 (48%)	148.6 (39%)	377.6	308,300,000	48.2 (13%)	180.8 (48%)	148.6 (39%)	377.6	308,300,000
2025	52.9 (11%)	265.0 (53%)	179.6 (36%)	497.5	372,700,000	52.4 (10%)	279.0 (55%)	178.2 (35%)	509.5	369,900,000
2055	61.9 (15%)	156.7 (37%)	208.3 (49%)	427.0	432,300,000	55.3 (10%)	324.2 (57%)	187.3 (33%)	566.8	387,100,000
2075	66.5 (17%)	111.0 (28%)	222.2 (56%)	400.0	463,100,000	56.3 (10%)	326.2 (57%)	190.3 (33%)	572.8	393,400,000

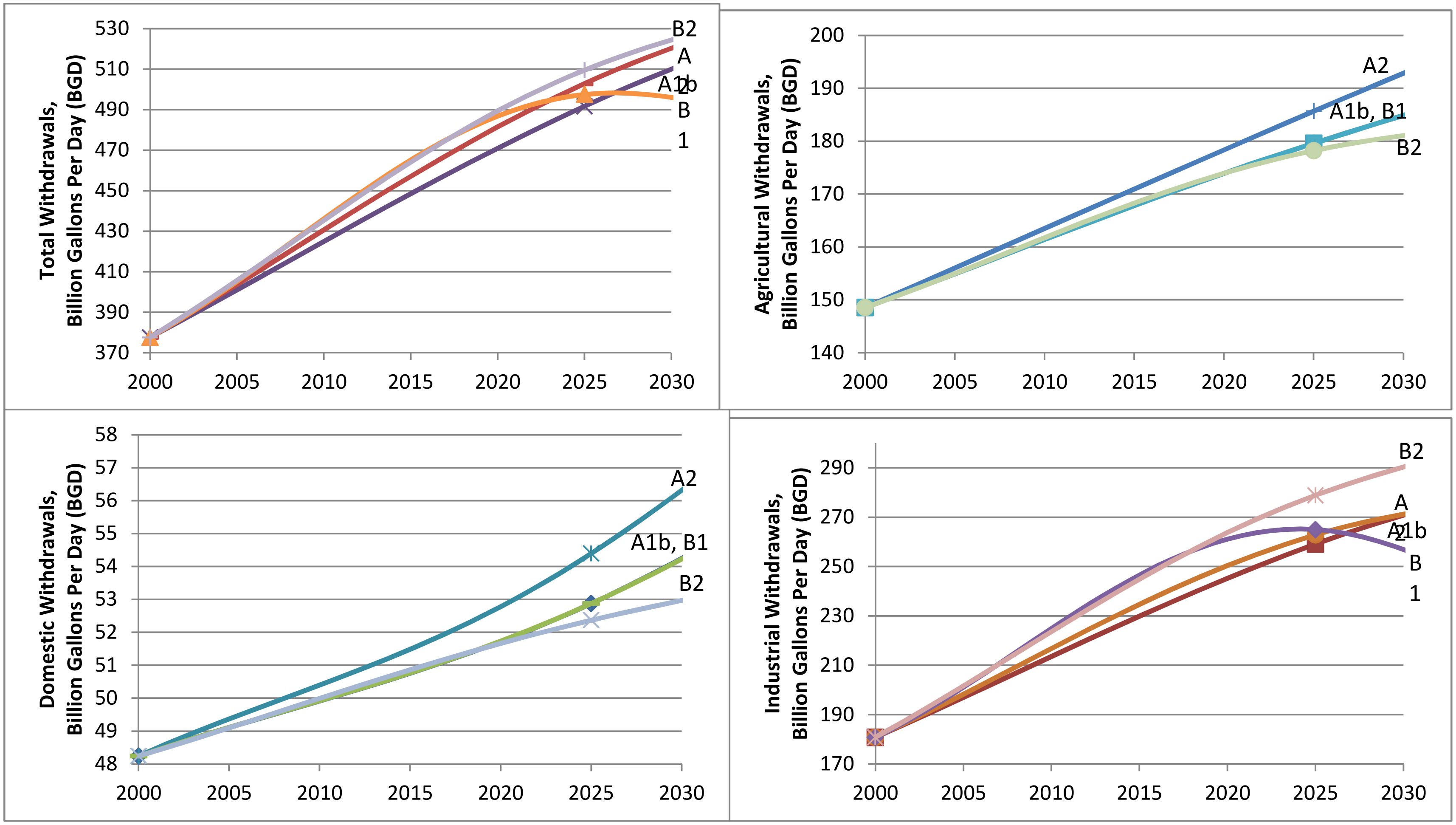


Figure 3 - Projections of Water Withdrawals in North America, 2000-2030 from Shen et al., 2008

This study also used two indicators to help represent socioeconomic and water management policy needs. The first indicator is the water withdrawal intensity, which is measured as the amount of water withdrawal per capita (W/c). This measure reflects the overall pressure that humans are placing on freshwater resources. By comparing the values of W/c in different regions or across different time spans, the need for adjustments to water management policies may be found. The second indicator is water productive efficiency (WPE). This is defined as the amount of GDP per unit of withdrawn water, which can be used to represent overall socioeconomic effects on how water is used (either efficiently, or inefficiently).

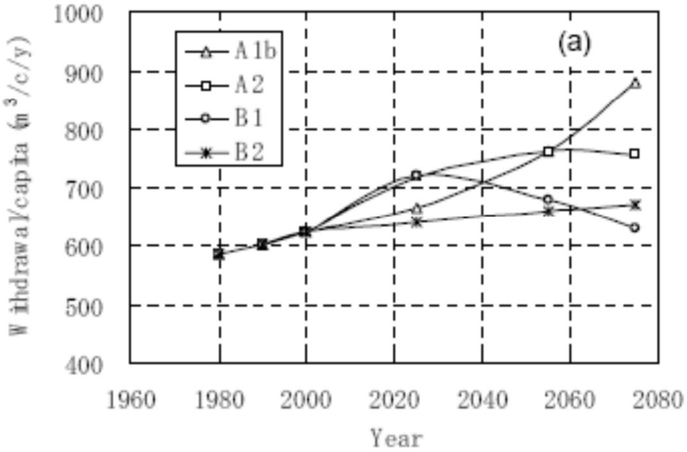


Figure 4 - The changes of global averaged water withdrawal intensity (withdrawal per capita) for the IPCC SRES scenarios (Shen et al., 2008)

Globally in the year 2000, the United Nations Environmental Programme reported that the average water withdrawal intensity was 633 m^3 per capita, per year. The A1b scenario shows a continuously increasing trend that climbs rapidly with the projected economic growth to approximately 880 m^3/(capita year) by the year 2075. The W/c for the A2 scenario climbs rapidly until 2025 and then slows due to rapid population growth, reaching around 755 m^3/(capita year) by 2075. The W/c value for the B1 scenario follows a trend similar to its water withdrawal projections, which increases rapidly until 2025 and then steadily decreases thereafter. The ending value of 630 m^3/(capita year) in 2075 matches the year W/c in 2000. The increase in water use per capita increases much more slowly for scenario B2, ending at 672 m^3/(capita year) in 2075.

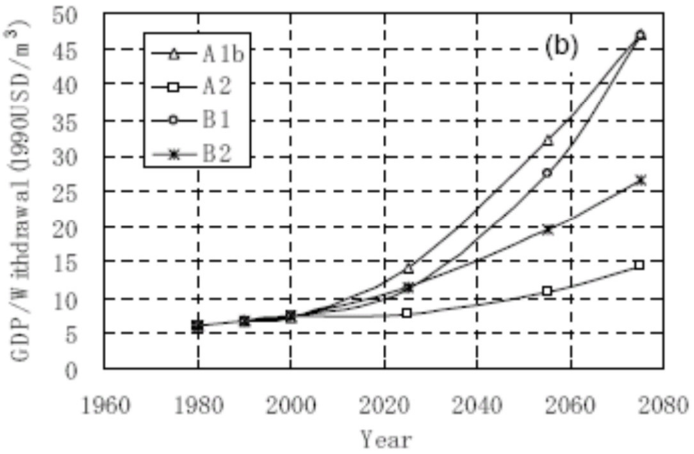


Figure 5 - The changes of global water producing efficiency (GDP per unit water) for the IPCC SRES scenarios (Shen et al. 2008)

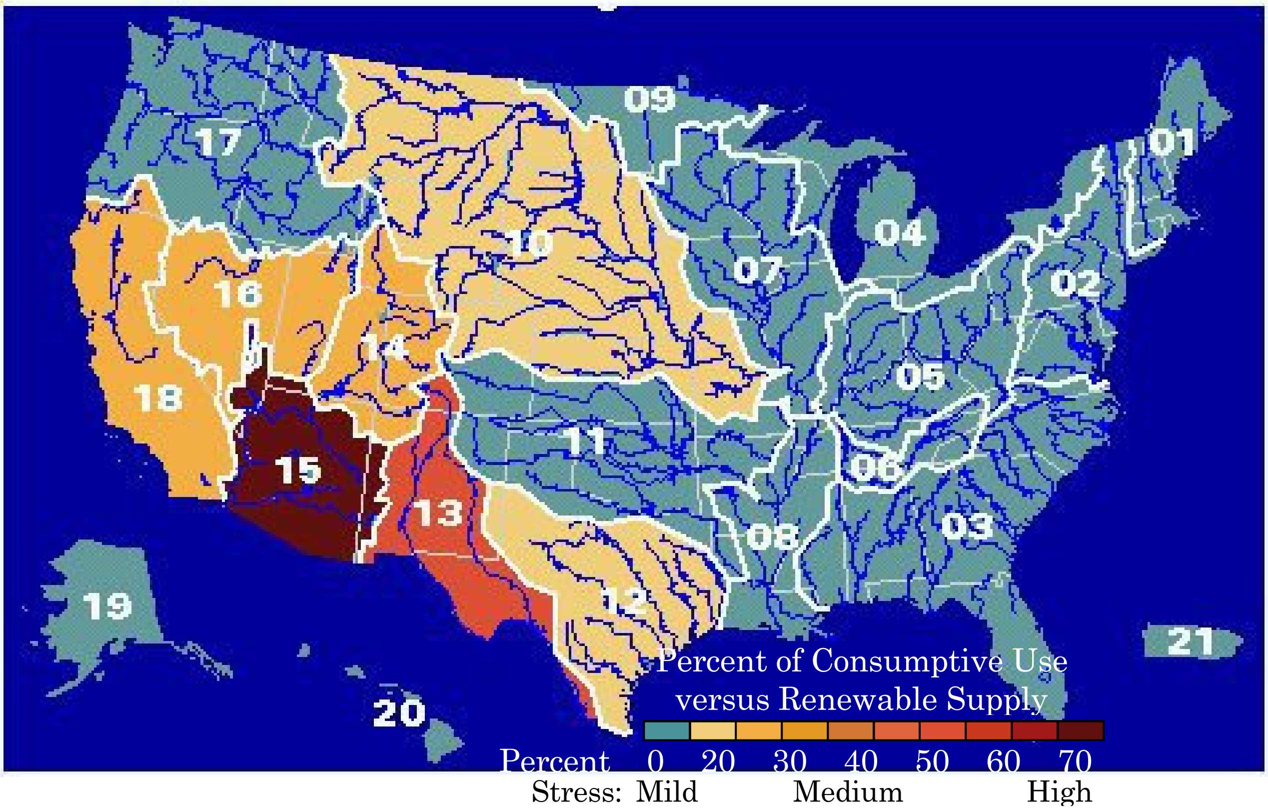
Looking at the water productive efficiency, in the year 2000, a cubic meter of water was likely to bring about US$7.3. By 2075, the A1b and B1 scenarios predict that the economic benefits from water withdrawals will increase to US$47 per cubic meter of water. Scenario A2 projects the lowest growth in the value of WPE, increasing to US$15 by 2075. The WPE for the B2 scenario outpaces A2, reaching US-$26 in 2075.

These results suggest that the effects of population and socioeconomic factors do impact the economic effects derived from water in these scenarios. Both the A1b and the B1 scenarios show a rapid increase in WPE and share high economic growth rates. However, the water use per capita varies dramatically between these two scenarios. This shows that economic development is possible while using less water per capita, and possibly even managing water resources sustainably.

A.2.4 Water Stress

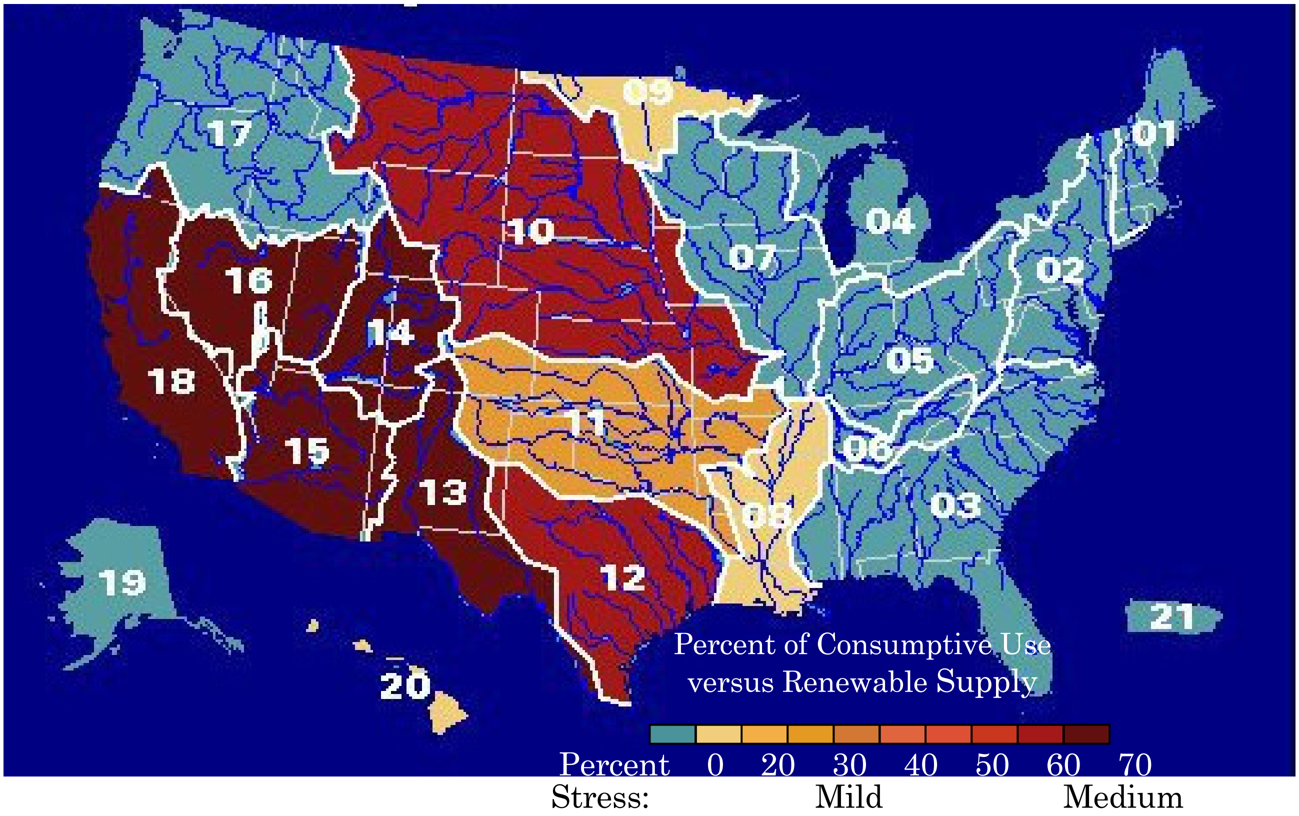
Water stress can be measured using the relation in percent between the amount of water withdrawn and the total renewable water resources available. Typically, a value above 20% indicates water stress, which becomes more critical as the percentage increases. When the value exceeds 100%, more water is being withdrawn than can be sustainably replenished. In 1995, most of the western major water basins in the United faced some degree of water stress. (See Figure 6 below.)

If you make the simple assumption that the proportion of the total U.S. withdrawals in a region will continue at the same level through the year 2030, then it is possible to project water stress levels in the year 2030. By using the withdrawal values from the Shen et al. study and assuming the proportion of total withdrawals remains the same In each region from Figure 6, new percentages of total consumption can be calculated. The number of water stressed regions increases, and previously stressed areas see the degree of water stress intensify. The total percentage of withdrawals compared to the total renewable supply for the entire U.S. approaches 20 percent, making the country, as a whole, water stressed. The values calculated for each scenario result in the same degree of water stress, thus Figure 7 is valid for all four IPCC scenarios that have been discussed.



Water Resource Region Number	Water Resource Region Name	Use as % of Total renewable supply (%)	Water Resource Region Number	Water Resource Region Name	Use as % of Total renewable supply (%)
1	New England	0.8	12	Texas-Gulf	27.5
2	Mid Atlantic	1.6	13	Rio Grande	70.4
3	South Atlantic-Gulf	2.6	14	Upper Colorado	30.2
4	Great Lakes	2.6	15	Lower Colorado	102.9
5	Ohio	1.6	16	Great Basin	35.0
6	Tennessee	0.7	17	Pacific-Northwest	4.1
7	Upper Mississippi	3.0	18	California	33.9
8	Lower Mississippi	8.7	19	Alaska	0.0
9	Souris-Red-Rainy	7.7	20	Hawaii	6.8
10	Missouri	27.8	21	Caribbean	3.9
11	Arkansas-White-Red	14.0			
				TOTAL U.S. USE	5.5

Figure 6 - Comparison of Renewable Water Availability and Consumptive Use in the United States and Relative Water Stress Levels in 1995. (USGS, 1984)



Water Resource Region Number	Water Resource Region Name	Use as % of Total renewable supply (%)	Water Resource Region Number	Water Resource Region Name	Use as % of Total renewable supply (%)
1	New England	2.5-2.6	12	Texas-Gulf	90.5-94.0
2	Mid Atlantic	5.3-5.5	13	Rio Grande	231.7-240.5
3	South Atlantic-Gulf	8.6-8.9	14	Upper Colorado	99.5-103.3
4	Great Lakes	8.4-8.7	15	Lower Colorado	338.9-351.8
5	Ohio	5.4-5.6	16	Great Basin	115.2-119.6
6	Tennessee	2.4-2.5	17	Pacific-Northwest	13.4-13.9
7	Upper Mississippi	9.8-10.2	18	California	111.7-115.9
8	Lower Mississippi	28.5-29.6	19	Alaska	0.010-0.011
9	Souris-Red-Rainy	25.3-26.3	20	Hawaii	18.2-18.9
10	Missouri	91.6-95.1	21	Caribbean	12.9-13.4
11	Arkansas-White-Red	46.0-47.8			
				TOTAL U.S. USE	~18.9

Figure 7 - Comparison of Renewable Water Availability and Consumptive Use ,and Relative Water Stress Levels in the U.S. in 2030 for IPCC Scenarios A1b, A2, B1, and B2. (Calculated from USGS 1984 and Shen et al., 2008)

In reality, the values above that are well above 100% are not very likely. It is hoped that measures to use water more responsibly would occur before that level of over-extraction occurred. However, this simple calculation does provide an interesting picture of how the number of water stressed areas is likely to increase by 2030.

Government officials tend to agree that water shortages are in the future of the United States. For example, a study conducted by the United States General Accounting Office in 2003 (GAO, 2003) found that given normal climate conditions, most state water managers expect either regional or local water shortages by the year 2013.

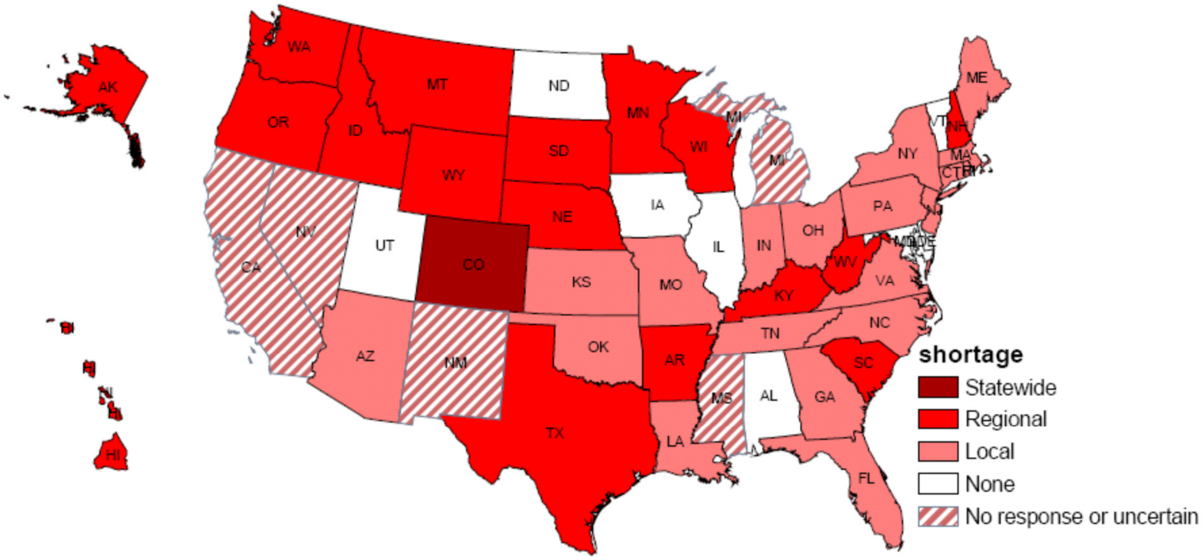


Figure 8 – United States General Accounting Office Survey of State Water Managers' Expectations of Water Shortages by 2013 under "Average" Conditions (GAO 2003)

The World Water Council conducted a scenario study called the World Water Vision Project which created scenarios related to water in the future. Figure 6 below shows the water stress projected for the year 2025 under a “status-quo” scenario. It shows various levels of water stress are possible in the United States, especially in the west and south-west.

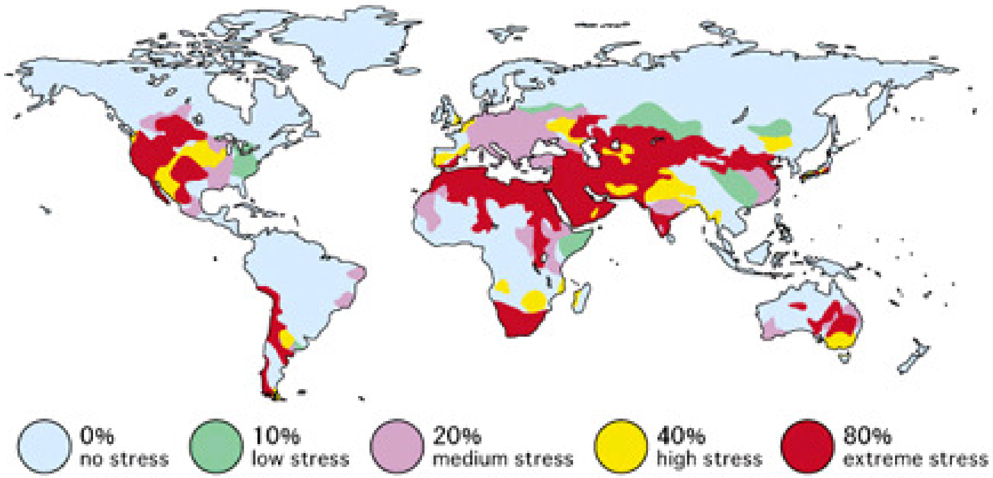


Figure 9 - Water Stress in 2025 under a "Status-Quo" Scenario in the World Water Vision Project (Cosgrove & Rijsberman,2000)