Project Number JIB-0502

WATER REUSE

An Interactive Qualifying Project Report
submitted to the Faculty
of the
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
By

Nathanael Beatty

David Cozzens

Lacey Larson

Professor John Bergendahl, Advisor

Professor Susan Vernon-Gerstenfeld, Co-advisor

Abstract

In this project we investigated water reuse at universities to determine the feasibility of implementation of water reuse at Worcester Polytechnic Institute. We conducted interviews and researched the history of water reuse at various universities in the United States. These universities have factors that make water reuse necessary and beneficial. For universities that have an urgent need to use less water, water reuse is very favorable, but Worcester Polytechnic Institute does not need to implement water reuse now.

Table of Contents

Authorship

David Cozzens, Lacey Larson and Nathanael Beatty all contributed equally to this project. Everyone reviewed all the sections but generally in the background Lacey wrote the “Why Water Reuse is Important” and the “History of Water Reuse” sections, Nathanael wrote the “Reclaimed Water Uses” section and David wrote the “Treatment” and “Constituents in Wastewater” sections. In the Data section David researched and wrote the Stanford University case study and the Washington State University case study, Lacey researched are wrote the University of San Diego case study, and Nate researched and wrote the University of Idaho case study.

Introduction

Water is necessary to sustain life. Access to clean and abundant water is a desired goal of most populations. Unfortunately however, many countries do not have sufficient clean water supplies. In the world 1.1 billion people lack access to a potable water supply and as a result many people die (Statistics on Water, 2005). In Afghanistan only thirteen percent of the population has reliable access to a potable water supply (Millennium Development, 2005). Similarly in Ethiopia only 22 percent, in Chad 34 percent, in Somalia 29 percent, and in Cambodia 34 percent of the population has access to an acceptable potable water supply. This situation extends to many countries around the world.

Geographical and climatic issues prevent some countries from having an ample water supply. For example, Somalia has erratic rainfall patterns which produces both flooding and drought. An estimated sixty-five percent of the population does not have reliable access to safe water on a regular basis (Unicef Somalia, 2005). Water-borne diseases such as cholera and dysentery are taking lives in this country and others. This is a situation where there is a severe imbalance between available clean water and population; however this water crisis for reasons of demographic and climatic restrictions is spreading.

According to the U.S. Census Bureau's projections, the population of the United States will be 400 million people by the year 2050 (Fast Facts). That means in just forty-five years, the population will increase by thirty-three percent. Thus the world will become much more populated and there will eventually be a strain on the water supply even in places that currently do not have water issues

In the United States lack of water is an issue in some areas, and water reuse can help alleviate shortages. Water reuse is the use of treated wastewater for appropriate applications. According to EPA standards in the "National Interim Primary Drinking Water Regulations", using polluted sources of water such as wastewater should be turned to only when pure sources are economically unavailable (U.S. EPA, 1975). Furthermore, the strains on the water supply in other parts of the country have led to municipalities turning to alternative sources of water (Issues in Potable Reuse, 1998). For example, in the summer of 2001 approximately fifty-five cities in Massachusetts experienced water bans, due to dry conditions (Why do we have water bans?, 2001). Although the ban in Massachusetts was on outdoor use, such as filling pools and lawn watering. With this increased population and water being contaminated at a faster rate, water for necessities will be stressed. Clearly America will soon need to face up to the rapidly spreading challenge of generating more clean, safe water.

In some instances, reclaimed water (see glossary) has been used for toilet water, irrigation, and drinking water. In 2002, the construction of Gillette Stadium in Foxboro, MA was proposed. The town already had a strain on its water supply. On days when there is a football game the population can increase to up to four times the city's population. Therefore the stadium engineers built a water reuse system in Gillette Stadium when the stadium was constructed (Town of Foxborough, 2005). At Gillette Stadium reclaimed water is used for toilet flushing. As a result, Gillette Stadium expects fifty percent savings in water use (Massachusetts Water Policy, 2004). Windhoek, Namibia has a very advanced water treatment system, and employs direct potable reuse.

In Massachusetts, water reuse is limited to toilet flushing, golf course irrigation, groundwater recharge, fire protection, and as cooling water in some industries.

This project aims to investigate the benefits of water reuse to society. This project addressed water reuse and how universities can expand the use of reclaimed water. Specifically it investigated universities across the United States, then analyzed different ways that water reuse can or has benefited these institutions. A small number of universities have water reuse systems present on their campuses. This project analyzed the history of these institutions and the factors leading to the implementation of water reuse systems to see how colleges like WPI can benefit from a water reuse system. Some of the data was obtained through interviews and case studies. This investigation should educate people concerning the economic and long-term environmental benefits of water reuse.

Background Chapter

This chapter discusses why water is important, the history of water reuse, uses for reclaimed water, and treatment of wastewater. The section concerning the importance of water will cover general and specific examples of water crises. The history of water reuse will be chronologically discussed. The section covering uses for reclaimed water will illustrate how water can be reused and the benefits associated with reuse. Lastly, the treatment of wastewater and also how specific constituents in the water are removed will be reviewed.

Why Water Reuse is Important

Water is very important to our survival. We can not live without it. Our bodies are mostly composed of water. We use it in our lives all the time. We need it for cooking, cleaning, bathing and of course drinking. It is estimated that an individual needs fifty liters of water per day for cooking, hygiene and drinking, but in many countries this is not realistic (Swanenburg, 1998). In poor or developing countries people do not have enough water to bath. They must make due with the water they can get and this poor hygiene can lead to disease.

Though the world is covered by vast oceans, most of the water is not useful without costly treatment because it is salt water. Salt water can not be used for drinking and many other important purposes without costly desalination. We must use fresh water for drinking, bathing, and washing clothes or dishes. Only a very small percentage of the earth’s freshwater is usable, because much of our freshwater is locked in the polar ice caps, swamps, and permafrost (Bryant & McLean, 2005).

Not only is the earths fresh water limited, but the available water is often polluted with illness causing contaminates. Over one-hundred million people in the world do not have access to safe drinking water (Swanenburg, 1998). One example of a disease caused by poor water conditions is cholera. This is a disease that is caused by bacteria that release toxins that cause diarrhea and can lead to dehydration and death (Encyclopedia Britannica Online, 2006). In 1991 an epidemic of cholera killed thousands of people in Latin America (Population Action International, 1993). Without any proper water treatment many people can become ill and die.

Besides countries that do not currently have enough water, almost all countries go through periods of drought when they do not have enough water to support their population. Australia is the world's driest continent (Maynard, 2005). It often experiences devastating droughts. Sometimes areas in need can import water from other areas, but this is not always a possibility when the need is too great. The area around the agricultural city of Goulburn, Australia, known for its grazing land, is too large to be able to bring in enough water. This area has been experiencing a drought for four years. Though Australia is used to droughts this is starting to devastate the area (Maynard, 2005).

During droughts water is often rationed so that everyone gets an even amount, but this causes problems for those, like farms, that need far more water to support their business or farm. Though Australia is used to droughts areas like the Goulburn area is starting to become devastated and water has had to be rationed to only forty gallons per day per resident. The president of the New South Wales Farmers Association, Mal Peters, believes that it is up to the government to help them. He says that if the government does not help the farmers, the farming communities will be wiped out (Maynard, 2005).

Australia is not the only place experiencing drought. Many places across the world experience drought, including areas that are not as used to drought as Australia. In 2005 France was experiencing its worst drought in thirty years (Lichfield, 2005). Due to the severe lack of rain last winter and unusually high temperatures in the summer the once thriving rolling hills have been transformed into a dry, burnt wasteland. Many areas rationed water and prohibited certain uses of water. Some areas banned public use of water for irrigation. The farmers use the water mostly for irrigating their cereal and maize crops that are for feeding their livestock. Without the water their livestock would have to be sold or put down.

A newspaper journalist for the Independent, Johann Hari says that conditions like the drought in France may be due to global warming (Hari, 2005). If this is true, these conditions will only get worse over time. He describes several reasons that global warming will cause devastation to our water supply. One is that rain will fall in different places than normal. Global warming will cause a magnitude change of rain and snow fall that can lead to both floods and droughts (United Nations Commission, 1999). This causes problems because population is so dense in some areas that they depend on getting the exact right amount of water. Any less will cause water crises, like the situation in France. France is not experiencing a drought that would be terrible in some areas of Africa or Australia, but they usually get more water than the current rain fall and it is causing serious problems. Another reason global warming could cause water related disaster is because of the glacier melting. Places like China and India depend on glacier melting to supply their major rivers. If the glaciers dry up, then these areas and others that depend on them will lose their water resource (Hari, 2005). Global warming will cause a reduced glacier melt run off into these rivers. This could causes a change in the rivers seasonality (United Nations Commission, 1999). The other part of glacier melting is that it raises the sea level. According to a press release made by the United Nations in 2002 the sea levels are rising and this is due to global warming (United Nations Department of Public Information, 2002). As sea levels rise there will be salt water intrusion all around the world. This will cause contamination of the little remaining freshwater (Hari, 2005).

Another rising problem is populating an area too quickly and causing over use of the water supply. In Massachusetts we use ground water recharging in areas like the Charles River Basin because the communities have grown too quickly (Mass. DEP). An example of water source over drawing is the Dead Sea between Israel and Jordan. The Dead Sea has shrunk by a third in less than one-hundred years (Machintyre, 2005). This dramatic drop is due to the great strain of water use on the Jordan River. In addition to the strain on the river, a fertilizer company uses the nutrient rich water of the Dead Sea in its industry, to produce fertilizer. This accounts for up to thirty percent of the Dead Seas water loss.

Because the Jordan River is shared by the Israelites and the Palestinians the water situation has caused more problems than just thirst (Swanenburg, 1998). The two countries have never gotten along so this competition for water has only added to the already existing conflict between the two countries. Israel uses a lot of the water for irrigation and to release some stress on their water, they have already started to reuse treated sewage for irrigation.

History of Water Reuse

Treated wastewater was first reused in the early twentieth century. An early example of water reuse was in 1912, at the Golden Gate Park in San Francisco. There reclaimed water was used for irrigation. Later, in 1926 it was used in Arizona at the Grand Canyon National park, not only for irrigation but also toilets, cooling and boiler recharge. In 1962, in Los Angeles County, California the first major project to recharge the ground water to create a fresh water barrier against intrusion of saltwater was undertaken (Metcalf & Eddy, 1991). Sixteen percent of the water recharging their groundwater is recycled water. There is up to twenty-three percent recycled water in potable wells (Anderson, 2002). A twenty year study was done and there was no record of any measurable ill side effects from the groundwater recharge with wastewater (Metcalf & Eddy, 1991). In 1967, Burbank Water and Power was the first to use reclaimed water in place of potable water in its cooling towers (Burbank, 2005). In 1968 Windhoek, Namibia was the first to make a reclamation plant which produces water of a potable quality. About four percent of their total water supply is recycled water and during drought it can be as high as thirty-one percent (Anderson, 2003).

Currently there are over three-thousand water reuse sites in the world, eight-hundred of which are in the US. The US reuses 6.5 million m^3/d. Most of the US's sites are large scale projects, meaning that they are for agriculture and landscaping. Japan has some 1,800 sites but their sites are mostly small scale projects, meaning that the uses are urban, recreational and environmental (Bixio, 2005). There are many projects around the world utilizing reclaimed water in different ways. St. Petersburg, Florida in 1977 started a reuse scheme that supplies ten thousand properties, of which 9,300 are residential, with reused water. This water is used for landscaping, industrial uses, air conditioner cooling and fire protection (Anderson, 2003).

D. Bixio suggests that the amount of water being reused is related to public acceptance. A survey in Bixio conducted in Europe suggests that people there think reclaimed water is still wastewater. In Europe there are instances where wastewater is being put back into the surface or ground water without being treated at all. This is a case of accidental reuse. In these cases the secondary-treated wastewater is sometimes cleaner than the normal water supply (Bixio, 2005). One scenario when recycled water was used directly for drinking water was in Chanute, Kansas. In 1956 the nearby river in Chanute stopped flowing due to a drought. From 1952-1957 Chanute residents received treated wastewater from industrial and residential sources. Due to the water's strange color and smell it was not well accepted. People bought bottled water and drilled new wells. A survey done later suggests that only sixty-one percent of people in Chanute ever really accepted the water (U.S. Congress,1977).

A survey done in the US which included 303 people from the southeast tested the public perception of water reuse for certain applications. The results were that firefighting, golf course, lawn and agricultural irrigation were seen as more acceptable uses of reclaimed water than personal uses like laundry, reservoir, and groundwater recharge (Robinson, 2005). V. Lazarova suggests that the answer to dissatisfaction of reused water as a potable source may be to use reclaimed water for non-potable uses only, i.e. toilet flushing. Domestically toilet flushing is 29 to 47 percent of total water reuse (Lazarova, 2003). Toilet flushing commercially is generally higher, around 40 to 60 percent. If toilet flushing was entirely recycled water from other things like shower and sinks then there would be a dramatic decrease in water consumption (Lazarova, 2003).

Legislation and Policies

In Massachusetts a set of water reuse guidelines was developed by the Department of Environmental Protection in 2000 (Executive Office of Environmental Affairs, 2000). Their plan was to allow those that they thought would need or request to use water reclamation to use it. They have made regulations for urban uses such as golf course irrigation and landscape irrigation. These include regulations to minimize human exposure, such as employing reused water to irrigate in non-operation hours. When wastewater is discharged, it is intended to improve the surrounding environment. For example, it replenishes stream flow and refills aquifers. Reuse of water for toilet flushing should only be used where the public does not have access to plumbing such as in commercial buildings. For each water reuse project a permit must be submitted so that the uses can be judged in a case by case approach by the governing authorities. There are also some monitoring requirements to make sure that water quality is at appropriate levels (Executive Office of Environmental Affairs, 2000).

When water reuse is implemented it will be favorably accepted because of the recommendations put forth in the Massachusetts Water Policy Report. This document sanctions water reuse or recharge in all current water reuse situations. The document encourages expanding water reuse in the ways it is already implemented, plus in large scale developments such as industries and hotels. The Massachusetts government's intended methodology is to research water reuse in other states and identify suitable sites for recharge (Massachusetts Water Policy, 2004).

Reclaimed Water Uses

The first step in using water reuse is finding situations where reclaimed water can be used. Reclaimed water can be used for all applications in which water is used, but different applications require different unique levels of treatment. Irrigation uses thirty to forty percent of the total water used in the United States each year (Bryant & McLean, 2005). Any amount of water that is reused for irrigation would have environmental and social impacts on the local water supply in the area in which it is implemented. Industries use large amounts of water whether it is in their processes or in their final product. In 1995 industries used water on the magnitude of 27,000 million gallons every day (Bryant & McLean, 2005). Groundwater recharge is another use for reclaimed water. The environment can benefit from water reuse. When water is reused it results in less water being taken from aquifers, and water tables being more stable. Streams and marshes and most bodies of water can be augmented by the addition of treated waste water. In urban environments water is being consumed at an increasing rate. This need can be satiated in two ways. Nonpotable water can be employed for a variety of uses from fire protection to toilet flushing. Wastewater that has been treated to a degree that it can be labeled potable water can be introduced into the drinking water supply. This is done by blending in a reservoir or by a pipe to pipe exchange. This can all seem very complicated but once explained in greater detail it will become clearer.

Irrigation represents a growing potential use for reclaimed wastewater. Irrigation uses a large quantity of fresh water, especially in the western United States. In 1980 and 1985, the nine western water resource regions drew ninety-one percent of water used for irrigation (Metcalf & Eddy, 1991). In the eastern United States irrigation is used during times of drought and in addition to rainfall, but in the west most crops could not be grown without the use of irrigation. Reclaimed water could very much be used for irrigation. It is currently being used to irrigate many golf courses in urban areas. The water used to irrigate golf courses may not need to be the same quality as water designated for food crops (Brevard County, 2005). Many people may not like the idea of reclaimed wastewater being used on their produce. This is not an issue as long as the reclaimed water quality is kept to the guidelines supplied in the State of California: "Wastewater Reclamation Criteria". This documentation sets up a description for each irrigational use of waste water, and the degree of treatment which it must go through. For example fodder and seed crops have no standard (Metcalf & Eddy, 1991). Playgrounds and parks require water to have had secondary treatment including coagulation, filtration, and disinfection. More information explaining the types of water treatment can be found in the Treatment section.

Industries use very large amounts of water. The amount of water used is based on the processes and the products associated with the particular industry. One water intensive use is in cooling towers (JEA, 2004). In many industries one quarter to over one half of the water consumption is used as cooling tower make up water (see glossary). Cooling towers often are set up so that the water in them does not mix with anything else, so the quality of the water has different requirements then other uses (Vazquez, 2005).

The main requirement is that whatever pollution may be present in the cooling tower water must not inhibit its evaporation or produces hazardous vapors when evaporated. There are several requirements that can be avoided for the purpose of upkeep of the system.

A phenomenon known as scaling is caused when calcium compounds, magnesium compounds, and sometime silica deposits form in hard scales within the cooling tower apparatus and interfere with heat transfer. Scaling happens more when reclaimed wastewater is used because it can have a higher concentration of these compounds. Fortunately, sulfuric acid can remove these deposits and as long as pH is kept in check this does not cause any problems. Metallic corrosion within a cooling tower is a problem in cooling towers independent of water quality. The damage of corrosion can be much more severe when reclaimed waste water is used because it contains higher amounts of the contaminants that allow corrosion. Chemical corrosion inhibitors are used to reduce corrosion. Cooling towers are warm damp places and are susceptible to growth of biological matter. Wastewater can contain many nutrients that are beneficial to this kind of growth. Biocides like activated bromine can stop this problem by killing the growth (Electric Power Research Institute, 2004). Fouling is when scales, biologic material and corrosion compounds bond together and inhibit heat exchange. Fouling can be worse when reclaimed waste water is used, but can be avoided through the techniques mentioned above and by the National Academy of Science (Metcalf & Eddy, 1991). Reclaimed wastewater can make many problems in cooling towers worse, but the problems are manageable and can be prevented by more initial treatment of the water before it is introduced to the cooling tower. So much water is used by cooling towers that using reclaimed wastewater is still necessary despite the problems addressed above.

There are many reasons to recharge ground water. Recharging aquifers can raise water tables, prevent salt water intrusion in coastal areas, and help save water for later use. When water is saved underground instead of in surface reservoirs it is less likely to become polluted, evaporate, or become host to algae or other aquatic growth. Economically this can also be helpful. Above ground reservoirs do not have to be built, nor does the distribution network that would be associated with an above ground reservoir. It is very necessary for water levels to be maintained, a sudden drop in the water table under a forest can result in the death of the entire forest. When the water levels in the ground containing a well drop to below the level of the well, then it will no longer serve as a source of water. Coastal water barriers are very important, without one, salt water from the ocean will enter into the ground water of coastal areas, causing the death of much of the environment in the area, and any wells nearby will yield brine. There are two processes for recharging ground water: Direct Injection, and Surface Spreading. The first involves the forcible injection of water into an aquifer. The latter is simpler and requires the water to be distributed in recharge zones (Metcalf & Eddy, 1991; Asano, 1999). Surface spreading is the desired technique for recharging aquifers, because it requires little maintenance and the water does not have to be treated to as high a degree as water for direct injection. Direct Injection means water is put directly into the aquifer. This means that the water put in is the same quality as the water later removed from a well. With Surface Spreading the reclaimed wastewater percolates through ten to fifty feet of undisturbed soil, so the land actually filters it (Asano, 1999). This is why water for Direct Injection must be treated to such a high degree as to require reverse osmosis, or another membrane technique, and carbon adsorption, while Surface Spreading does not.

Currently, reclaimed wastewater is not being used as a direct potable resource in the United States. This means that no wastewater treatment plant is sending its effluent (see glossary) directly into anyone's tap water. Indirect potable water reuse is being used however. Water is being deposited into aquifers through ground water recharge, then several months to a year later, after it has mingled with the native ground water, it is removed through wells for drinking. Another type of indirect potable water reuse is occurring in the Occoquan Reservoir (Metcalf & Eddy, 1991). The advanced wastewater treatment plant in Manassas, VA deposits its effluent into the Occoquan Reservoir which contains the drinking water of 660,000 people. The problem with indirect potable water reuse is the amount of uncertainty involved. Only a small portion of the contaminants in surface and ground water can be identified. Even if everything that can be tested for is within safe levels, there may be other constituents of the water that may be problematic over long periods of time.

Treatment

We will look at the present science and technology of wastewater treatment to be able to investigate why water reuse is currently not a widespread practice. Water must be thoroughly expunged of any harmful constituents in order to discharge or reuse it, which is why there has been so much concern for ways to purify water.

Most wastewater flows through sewers, and it is treated in a communal wastewater treatment site. First the water flows through a screen that filters out large objects like rags, sticks, or even dead animals (How Wastewater Treatment Works, 1998). Next, the water enters a grit chamber where sand, gravel, cinder and other large particles settle to the bottom. At this point, the wastewater still contains inorganic and organic materials. The water then flows to a sedimentation tank, where any minute particles or inorganic materials, since they are heavier than water, will settle and accumulate into sludge at the bottom. Next, water flows to an aeration tank, where aerobic microorganisms (see glossary) consume organic matter. This process goes on for several hours to ensure that a large fraction of the organic matter is consumed. After the organic matter is mineralized by the bacteria, the water flows to another sedimentation tank, where the bacteria are removed. Finally, the water is treated with chlorine, ozone, or UV radiation to kill any pathogenic bacteria. Chlorination is an effective process, in that it may kill ninety-nine percent of bacteria in water, and may reduce some odor (Metcalf & Eddy, 2003). If chlorination is used, then afterwards dechlorination is needed which essentially removes residual chlorine from the treated water, usually with SO_2 (Wastewater Technology Fact Sheet, 2000). Ozone is sometimes used, since chlorine is detrimental to everything downstream of the treatment. This process for treating wastewater is used for any wastewater which is discharged to the environment, not necessarily water for reuse.

Additional processes to purify water include micro-filtration, reverse osmosis, distillation, and carbon adsorption. Using these techniques it is possible to get water to a potable (see Appendix B) level (How Wastewater Treatment Works, 1998). The reason wastewater is not usually treated in such a way is because it is less expensive to use the existing water supply, than to design and set up a new water reuse system. A proposed system in Natick, MA presents a good example of this (Brown, Ferraro, & Padden, 2004). In certain cases as mentioned above there are water shortages, so water reuse is necessary.

Constituents in Wastewater

There are many constituents in wastewater; however not all of these are of concern for reclamation. The constituents of concern include suspended solids, biodegradable organics, pathogens, nutrients, priority pollutants, refractory organics, heavy metals, and dissolved inorganics (Metcalf & Eddy, 2003). Now we will look at why each constituent is harmful and how they are treated in wastewater reclamation. It is useful to understand this so that we can analyze how the reuse systems in the other colleges operate and why there is a difference in the water reuse situations.

Suspended solids are simply solids that do not settle, such as large sand particles, and thus are not easy to filter out. These solids can lead to development of sludge deposits and conditions conducive to bacterial growth (Metcalf & Eddy, 2003). Almost all suspended solids can be filtered out of solution by filtering through a membrane with a given pore size. Particles smaller than this pore size are considered to be dissolved in solution.

Biodegradable organics are organic macromolecules (proteins, fats, carbohydrates or nucleic acids), but are not alive as are pathogens. These organics are primarily what is found in feces, and can also include industrial organics. To leave these constituents alone could lead to septic conditions, or the depletion of oxygen resources (Metcalf & Eddy, 2003). It could also shield the bacteria during disinfection. The treatment of these organics will be mentioned later.

Pathogens are transmittable diseases. These are live organisms and include protozoa, bacteria, helminths (worms), and viruses and are obviously detrimental because of the diseases that they can cause in humans or animals, such as Shigella, E. coli, or Salmonella (Metcalf & Eddy, 2003). Almost all pathogens are destroyed in the final process of water treatment called disinfection. Chemical methods of disinfection range from chlorination to ozonation to the use of bases or acids. Physical methods include heat, light and sound waves. Radiation methods involve gamma rays, electromagnetic, acoustic and particle radiation. All of the above methods effectively kill pathogens in water. In most cases what occurs is that the disinfecting agent destroys the cell wall, and the organism falls apart. Furthermore, radiation goes as far as to damage DNA or RNA (for bacteria), and thus inactivates the cells. There are benefits and disadvantages for each of the chemical methods of disinfection, but usually only one method is used in the interest of saving money.

The word nutrient mentioned in wastewater describes molecules that contain nitrogen, phosphorus, or carbon. These are useful nutrients for growth, but unfortunately aquatic life also uses these nutrients for growth, so having this in the water helps unwanted biomaterial to replicate in the water (Metcalf & Eddy, 2003). As mentioned earlier, bacteria are utilized in the activated sludge process/filtration where they consume the organic material mentioned above, and with the help of these nutrients, yield simple non-damaging products such as CO_2 and H_2O as well as more bacterial cells. The new cells produced do not generate more distress because most bacteria are later filtered out of the water.

Refractory organics are organic materials that resist conventional wastewater treatment (Metcalf & Eddy, 2003). These may include phenols, surfactants, and pesticides. There are not any methods that are sure to eliminate all of these refractory organics, but there are certain methods of chemical oxidation using H_2O_2, MnO_4, ClO^-, or ClO_2.

Heavy metals are elements that are dangerous when ingested. We normally do intake small amounts of metals such as Fe, Cr, and Cu. Techniques for removing heavy metals include chemical precipitation, carbon adsorption, or ion exchange (Metcalf & Eddy, 2003). Chemical precipitation simply involves introducing a substance that reacts with the heavy metal, which then precipitates out of solution. This is the most commonly used, and inexpensive method.

Dissolved inorganics include things like Na^+, Ca^{2+}, and SO_4^-. The removal of these inorganics involves membrane filtration or chemical processes (Metcalf & Eddy, 2003). There are biomembranes, which filter the water and many organic and inorganic materials are collected and/or consumed in this process. Chemical processes involve things like reverse osmosis, electrodialysis and distillation. These are the best methods to purify water and do not usually occur as commonly as primary or secondary treatment of water only.

Methodology

This project's goal is to assess the feasibility of applying water reuse systems at WPI. To do a comparison we investigated WPI, which does not have a water reuse system, by collecting data concerning water uses. We then investigated colleges that currently implement water reuse systems to determine their degree of success. To achieve our goals we conducted interviews, and case studies. In order to learn how water is being used at WPI we interviewed college staff. Of colleges that already have water reuse systems we did case studies.

In our case studies of Stanford University; University of California, San Diego; University of Idaho; and Washington State University (WSU) we examined the history of implementation of these water reuse systems and the benefits they resulted in. Colleges which implement water reuse systems are not a common occurrence; therefore we desired to investigate what factors brought about this structural change at these colleges. We explored areas such as need for water, political engagements, extent of water reuse at these institutions, and the public perception regarding these systems. In doing so, we discovered some demographic and environmental patterns that instigate a need for water reuse. The questionnaires for each institution were different due to the particular circumstances surrounding them.

In the case of Stanford University, we investigated what made the water conservation plan so successful or desirable to the college. We interviewed Marty Laporte, Water Resource & Environmental Quality Manager, who was in charge of the Stanford University Water Conservation, Reuse, and Recycling plan to acquire information concerning water reuse at Stanford. The information that we obtained via a phone interview pertained to the organization of the water reuse system and how extensively it is being applied at Stanford. We will obtain information regarding how much water they save from both an economic and environmental perspective. The questions asked are in Appendix 2.

Kirk Pawlowski, the Washington State University Capital Planning and Development manager was contacted, to learn about their water conservation efforts. The questions we asked him are in Appendix 3. We investigated the social issues surrounding the rejection of the water reuse plan.

We contacted Peter Fox, Director of the NCSWS at ASU. Unfortunately our email did not elicit a response. Upon further investigation we discovered that they were not really reusing water. The questions we asked him are in Appendix 4.

We emailed Charles Morgan, director of Landscape Services at UCSD. The questions we asked him are in Appendix 5. We received no response from him. We discovered that UCSD gets its water from a city reclamation plant. We did online research about the plant.

We contacted Larry Kirkland, Energy and Environmental engineer at University of Idaho. We could not elicit a response, and were directed to Mr. Michael Holthaus, Water Systems Manager at University Idaho. We interviewed him by telephone. The questions we asked him are in Appendix 6.

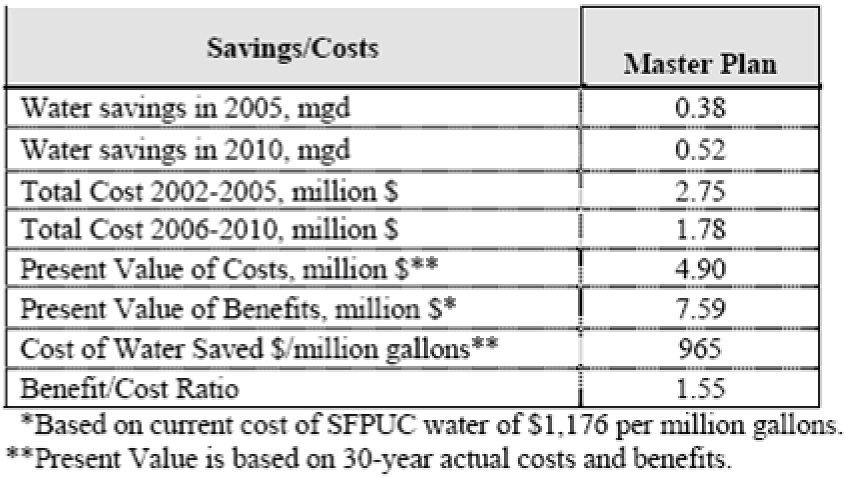
To get a better understanding of how a water reuse system would be implemented, it is important to gather quantitative information. This includes rates of freshwater being brought into campuses, rates of used water leaving campus, and other similar, relevant information. We interviewed the director of physical plant at WPI, John Miller. The questions we asked him are in Appendix 1.

Case Studies

We conducted case studies of four different institutions. The usage of reclaimed water by these institutions differs greatly. They all serve to show the benefits of water reuse.

Stanford University

Stanford University is one example of a university that already has been investigating water conservation techniques. The reason for the proposed water conservation, reuse and recycling plan was that they needed to show that they could alleviate the impact of Stanford's expanding use of water. This project was finished in 2003 and is used to this day. Their plan primarily includes conservation in the form of water-efficient toilets, urinals, and showerheads. By implementing that plan, they were to be able to keep their water consumption under the quota of 3.033 million gallons per day (mgd). In 2000 they used only 2.7 mgd, but the projection for 2010 was 3.6 mgd which would exceed their allocation of 3.033 mgd. According to Marty Laporte, director of facilities operations at Stanford University, the average water use for the last 2003-2004 academic school year was 2.3 mgd. According to their final recommended plan, the motivation for this conservation, reuse and recycling plan was because of the projected available clean water supply. According to Marty Laporte at Stanford University, there was not a lack of clean water at the time the plan was implemented, but they foresaw the need and benefits of water reuse. As well as mitigating environmental strain, their plan also saved them money in the long run. A summary of their costs and savings in this water saving plan can be found in Figure 1.

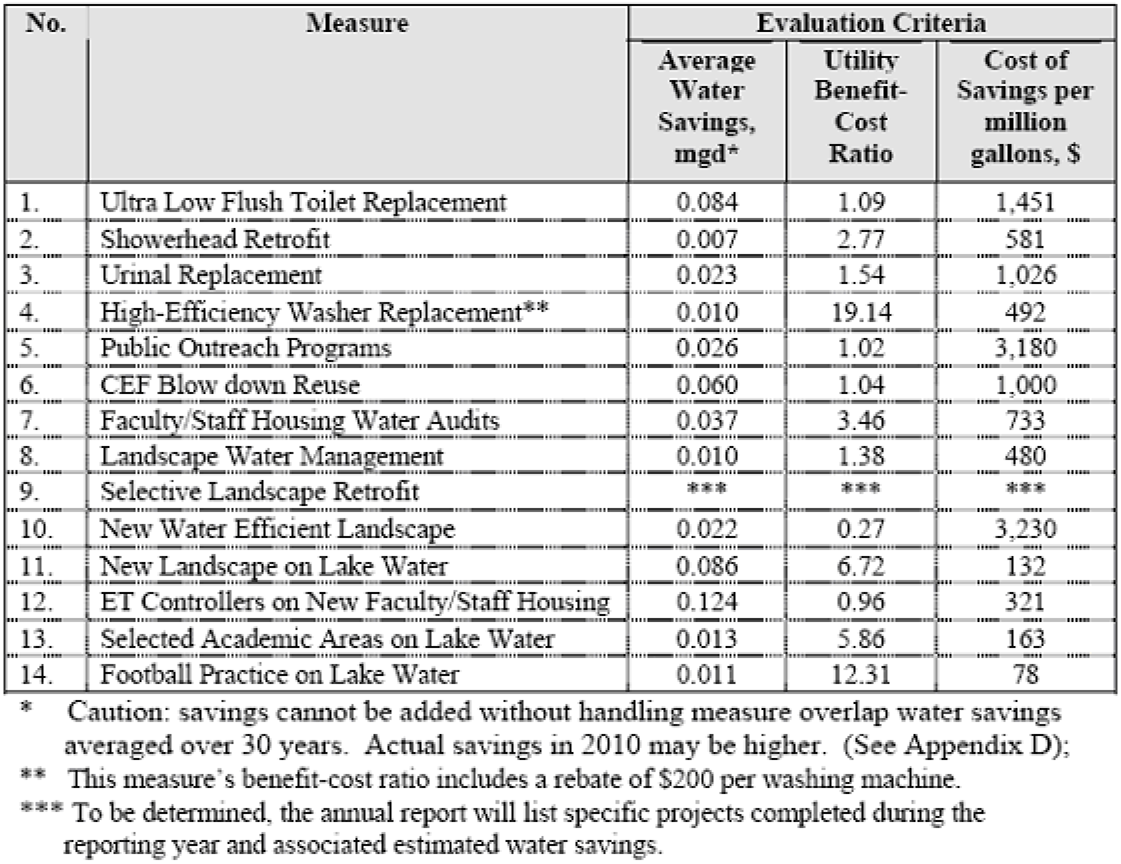


Savings/Costs	Master Plan
Water savings in 2005, mgd	0.38
Water savings in 2010, mgd	0.52
Total Cost 2002-2005, million $	2.75
Total Cost 2006-2010, million $	1.78
Present Value of Costs, million $**	4.90
Present Value of Benefits, million $*	7.59
Cost of Water Saved $/million gallons**	965
Benefit/Cost Ratio	1.55

*Based on current cost of SFPUC water of $1,176 per million gallons.
**Present Value is based on 30-year actual costs and benefits.

Figure 1. Estimated Savings and Costs of Water Conservation, Reuse and Recycling Master Plan at Stanford University. (Maddaus & Stanford, 2003)
SFPUC – San Francisco Public Utilities Commision

Initially, Stanford surveyed and gathered information concerning how much water is used and where on their campus (see Figure 1). They worked in cooperation with Maddaus Water Management, who took Stanford's data, analyzed the data and modeled uses of water. As a result, they discovered what critical points would reduce water use most significantly. The single largest contributor to water consumption (twenty-two percent) is their cooling systems for chilled water for their Central Energy Facility and cooling tower water for their power plant. After that, about seventeen percent of their water use goes to toilets and showers in residence halls. As a result they retrofitted showerheads, toilets, urinals, and sinks to low-flow models (see Figure 2). As mentioned earlier, water use has been reduced, and the students have accepted it well.



No.	Measure	Evaluation Criteria		
		Average Water Savings, mgd*	Utility Benefit-Cost Ratio	Cost of Savings per million gallons, $
1.	Ultra Low Flush Toilet Replacement	0.084	1.09	1,451
2.	Showerhead Retrofit	0.007	2.77	581
3.	Urinal Replacement	0.023	1.54	1,026
4.	High-Efficiency Washer Replacement**	0.010	19.14	492
5.	Public Outreach Programs	0.026	1.02	3,180
6.	CEF Blow down Reuse	0.060	1.04	1,000
7.	Faculty/Staff Housing Water Audits	0.037	3.46	733
8.	Landscape Water Management	0.010	1.38	480
9.	Selective Landscape Retrofit	***	***	***
10.	New Water Efficient Landscape	0.022	0.27	3,230
11.	New Landscape on Lake Water	0.086	6.72	132
12.	ET Controllers on New Faculty/Staff Housing	0.124	0.96	321
13.	Selected Academic Areas on Lake Water	0.013	5.86	163
14.	Football Practice on Lake Water	0.011	12.31	78

* Caution: savings cannot be added without handling measure overlap water savings averaged over 30 years. Actual savings in 2010 may be higher. (See Appendix D);

** This measure's benefit-cost ratio includes a rebate of $200 per washing machine.

*** To be determined, the annual report will list specific projects completed during the reporting year and associated estimated water savings.

Figure 2. Results of Evaluation of Individual Measures. (Maddaus & Stanford, 2003)

The cooling systems water in their central energy facility (CEF/Cogen) is a unique example of water reuse. They use the same water 10 to15 times through the cycle of cooling. They also reuse water in quenching glassware (see glossary). In 2005, the 15,800 gallons of water per day used to irrigate the football field was changed to non-potable lake water. Lake water is also being used for irrigation in more common places such as their mall, as well as for backup fire protection.

The funding for this project was obtained from Stanford University's budget. Unlike Massachusetts' Gillette Stadium, they do not have an on-site wastewater treatment plant, but are planning to look into such developments in the future.

> "Information from the Palo Alto Regional Water Quality Control Plant (RWQCP) Engineer indicates that it is likely that the cost of recycled

> water would be about fifty percent of the price of domestic water (Daisy Stark, pers. commun. 4/24/02). This estimated cost did not include the customer's costs for design, installation, and maintenance of distribution system infrastructure, such as blending tanks, and distribution lines throughout Stanford University." (Maddaus & Stanford, 2003)

In order to construct an on-site treatment plant, it would require a lot of money, more than they could initially invest. Furthermore, to use the reclaimed water from the city of Santa Clara, they would need to put up miles of pipeline, which is also very expensive. Typically it is financially difficult to get the sufficient funding for such large scale projects since the results are not instantly gratifying.

The final results were tabulated (see Figure 3) concerning water saved and dollars saved. Marty Laporte's personal recommendation to people investigating water conservation is to install plumbing using the available technology to save water. Retrofitting costs more money than installing conservatively. Evidently this is successful like at Stanford University where they have water-saving lab equipment, washing machines, shower heads, toilets, etc. and it is saving thousands of gallons of water each day.

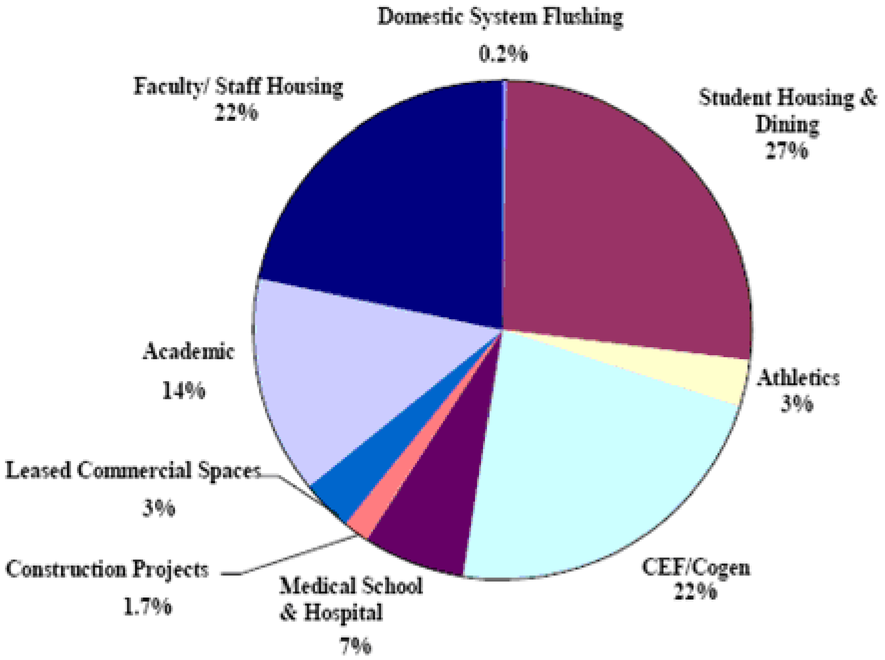


Figure 3. Average Annual Demand By Category for Domestic Water System. (Maddaus & Stanford, 2003)

University of California, San Diego

University of California San Diego (UCSD) uses reclaimed water for irrigation on campus. They use 254,000 gallons of potable water for irrigation per day. Since UCSD has started using reclaimed water for irrigation they have saved twenty-five percent of water and sewage cost (UCSD Blink, 2005). UCSD receives its reclaimed water from a reclamation plant in San Diego (Water Recycling Overview). In the early 1990s there was a drought in San Diego and the need for improved water utilization was foreseen since San Diego imports over ninety percent of its water from Northern California and the Colorado River (Water Recycling FAQ). Two water reclamation plants were built, the North City Water Reclamation Plant and the South Bay Water Reclamation Plant. The plants are approved to provide water for irrigation, manufacturing and non-potable uses such as cooling towers (Water Recycling). The San Diego Water Department began selling water in October, 1997. When it started, they sold reclaimed water for $1.34 per 100ft^3, but the price was decreased to $0.80 per 100ft^3 in 2001, to encourage business (Future Water Recycling).

The Northern City Water Reclamation Plant treats, on average, 22.5 million gallons per day (MGD), only seventy-five percent of its capacity (Water Recycling Overview). This plant supplies water using seventy-nine miles of pipeline as well as two pump stations and two water storage tanks (Figure 4).

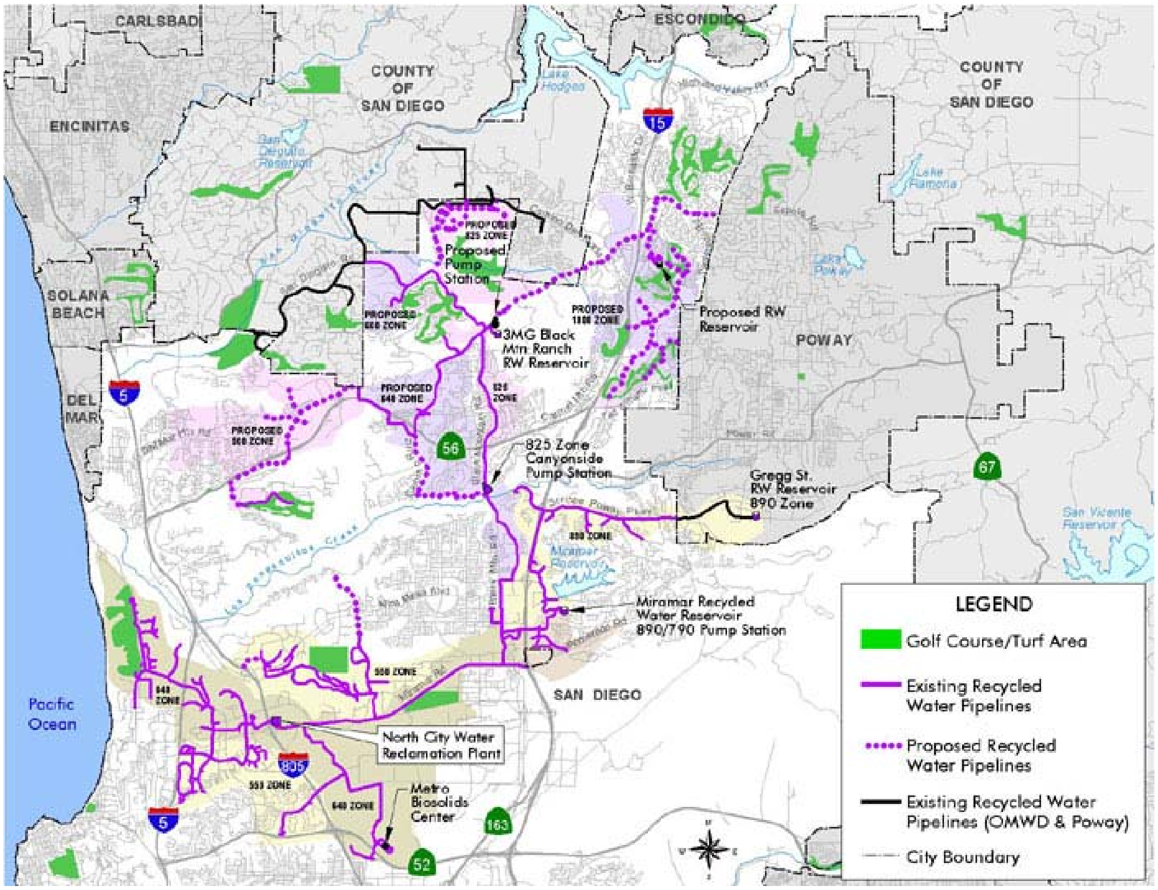


Figure 4. Recycled Water Availability Zone in San Diego. (Recycled Water Availability)

The reclamation plant serves UCSD and other corporation such as General Atomics, Caltrans, Miramar Nursery, San Diego California Temple, and Miramar Marine Corps Air Station Golf Course, as well as some public parks and landfills. The Southern

Bay Water Reclamation Plant can treat 15 MGD, but is currently only treating 9 MGD. This water is treated with a secondary system and is then either discharged to the ocean or sent on to tertiary treatment which meets all standards for "full body contact" (South Bay).

University of Idaho

The University of Idaho is located near the Washington state border in the city of Moscow, above the Grande Ronde aquifer. The towns of Moscow and Pullman along with Washington State University and the University of Idaho have been pumping from the Grande Ronde aquifer at an unsustainable rate (Figure 5).

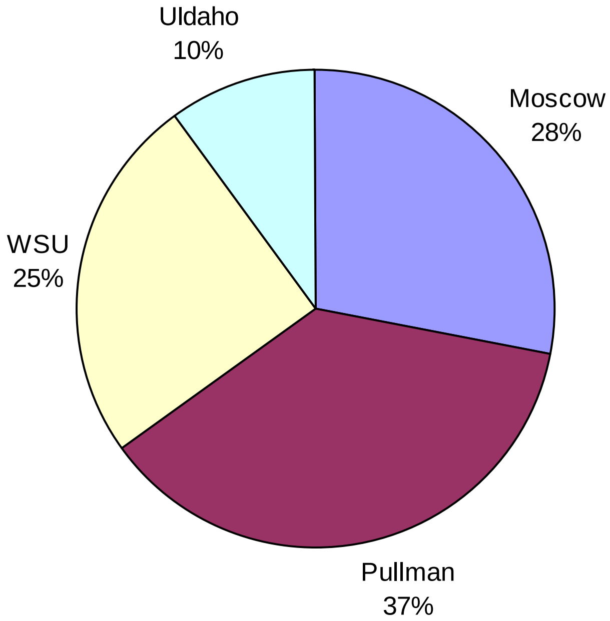


Figure 5. Breakdown of groundwater drawers in Palouse Basin, as of 2003. Adapted from (Palouse Water Conservation Network)

For many years the water level in this Palouse basin aquifer was falling. This problem of water mining worsened to a degree that the State of Idaho Water Resources Board mandated that the issue be dealt with (UI Facilities Maintenance and Operations). Because of this, over the past fourteen years the amount of water being pumped has been abated. As a result the water levels seemed to have stabilized during the past four years. In 2001 a quarter of the water the University of Idaho used was reclaimed water. By 2005 a third of the water the university used was reclaimed water (Figure 6).

	2001	2002	2003	2004	2005
Domestic water	429,264	350,449	293,458	322,805	291,653
Recycled water	100,325	96,381	96,381	131,566	101,711

Figure 6. Water Consumption at the University of Idaho.
Quantities are given in 100 ft^3. (Adapted from Energy Systems Background)

This stabilization was possible because of the University of Idaho's ability to cut back on the amount of domestic water it uses (Figure 7, 8) (Domestic Water System).

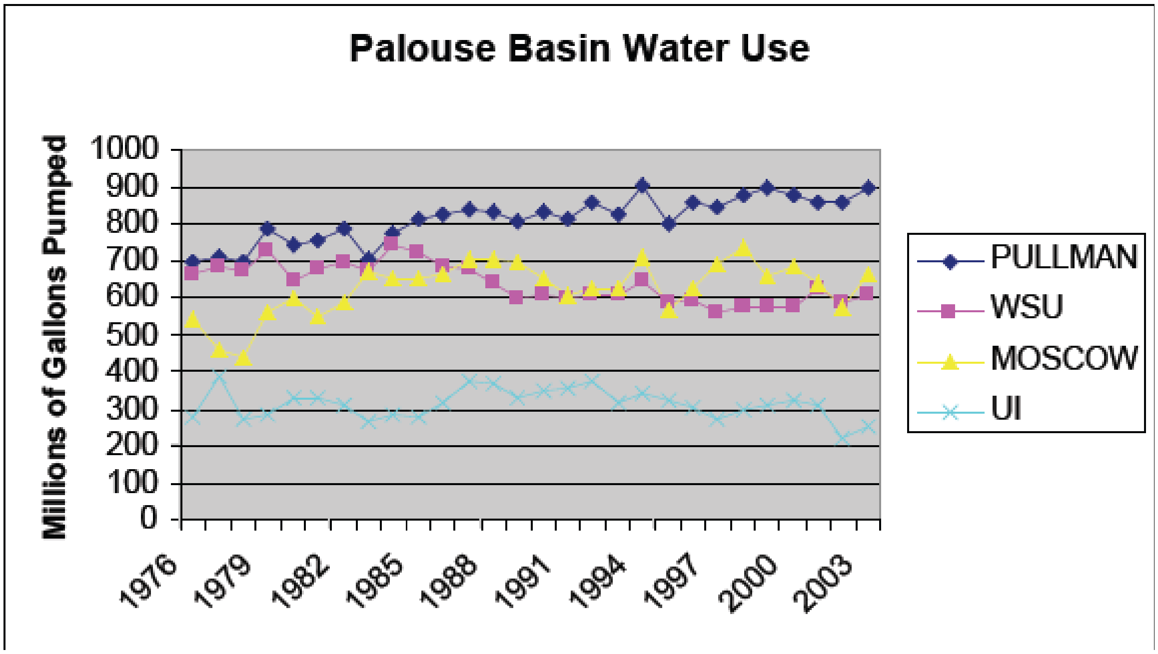


Figure 7. Water Use Over Time. (Palouse Water Conservation Network**)**

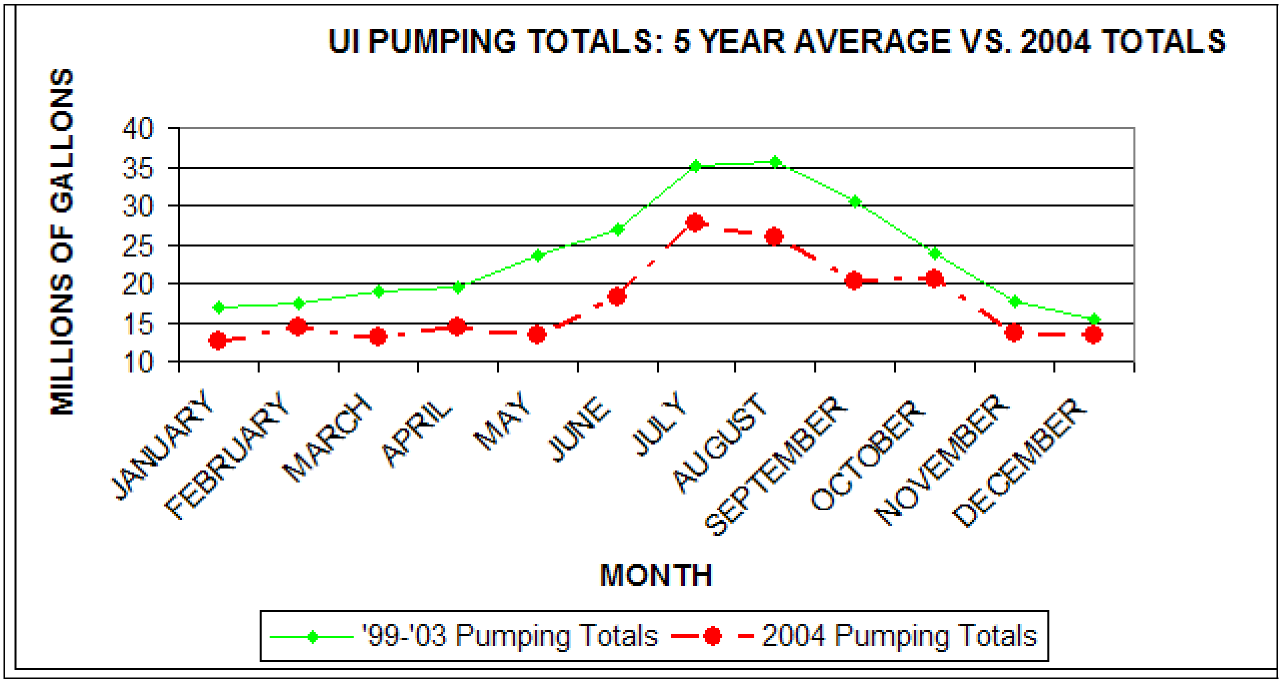


Figure 8. UI Pumping Totals. (University of Idaho)

Replacing this domestic water is reclaimed water from the City of Moscow Wastewater Treatment Plant. This reclaimed water is used for the irrigation of the university golf course, landscaping, sports fields and the arboretum. (Palouse Water Conservation Network, 2002) Currently the University is irrigating two hundred acres with reclaimed water. Forty five acres were added over the past six years. There are also plans to irrigate another twenty acres over the next five to ten years and potentially start irrigating the parks of Moscow city as well (Domestic Water System).

The water level of the Grande Ronde would have continued to drop if the University of Idaho had not started using reclaimed water for irrigation. If the situation had gone unchecked then the entire area would have suffered. Eventually wells would have to be drilled deeper to get at the last remaining water. A lack of water in this deep aquifer could eventually cause a shift in the water tables, resulting in many environmental changes. If the water levels were to change then the trees in the area could suffer. This would be devastating to the regional timber mills, and potentially put people out of work. Sink holes could develop causing architectural damage. Other ways of saving water would have to of been put into place in order to prevent this from happening. This could have put a stop to the expansion of the area. Once the aquifer had reached a critical point bands would have been needed to prevent using too much of the little remaining water. The University of Idaho is using reclaimed water which avoids this problem.

Washington State University

In Washington an aquifer that stretches beneath the towns of Pullman, Palouse, and others has been dropping about a foot per year. Washington State University (WSU), a state school that uses a large proportion of water each day endeavored to implement a water reuse system on their campus following research and calculations. If successful, the project would have alleviated the amount of water drawn from the aquifer, thereby reducing dependence on groundwater. WSU consumes a large portion of the Palouse Basin aquifer, so to relieve stress on the aquifer would be beneficial to all the towns that partake of its freshwater (see Figure 5, 7). Unfortunately after all the planning and research had been finished, the plan was turned down at the last step because of the state's budget constraints.

Since the mid-1980's WSU's Pullman campus has reduced the amount of water it uses despite its growing enrollment by the use of conservation techniques in the form of water-efficient applications (WSU Water Conservation, 2004). WSU had a proposed plan working with the city of Pullman on water reclamation; however the plan was vetoed by Gov. Gary Locke. If the project were implemented, it would provide 1 million gallons of reclaimed water each day to the WSU campus to be used for irrigation (WSU

Water Conservation, 2004). The system would have been built with the capacity to increase production up to three million gallons of reclaimed water each day. As the campus grows with an 18-hole NCAA championship golf course and veterinary medical facilities, the water needs could also have been accommodated for via the water reclamation system.

The funding which was not anticipated to be a barrier was because of Gov. Locke's decision saying that the other $7.3 million need for the project should be acquired elsewhere (Roesler, 2004). The governor himself had proposed $3.4 million for the project, but was afraid that the rest of the budget would be shouldered by the state. According to Gov. Gary Locke Washington state is spending its budget primarily on promoting higher education and transportation (Washington State Office of the Governor, 2004). WSU's budget executive said that this decision to veto the funding was short-sighted and it is easy to put this kind of project off, since the need is not so evident right now (Roesler, 2004). WSU ensured the taxpayers of Washington that the water reclamation project was needed aside from expanding their golf course. Consequently, WSU will continue to pursue funding for this water reclamation project, as it is viewed as environmentally and economically beneficial.

Worcester Polytechnic Institute

WPI consumes around 50,000 hundred cubic feet of water per year according to water budget projection (Figure 9). This is significantly less than other universities we have studied. According to our interview with John Miller WPI was recognized for being one of the most water saving institutions in Worcester. WPI uses water conservation devices in our bathrooms such as low flow shower heads and toilets. Unlike other colleges we studied we do not use a lot of water for irrigation. Most of our water is used for WPI's heating plant and water boilers (Figure 10).

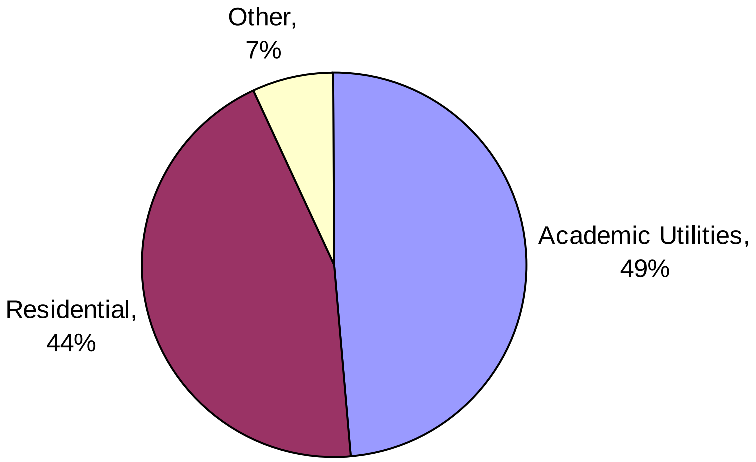


Figure 10. WPI Water Use. (Adapted from 2007 Water budget projection sheet)

We of course do not irrigate at all in the winter. During the other seasons we irrigate grassy areas like the quad and also the gardens on campus two to three times a week for half an hour. The athletic field we irrigate as needed.

Units in CCF

Location	**Rate**	**Consumption**	**Extended Cost***
Academic			
Utilities Service	$6.00	23906	$143,436.00
One Drury Lane	$6.00	118	$708.00
15 Regent Street	$6.00	60	$360.00
4 Regent Street	$6.00	111	$666.00
Total		24195	$145,170.00
Residential			
General	$6.00	21,800	$130,800.00
Peripheral Properties			
2 Elbridge St.	$6.00	136	$816.00
8 Elbridge St.	$6.00	238	$1,428.00
10 Elbridge St.	$6.00	298	$1,788.00
20 Elbridge St.	$6.00	72	$432.00
30 Elbridge St.	$6.00	112	$672.00
11 Einhorn Rd	$6.00	162	$972.00

15 Einhorn Rd	$6.00	68	$408.00
16 Einhorn Rd	$6.00	44	$264.00
17 Einhorn Rd	$6.00	113	$678.00
8 Hackfeld Rd	$6.00	231	$1,386.00
10 Hackfeld Rd	$6.00	116	$696.00
11 Hackfeld Rd	$6.00	60	$360.00
12 Hackfeld Rd	$6.00	230	$1,380.00
18 Hackfeld Rd	$6.00	185	$1,110.00
23 Hackfeld Rd	$6.00	21	$126.00
24 Hackfeld Rd	$6.00	33	$198.00
47 Institute Rd	$6.00	171	$1,026.00
49 Institute Rd.	$6.00	177	$1,062.00
13 Schussler Rd	$6.00	85	$510.00
15 Schussler Rd	$6.00	177	$1,062.00
20 Schussler Rd	$6.00	60	$360.00
67 Wachusett St	$6.00	175	$1,050.00
150 West St.	$6.00	431	$2,586.00
Total		3395	$20,370.00
Grand Total		49,390	$296,340.00

*** Extended Cost = rate x consumption**

Figure 9. 2007 Water Budget Projection Sheet for WPI. (Provided by John Miller on 12/6/05)

	Stanford	UCSD	U Idaho	WSU	WPI
Amount of water reused	60,000 gal/d	254,000 gal/d	208,000 gal/d	550,000 gal/d*	NA
Total water used	2,400,000 g/d		598,000 gal/d	2,800,000 gal/d	
Total water used for irrigation	648,000 g/d	254,000 gal/d	208,000 gal/d		
Campus size (acres)	8,180		1,585	230	80
Enrolled students	14,400	12,476	9,715	18,622	3,805
On campus residence	10,260	9,452	3,500	8570	1,268
Cost of potable water ($/100CF)	0.88	1.87	0.40		0.51***
Cost of reclaimed water($/100CF)	0-2.75**	0.80	0.40		NA
Number of Buildings	678	50	253		34
Number of Residence Halls	9	15	23	16	6
Number of Dining Halls	10	9	5	7	3

*** projected number if they had a water reuse system**
**** Palo Alto’s estimated cost**
***** obtained from Worcester Department of Public Works**

Figure 11. Comparison of Colleges. (Sources referenced below)

Discussion

Through our research of universities in the United States we discovered that implementing water reuse in Worcester is not realistic at this time. A few universities did take advantage of water reuse. While this was sensible for these institutions it is not necessarily prudent for all institutions. The factors that affect whether or not universities would benefit from implementing water reuse are the region's climate, geology, water consumption and money. We will show why water reuse was practical in the universities we researched, and how the factors present at WPI do not contribute to urgency for water reuse. An ideal situation of a location that should utilize water reuse will be presented, then contrasted, with WPI in order to show what would need to happen before water reclamation becomes important.

Climate is the first and most important deciding factor for determining if water reuse is necessary. A rainforest would have no need for a water reuse program. The greatest need would be in a place that is dry. A location that received no precipitation would require water to be reused or imported. When all water is imported the dry region is entirely dependent on the water supplying region. In order for the dry region to lessen the amount of water it imports it must make the water that it imports last longer. This shows the need for water reuse in an area due to climate. University of California San Diego and Stanford University receives an average of a tenth of an inch of rain per month during the summer when rain is most needed (County Studies US, 2003). Worcester gets an average of 3.8 inches during the same summer month. UCSD experienced a drought in the early 1990's and this led to the implementation of a wastewater reclamation plant in

San Diego (Water Recycling FAQ). Based on climate WPI does not need to implement water reuse.

San Diego imports ninety percent of its water, mostly from the Colorado River. Seven states receive their water from the Colorado River and the river is being overdrawn. Previous estimates for river flow were too high and there will soon be problems supplying everyone with enough water (McFadden, 1999). If Worcester Polytechnic Institute was getting its water from a river that was being overdrawn from, we would also want to do water reuse to save water, benefiting all.

The geology of a region can help to determine how necessary water reuse is there. Aquifers take longer to recharge than reservoirs because while reservoirs can be augmented through precipitation and surface runoff, water destined for aquifers must percolate through ten to fifty feet of soil (Asano, 1999). Furthermore, not all the water reaches the aquifer. Transpiration, evaporation, and absorption by vegetation divert the water from assimilating into the freshwater source. A region with an aquifer of the same capacity as another regions reservoir is automatically at a disadvantage. With heavy rains a reservoir may flood its banks. This represents an overabundance of water, too much of a good thing. A large quantity of water on the ground surface will result in smaller addition to an aquifer, especially a deep aquifer, than it would have if there were a surface reservoir to capture the immediate runoff (Asano, 1999; Metcalf & Eddy, 2003). University of Idaho draws its water from an aquifer. This combined with the large population using this aquifer resulted in the University of Idaho’s need to decrease their total water consumption. Worcester’s public water supply comes from reservoirs in

Holden. The ground water is used on a much smaller scale here than in the kind of place where water reuse would be sought for to help with water shortages.

The amount of water used in a region is dependent on what the water is being used for. According to the EPA, the applications that consume the most water are thermoelectric generation and irrigation (How We Use Water, 2003). Irrigation accounts for thirty four percent of all water used in the U.S. Public supply (drinking, washing, etc.) accounts for a mere nine percent. An agrarian region requires far more water then an urban setting with the same population would. This shows that while an individual person requires a given amount of water the population density does not directly correlate with a rate of water consumption. To maximize the effect of water reuse it should be used where it is needed, such as irrigation. Another reason that irrigation is one of the best uses of reclaimed water is because it does not necessarily come in direct contact with humans. In addition installing a reclaimed water pipeline on a golf course is much easier than to replumb a single city block. The universities that employ water reuse do a lot of irrigation. University of Idaho does a great deal of irrigation due to its golf course and since there is so little rain at these schools they must irrigate frequently to keep their grass green. A place that would most need water reuse would be a place where they need an enormous amount of water. In Worcester we get enough rain so that irrigation does not require a great amount of our water.

The amount of water consumed is another factor contributing to water reuse. If a household has a single well it will suffice for their needs. If an entire town were to utilize that same well, it would not be a sufficient water source. In the areas of the schools we researched; Moscow, Idaho; and San Diego, California have large populations drawing from the same limited water source. Stanford University implemented a water conservation plan because the predicted water expenditures were greater then their allocated water supply. As we have already discussed, water is not in short supply in Worcester relative to the population. Again, Worcester does not see any urgency for water reuse.

At this time water reuse is costly. Orange Water and Sewer Authority (OWASA) in Carboro, North Carolina estimated the cost of designing and building a wastewater reclaimation plant at ten million dollars (OWASA). Many of the schools that we investigated had special conditions that allowed them to overcome the economic factor. Stanford University had a significant sum of money set aside for social and technological projects such as the conservation and reuse plan that they finished implementing in 2003. To either build a water reclamation plant or construct miles of pipeline from the nearest existing plant in Santa Clara would have been too great for their significant budget. The University of Idaho took out a government loan for the construction of their reuse plant; however the school itself maintains the plant of its own resources. The University of California, San Diego simply began purchasing reclaimed water from the city. UCSD’s transition into the use of reclaimed water has saved them twenty-five percent in costs of water and sewage. This was only possible because the cost was lowered by the city to encourage water reuse in San Diego. In this case, not much money was involved in initiating water reuse, and for the other two universities they were able to obtain the money in a timely and fashionable manner. At Washington State University, the plan was rejected due to lack of funds. This was the only factor restraining them from carrying out their water reuse plan; however the need and benefit from water reuse was accepted. In their particular case, the governor said that there are more urgent needs for money such as for transportation, highways, etc. We have seen that for water reuse to be affordable to universities they often have support from the government and the government must see a need for water reuse to fund this kind of project. For these universities water reuse or conservation is a substantial issue due to their climate, geology, and amount of water consumed. This makes water reuse an important concern to the universities and a good use of their budget. Given the effects of these factors in Worcester, WPI should use its money elsewhere.

We see that water reuse is not currently feasible at WPI. What would need to change in Worcester to bring about a need for water reuse? If the population were to increase dramatically, we would need a way to cope with the rapidly increasing amount of defiled water and decreasing amount of freshwater. If we were to build several golf courses and if precipitation were to decrease, or if we had some massive thermoelectric power generation plants, then water reuse would be desirable. Ultimately we can conclude that water reuse would not be environmentally or economically applicable at WPI, but through our research we have discovered instances where water reuse would be applicable. Even though our area would not benefit from water reuse there are many places that would benefit. Other universities that fit the previously stated conditions should look into water reuse to save water such as universities that have golf courses and are in dry areas. WPI does not have a lack of water and has other projects underway; therefore WPI does not need water reuse because it has better things to spend its money on at this time. In all these instances water reuse is a system that will pay off in the long run and is environmentally as well as economically beneficial, but only in the places that are in need of water.

Conclusion

The goal of our project was to investigate water reuse in universities and examine how it could be expanded to other schools like WPI. Through our investigation we found several factors that oppose the idea of doing water reuse at WPI. Mainly we found that WPI does not have an urgent need for water like the current schools that employ water reuse. The cost of building a water reclamation plant is impractical because our need for water does not present a problem at this time. However other schools that are facing water shortage predicaments should consider water reuse because it has worked well for those schools that currently implement it.

Appendix A. Interviews

Interview with Michael Holthaus, Water Systems Manager at the University of Idaho, on Friday 12-9-05, at 1:30 pm

How long has the university been using reclaimed water for irrigation?

> Since 1979

Do you think the university will start using reclaimed water for other uses?

> Not likely, irrigation is our primary concern

How much money is being saved because of water reuse, do you know how much reclaimed water costs?

> The reclaimed water is actually more expensive because the university has to do additional treatment of it, chlorine is added.

How has funding been appropriated?

> The state legislature takes care of the large lump sums, and the university handles the upkeep. There is still a loan out which helped for funding. The last upgrade ran 250 grand, and the total investment and upkeep cost are less then a million dollars

Does your power plant use a cooling tower, and if so how much is used for water makeup?

> Yes, 5 million gallons were used this year for makeup because of problems with water hardness. Last year however, used only 3.8 million due to the mild winter.

Where does the make up water for the steam come from?

> Domestic water is used.

The water cooled equipment uses chilled water from the central chilled water system. So where does the water in the chilling system come from?

> The chilling water comes from the aquifer, and is used in the university labs on the water cooled equipment

Is it a closed loop?

> Yes but water is still added due to water hardness

References:

UI Facilities Maintenance and Operations. 8/1/01. Energy Alert #3. Retrieved 12/12/05, from http://www.webs.uidaho.edu/energy/energy_alert3.htm

Email Interview with Kirk Pawlowski

Q1. Why was the plan for water reuse proposed?

A1. The reuse project was proposed to protect the groundwater resources that all of the local communities use for potable water. Since the aquifer has been in decline throughout the past decades, water reuse is seen as a reliable way to reduce our dependency on groundwater (especially for irrigation and industrial uses).

Q2. What were the economic, political, and social reasons for the plan's rejection?

A2. It is my understanding that the legislature chose not to fund the project due to budget constraints and some uncertainty as to which municipality (WSU or Pullman) should be pursuing funding and what form that funding should take.

Q3. How would the plan have helped the campus?

- Socially, environmentally and economically?

A3. The plan would have helped campus by:

- Deferring the need for additional campus water infrastructure upgrades to support campus growth.
- Environmentally, this project would help WSU continue its reduction in overall water use by initially removing a large chunk of irrigation from the domestic water system.

Q4. Do you think there is a future for water reclamation at Washington State University?

A4. WSU believes in the Water Reclamation project and will continue to actively seek funding from the legislature. The benefits of this type of system can be seen at the Univ of Idaho (over the last 20+ years) which is only 8mi from the Pullman campus.

Interview on 11/22/05 at 1:00 pm with John Miller, Director of Physical Plant

1. How much water is used by WPI (gal/month)?
He doesn't know. Come back in two weeks, and he'll give us that information.

2. How much does water cost ($/gal or $/month)?
Not sure, maybe $5.49 per 100 ft^3. Come back in two weeks to get that number.

3. Is there a cost for wastewater disposal? If so how much is it?
There is a water fee and disposal fee.

4. How old are our water systems?
They are all relatively new. The oldest would be 1970's.

5. How often do we irrigate?
Beech tree circle, campus center area, West St, and the athletic field are irrigated for about 30 minutes at a time, 2 or 3 times a week, on a need basis. They just got the quad a sprinkler system this fall(05).

6. Do we use a large amount of water for anything in particular (cooling tower or similar)?
Heating plant, water in boilers

7. Do we use water conservation devices such as low-flow shower heads?
Yes, we have it on everything. WPI was recognized as one of the best water saving institutions in Worcester.

8. Do you see a need for further water saving in the future?
Not too much needed

9. Do you think using reclaimed water would be a good way to save water?
Again, it's not really necessary now. The cost of plumbing isn't worth it.

10. What uses would you be comfortable using reclaimed water on? Such as irrigation, toilet flushing, etc.
Irrigation

Appendix B. Drinking Water Standards.

Microorganisms

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Cryptosporidium (pdf file)	zero	TT [3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and fecal animal waste
Giardia lamblia	zero	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste
Heterotrophic plate count	n/a	TT[3]	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC measures a range of bacteria that are naturally present in the environment
Legionella	zero	TT[3]	Legionnaire's Disease, a type of pneumonia	Found naturally in water; multiplies in heating systems
Total Coliforms (including fecal coliform and *E. Coli*)	zero	5.0%[4]	Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present[5]	Coliforms are naturally present in the environment; as well as feces; fecal coliforms and *E. coli* only come from human and animal fecal waste.
Turbidity	n/a	TT[3]	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff
Viruses (enteric)	zero	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste

Disinfection Byproducts

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Bromate	zero	0.010	Increased risk of cancer	Byproduct of drinking water disinfection
Chlorite	0.8	1.0	Anemia; infants & young children: nervous system effects	Byproduct of drinking water disinfection
Haloacetic acids (HAA5)	n/a[6]	0.060	Increased risk of cancer	Byproduct of drinking water disinfection
Total Trihalomethanes (TTHMs)	none[7] ---------- n/a[6]	0.10 ---------- 0.080	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection

Disinfectants

Contaminant	MRDLG[1] (mg/L)[2]	MRDL[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Chloramines (as Cl_2)	MRDLG=4[1]	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort, anemia	Water additive used to control microbes
Chlorine (as Cl_2)	MRDLG=4[1]	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort	Water additive used to control microbes
Chlorine dioxide (as ClO_2)	MRDLG=0.8[1]	MRDL=0.8[1]	Anemia; infants & young children: nervous system effects	Water additive used to control microbes

Inorganic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	0[7]	0.010 as of 01/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronicsproduction wastes
Asbestos (fiber >10 micrometers)	7 million fibers per liter	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromium (total)	0.1	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	1.3	TT[8]; Action Level=1.3	Short term exposure: Gastrointestinal distress Long term exposure: Liver or kidney damage People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits
Cyanide (as free cyanide)	0.2	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	4.0	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead	zero	TT[8]; Action Level=0.015	Infants and children: Delays in physical or mental development; children could show slight deficits	Corrosion of household plumbing systems; erosion of natural deposits

Inorganic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
			in attention span and learning abilities Adults: Kidney problems; high blood pressure	
Mercury (inorganic)	0.002	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands
Nitrate (measured as Nitrogen)	10	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Nitrite (measured as Nitrogen)	1	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Selenium	0.05	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines
Thallium	0.0005	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories

Organic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Acrylamide	zero	TT[9]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/wastewater treatment
Alachlor	zero	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops
Atrazine	0.003	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops
Benzene	zero	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills
Benzo(a)pyrene (PAHs)	zero	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines
Carbofuran	0.04	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa
Carbon tetrachloride	zero	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities
Chlordane	zero	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide
Chlorobenzene	0.1	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories
2,4-D	0.07	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops
Dalapon	0.2	0.2	Minor kidney changes	Runoff from herbicide used on rights of way
1,2-Dibromo-3-chloropropane (DBCP)	zero	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards
o-Dichlorobenzene	0.6	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories
p-Dichlorobenzene	0.075	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories
1,2-Dichloroethane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories

Organic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
1,1-Dichloroethylene	0.007	0.007	Liver problems	Discharge from industrial chemical factories
cis-1,2-Dichloroethylene	0.07	0.07	Liver problems	Discharge from industrial chemical factories
trans-1,2-Dichloroethylene	0.1	0.1	Liver problems	Discharge from industrial chemical factories
Dichloromethane	zero	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories
1,2-Dichloropropane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
Di(2-ethylhexyl) adipate	0.4	0.4	Weight loss, liver problems, or possible reproductive difficulties.	Discharge from chemical factories
Di(2-ethylhexyl) phthalate	zero	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories
Dinoseb	0.007	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables
Dioxin (2,3,7,8-TCDD)	zero	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories
Diquat	0.02	0.02	Cataracts	Runoff from herbicide use
Endothall	0.1	0.1	Stomach and intestinal problems	Runoff from herbicide use
Endrin	0.002	0.002	Liver problems	Residue of banned insecticide
Epichlorohydrin	zero	TT[9]	Increased cancer risk, and over a long period of time, stomach problems	Discharge from industrial chemical factories; an impurity of some water treatment chemicals
Ethylbenzene	0.7	0.7	Liver or kidneys problems	Discharge from petroleum refineries
Ethylene dibromide	zero	0.00005	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries
Glyphosate	0.7	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use
Heptachlor	zero	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide

Organic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Heptachlor epoxide	zero	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor
Hexachlorobenzene	zero	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories
Hexachlorocyclopentadiene	0.05	0.05	Kidney or stomach problems	Discharge from chemical factories
Lindane	0.0002	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens
Methoxychlor	0.04	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock
Oxamyl (Vydate)	0.2	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes
Polychlorinated biphenyls (PCBs)	zero	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals
Pentachlorophenol	zero	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood preserving factories
Picloram	0.5	0.5	Liver problems	Herbicide runoff
Simazine	0.004	0.004	Problems with blood	Herbicide runoff
Styrene	0.1	0.1	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills
Tetrachloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners
Toluene	1	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories
Toxaphene	zero	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle
2,4,5-TP (Silvex)	0.05	0.05	Liver problems	Residue of banned herbicide
1,2,4-Trichlorobenzene	0.07	0.07	Changes in adrenal glands	Discharge from textile finishing factories

Organic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
1,1,1-Trichloroethane	0.20	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories
1,1,2-Trichloroethane	0.003	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories
Trichloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories
Vinyl chloride	zero	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories
Xylenes (total)	10	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories

Radionuclides

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Alpha particles	none[7] ---------- zero	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation
Beta particles and photon emitters	none[7] ---------- zero	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation
Radium 226 and Radium 228 (combined)	none[7] ---------- zero	5 pCi/L	Increased risk of cancer	Erosion of natural deposits
Uranium	zero	30 ug/L as of 12/08/03	Increased risk of cancer, kidney toxicity	Erosion of natural deposits

[1] Definitions:
Maximum Contaminant Level (MCL) - The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.
Maximum Contaminant Level Goal (MCLG) - The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
Maximum Residual Disinfectant Level (MRDL) - The highest level of a disinfectant allowed in

drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

Maximum Residual Disinfectant Level Goal (MRDLG) - The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

Treatment Technique - A required process intended to reduce the level of a contaminant in drinking water.

(U.S. EPA, 2005)

Appendix C: Questions

Interview 1. John Miller, Director of Physical Plant, at WPI.

- How much water enters the campus?
  - Residential
  - Classrooms
  - Laboratories
  - Elsewhere
- Is there a distinct plumbing setup for the campus, such as a central water main, or is the plumbing incorporated into the municipal distribution system?
- How many athletic fields, labs, agricultural sectors require water?
- Is geography good for a leech field or other specific wastewater disposal systems?
- Where does wastewater currently go?
- What would you like to see happen with the wastewater?
- Do you think that a water reuse project would be useful and/or helpful? Why or why not?
- What uses would you be comfortable with reclaimed water being used on? Such as drinking, irrigation, toilet flushing, etc.
- Do you see any problems with reusing wastewater?

Interview 2. Questionnaire for Marty Laporte, Stanford University Water Resource & Environmental Quality Manager.

- How much water is being saved each month by water reuse?
- How much money do you save each month by water reuse?
- Why did you implement the water reuse system?
- What were the obstacles in starting the water reuse plan?
  - Politically, financially, and concerning public perception?
- How did you get support/funding for the water reuse system?
- How is water treatment maintained?
- Has water reuse only been implemented in new buildings or were there instances in which the plumbing was redesigned in already existing buildings? How many instances and what were they?
- Do you know of any other colleges that implement water reuse?

Interview 3. Questionnaire for Kirk Pawlowski, Washington State University Capital Planning and Development Manager.

- Why was the plan for water reuse proposed?
- What were the economic, political, and social reasons for the plan's
- rejection?
- How would the plan have helped the campus?
    - Socially, environmentally and economically?
- Do you think there is a future for water reclamation at Washington State University?

Interveiw 4. Questionnaire for Peter Fox, Director of the NCSWS at ASU.

- What are the obstacles that the NCSWS face in terms of water reuse?
    - Concerning technology, acceptance by other universities, politics?
- What is the current system for wastewater disposal at Arizona State
- University?
- How has wastewater disposal and water use been impacted by the creation
- of the NCSWS at Arizona State University?
- How do you feel about reusing water at universities?

Interview 5. Questionnaire for Charles Morgan, Director of Landscape Services at UCSD.

- How much total water do you use on campus?
- How large is the campus(acres)?
- How much money do you save each month by water reuse?
- Why did you implement the water reuse system?
- What were the obstacles in starting the water reuse plan?
  - Politically, financially, and concerning public perception?
- How did you get support/funding for the water reuse system?
- Where does your reclaimed water come from(on site treatment plant or municipal source)?

Interview 6. Questionnaire for Larry Kirkland, Environmental and Energy Engineer at University of Idaho.

- How much water is used for irrigation?
- How much money do you save each month by water reuse?
- Why did you implement the water reuse system?
- What were the obstacles in starting the water reuse plan?
    - Politically, financially, and concerning public perception?
- How did you get support/funding for the water reuse system?

Glossary

Aerobic microorganisms – bacteria that consume oxygen

Cooling tower make up water – water added to a cooling tower to replace water that becomes vapor that is blown away

Direct Potable Water Reuse – using reclaimed water for drinking purposes directly following treatment

Improved water supply – a supply of water obtained through a household connection, public standpipe, borehole, protected dug well, protected spring, or rainwater collection

Potable – drinkable (see Appendix B for drinking water standards)

Pumper – a person or group that draws from a source via pumping

Quenching glassware – a process in which water is used to cool glass reactors during a reaction

Reclaimed water – Wastewater that has been highly treated, and can be as clean as standard drinking water

Water recharge – to augment an existing water supply

Water Reuse – Use of reclaimed water

References

Anderson, J. (2003). Environmental benefits of water recycling and reuse. *Water Science & Technology: Water Supply*. 1-10

Asano, T. (1999). Groundwater Recharge with Reclaimed Municipal Wastewater -Regulatory Perspectives. Retrieved 1/28/06 from, http://www.unep.or.jp/ietc/Publications/ReportSeries/IETCRep9/4.paper-D/4-D-asan1.asp

Bixio, D. (2005). Municipal wastewater reclamation: Where do we stand? An overview of treatment technology and management. *Water Science & Technology: Water Supply*. 77

Brevard County. (2005). Reclaimed Water Information. Retrieved 2/5/06 from, http://countygovt.brevard.fl.us/water-resources/reusinfo.cfm

Brown, T. Ferraro, M. Padden, M. (2005). *Design of Water Reuse System, an Interactive Qualifying Project*. (Report No. PSM-MS03-05). Worcester, MA.

Bryant, K.L.; McLean, J.S. (2005). *Technology and Environment, an Interactive Qualifying Project*. (Report No. IQP-JIB-0502). Worcester, MA.

Burbank Water and Power. Burbank Water and Power-Water Treatment. (2005). Retrieved 9/23/05, from http://www.burbankwaterandpower.com/watertreatment.html

County Studies US. (2003). US Weather. Retrieved 2/3/06, from http://countrystudies.us/united-states/weather/

Domestic Water System. (n.d.). University if Idaho. Retrieved 12/12/05, from www.webs.uidaho.edu/energy/Domestic_Water_System.htm

Electric Power Research Institute. (2004). *The Formation and Fate of Trihalomethanes in Power Plant Cooling Water Systems* (Report No. 500-04-035) Berkley, CA: MND Construction

Encyclopedia Britannica Online. (2006) Retrieved 2/5/06, from http://www.britannica.com

Energy Systems Background. (n.d.). Retrieved 12/8/05, from http://www.webs.uidaho.edu/energy/background.htm

Executive Office of Environmental Affairs. (2004). Massachusetts Water Policy 2004. Boston, MA. U.S. Government Printing Office. Retrieved 10/9/05, from www.mass.gov/envir/wptf/publications/mass_water_policy_2004.pdf

Executive Office of Environmental Affairs. (2000). *Interim Guidelines on Reclaimed Water (Revised).* Boston, MA.

Fast facts about U.S. population growth. (n.d.). Retrieved 10/11/05, from www.npg.org/popfacts.htm

Future Water Recycling Rate Increase. (n.d.). San Diego Water Dept. Retrieved 12/5/05, from www.sandiego.gov/water/recycled/rateincrease.shtml

Hari, J. (2005, July 22). This Summer's Drought Represents Just The Beginning Of A Thirsty Century. *The Independent (London)*. p. Features 35.

How Wastewater Treatment Works…the Basics. (1998). United States Environmental Protection Agency. Retrieved 9/13/06 from, http://www.epa.gov/npdes/pubs/bastre.pdf

Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water. (1998). National Academy Press. Washington, D.C.

JEA. (2004). Reclaimed Water. Retrieved 2/5/06, from http://www.jea.com/community/reclaim.asp

Lazarova, V.; Hills, S.; Birks, R. September 2003. Using recycled water for non-potable urban uses: A review with particular reference to toilet flushing. *Water Science & Technology: Water Supply*. 69-78.

Lichfield, J. (2005, July 2). The French Drought: The Rivers Run Dry; Parched Meadows and Water Shortages Indicate France Is Already Facing. *The Independent (London)*. p. Foreign news 24-25.

Macintyre, D. (2005). Troubled Waters: New Life For The Dead Sea? *The Independent*

Maddaus Water Management and Stanford University. (2003). Water Conservation, Reuse, and Recycling Master Plan. Retrieved 11/27/05, from http://facilities.stanford.edu/conservation/FINALStanfordConservation_Recommended_Plan10_16_033.pdf

Massachusetts Department of Environmental Protection. (n.d.). Wastewater Reuse – Frequently Asked Questions. Retrieved 9/21/05, from http://www.mass.gov/dep/water/wastewater/wrfaqs.htm

Massachusetts Executive Office of Environmental Affairs. (2004). *Massachusetts Water Policy*. Boston, MA.

Maynard R. (2005). The taps are dry, the reservoirs empty: Australia runs out of water. *The Times* (London), pp. Overseas news 39.

McFadden, D. (1999). The Colorado River, a Strained Lifeline. MSNBC. Retrieved 2/5/06, from http://msnbc.msn.com/id/3072089/

Metcalf & Eddy. (1991). *Wastewater Engineering Treatment, Disposal and Reuse* 3rd ed.

Metcalf & Eddy. (2003). *Wastewater Engineering Treatment, Disposal and Reuse* 4th ed.

Middlebrooks, J.E. (1982). *Water Reuse*. Michigan: Arbon Science Publishers.

Millennium Development Goals Report 2005. (2004). Retrieved 10/2/05, from http://millenniumindicators.un.org/unsd/mi/mi_series_results.asp?rowID=665

Orange Water and Sewer Authority. (n.d.). Water Reuse – Questions and Answers. Retrieved 1/16/06, from http://www.owasa.org/pages/WaterReuse/questionsandanswers.html

Palouse Water Conservation Network. (2002). H_2Know: Frequently Asked Questions. Retrieved 12/12/05, from www.pcei.org/water/WaterForumFAQSheet.pdf

Pawlowski, K. Email interview. 17 Nov. 2005

Population Action International. (1993). Sustaining Water: Population and the Future of Renewable Water Supply. Retrieved 2/5/06, from http://www.cnie.org/pop/pai/water-21.html

Recycled Water Availability. (n.d.) San Diego Water Dept. Retrieved 12/5/05, from www.sandiego.gov/water/recycled/availability.shtml

Robinson, K.G.; Robinson, C.H.; Hawkins, S. A. (2005). Assessment of public perception regarding wastewater reuse. *Water Science & Technology: Water Supply*

Roesler, R. (2004). Locke Vetoes funding for wastewater project. Retrieved 12/3/06, from www.spokesmanreview.com/local/story_txt.asp?date=040304&ID=s1505751

South Bay Water Reclamation Plant. (n.d.). San Diego Water Dept. Retrieved 12/5/05, from www.sandiego.gov/mwwd/facilities/southbay.shtml

.

Swanenburg (Director). (1998). *The Last Drop*. [Motion Picture] Princeton, NJ: Films for the Humanities & Sciences

Town of Foxborough Annual Report. (2004). Retrieved 9/20/05, from http://www.townfoxborough.us/water/files/Annual%20Town%20Report.pdf

UCSD Blink: Reclaimed Water on Campus. (2005). University of California, San Diego. Retrieved12/5/05, from blink.ucsd.edu/Blink/External/Topics/Policy/0,1162,12895,00.html#a

UI Facilities and Maintenance Operations. (2001). Energy Alert #3. University of Idaho. Retrieved 12/12/05 from www.webs.uidaho.edu/energy/energy_alert3.htm

Unicef Somalia – Water, environment, and sanitation. (2005). UNICEF. Retrieved 10/2/05, from http://www.unicef.org/somalia/wes.html>

United Nations Commission on Sustainable Development. (1999). Natural Disasters and Freshwater Resources. Retrieved 10/11/2005, from http://www.un.org/documents/ecosoc/cn17/1998/background/ecn171998-disast2.htm

United Nations Department of Public Information. (2002). 11am EDT. Press Release. On Eve of World Summit, New UN Report Warns that Current Patterns of Development Compromise Long-term Security of Earth and its People.

University of Idaho. (n.d.). Graphs for University of Idaho. Retrieved 12/7/05, from http://www.webs.uidaho.edu/pbac/Graphs/UI%20Water%20Use%20Graphs.htm

U.S. Congress. (1977). The Clean Water Act. US Government Printing Office. Washington, DC.

U.S. Environmental Protection Agency. (1975). National Interim Primary Drinking Water Regulations. Fed. Reg. 40(248), 59566-59587 (Dec. 24, 1975).

U.S. Environmental Protection Agency. (2000). Wastewater Technology Fact Sheet: Dechlorination.

U.S. Environmental Protection Agency. (2005). Current Drinking Water Standards. Retrieved 10/11/05, from www.epa.gov/safewater/mcl.html#mcls>

Vazquez A. (2005). Save water while quenching cooling towers. *TMF*. Retrieved 2/5/06, from http://www.todaysfacilitymanager.com/tfm_05_09_sustainable.php

Washington State Office of the Governor. (2004). Governor Gary Locke. Retrieved 2/1, from http://www.digitalarchives.wa.gov/governorlocke/default.asp

Water Recycling. (n.d.). San Diego Water Dept. Retrieved 12/5/05, from www.sandiego.gov/water/recycled/

Water Recycling Frequently Asked Questions. (n.d.). San Diego Water Dept. Retrieved 12/5/05, from www.sandiego.gov/water/recycled/faq.shtml

Water Recycling Overview. (n.d.). San Diego Water Dept. Retrieved 12/5/05, from www.sandiego.gov/water/recycled/overview.shtml

Why do we have water bans? (Spring 2001). *Newslink, 5(3)*

Wieland, U. 2005. Statistics on Water (Introduction). UNSD. ECOWAS workshop on environment statistics. Retrieved 10/3/05, from http://unstats.un.org/unsd/environment/session013act.pdf

WSU Water Conservation Efforts Making an Impact. (Aug. 2004). Washington State University News. Retrieved 12/3/05, from www.wsunews.wsu.edu/detail.asp?StoryID=4711