Reclamation and Re-use of Wastewater

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ABSTRACT
Everyday large volumes of potable water are used for applications which do not necessarily require such a high level of treatment. The largest portion of water consumed in the United States is by irrigation (34%) and thermoelectric power generation (48%), neither of which involves potable water consumption (AWWA, 2006). Public opinion and politics highly influence actions taken in regard to water re-ruse, therefore, it is important that people are educated and understand reclamation processes. The re-use of reclaimed wastewater is not a new topic in a global sense, but has been gaining attention in the United States over the recent years. Key concerns of society are related to public health and safety of drinking water. It is crucial that wastewater and water, reclaimed or discharged, are treated properly in order to reduce disease outbreaks caused by pathogenic bacteria, viruses, protozoans and helminths. In effort to remove pathogenic microorganisms, tertiary treatment is used in the final steps of water reclamation. Effluent quality of wastewater prior to tertiary treatment impacts the efficiency of filtration and disinfection processes. Membrane bioreactor technology has been developed and shows significant increases in water quality leaving secondary treatment processes. Cities such as San Diego, California and San Antonio, Texas have employed water reclamation treatment and are in full operation. These cities are able to experience the benefits achieved through water recycling and are on their way to create a sustainable environment.

KEYWORDS
Reclamation, re-use, tertiary treatment, pathogen

INTRODUCTION
Water is a necessity of life, as well as a limited, non-renewable resource. According to the United States Geological Survey (USGS, 2000), the United States alone consumes 408 billion gallons of water per day. Considering that 99% of the water on planet Earth is tied up in ice caps, glaciers and oceans, there is approximately 1% remaining for human consumption. The need for reclamation and re-use of wastewater is becoming even more evident as the remaining water on planet Earth is being consumed by a growing population and threatened by environmental factors such as drought conditions. Preserving high quality drinking water for potable uses and taking advantage of treatment technology for non-potable water uses will be necessary in confronting the current issue of water conservation.

In order to provide an understanding of the importance of wastewater reclamation and re-use this paper will begin by explaining the need for reclamation processes. Definitions of relevant terminology and applications for reclaimed water will then be discussed. Regulations and water reclamation applications will be discussed before the treatment processes of wastewater. Environmental and health risks will be addressed as well as an evaluation of case studies where reclaimed water is being used.

DEFINITIONS
In order to fully understand wastewater reclamation and re-use, a background of the terminology and definitions are necessary. Below is a bulleted list of important terms and definitions (Kasperson, 1977):

- Water reclamation: Upgrading of water in order to make it usable again.
- Potable Usage: Water used for human consumption.
- Non-Potable Usage: Water not intended for human consumption.
- Water Re-use: Actual use of wastewater or reclaimed water.
- Planned Re-use: Collection and purposeful treatment of wastewater for subsequent use.

- Inadvertent Re-use: Water which is withdrawn, used and treated by one party before being discharged without specific intentions to provide the water for future use by other parties (Figure 1A).

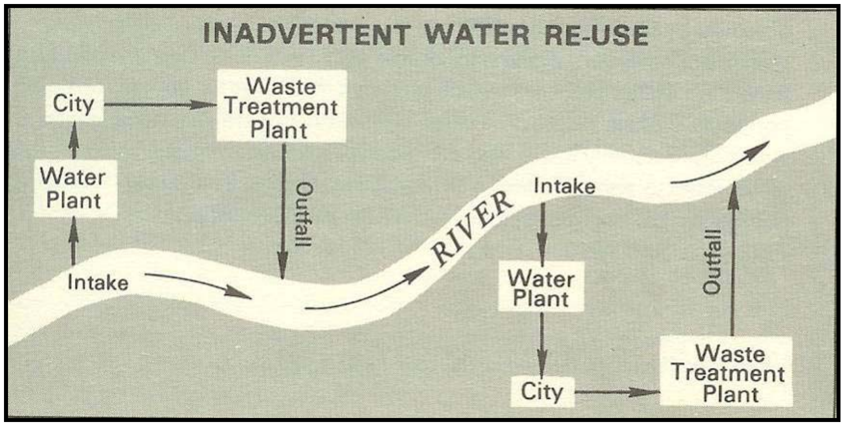

Figure 1A: Inadvertent Water Re-use (Kasperson, 1977)

- Direct Re-use: Specific intended use of reclaimed water (Figure 1B).

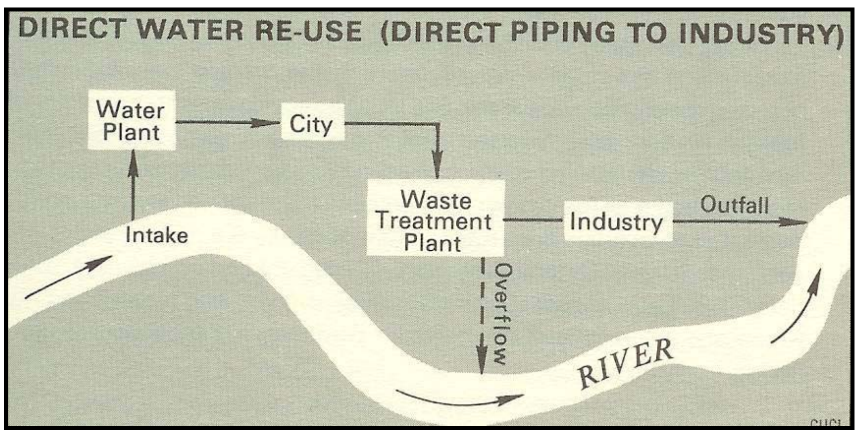

Figure 1B: Direct Re-use (Kasperson, 1977)

- Indirect Re-use: Return of water to natural hydrologic cycle (Figure 1C).

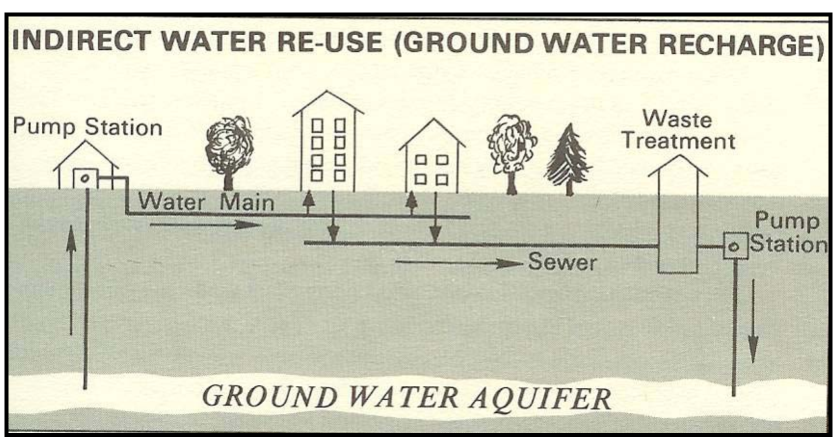

Figure 1C: Indirect Water Re-use (Kasperson, 1977)

APPLICATIONS

In effort to save water for human consumption and other activities requiring high quality water, several application options are currently in use. The re-use of reclaimed wastewater is not a new topic, but has been around since the early 1900's and is much more actively practiced in countries other than the United States. Reclaimed wastewater has several uses which include (Metcalf & Eddy, 2003):

- Agricultural Irrigation
- Landscape Irrigation
- Industrial Activities
- Groundwater Recharge
- Recreational/Environmental Uses
- Nonpotable Urban Uses
- Potable Use

Agricultural Irrigation

Agricultural irrigation consumes approximately 137,000 million gallons of water per day (USGS, 2000). The Monterey Regional Water Pollution Control Agency in Monterey, California began using re-using reclaimed wastewater in 1987 for food crops such as celery and broccoli which were eaten uncooked (Metcalf & Eddy, 2003). It is important that the necessary precautions are taken in respect to the health issues which may arise.

Landscape Irrigation

Irrigation of parks, school yards, freeway medians, golf courses and cemeteries can be accomplished through the use of reclaimed water. In 1960 the City of Colorado Springs, Colorado began re-using water for landscaped areas (Metcalf & Eddy, 2003).

Industrial Activities

Industrial activities such as processing, cooling and fabrication of products consume 19,700 million gallons of water per day (USGS, 2000). One of the first industrial applications of wastewater took place in Baltimore, Maryland in 1942 at Bethlehem Steel Company in steel processing and metal cooling (Metcalf & Eddy, 2003). The use of high volumes of potable water for industrial applications is unnecessary when more environmentally friendly methods can be employed.

Groundwater Recharge

Re-used water is applied to recharge the groundwater by spreading basins or direct injection into the ground. Spreading basins were used as early as 1962 in Los Angeles County California (Metcalf & Eddy, 2003). In many areas of the United States water is being withdrawn from underground reservoirs at a rate which exceeds the rate at which they are replenished. An example of this phenomenon is the cone of depression which has developed around the Chicago, Illinois area.

Recreational/Environmental Uses

Ponds, marshes and recreational lakes can add aesthetic value to land, especially that in a newly developed area or golf course. Reclaimed water can provide much benefit when used in wetland areas.

Non-potable Urban Uses

A re-use application not often considered is the use of nonpotable water in the fire sprinkler systems, toilet flushing and air conditioning of buildings. Grand Canyon National Park in Arizona began using reclaimed water for toilet flushing, lawns, cooling water and boiler feed water in 1926.

Potable Use

Potable use of reclaimed water would involve the blending of properly treated wastewater into the public water supply. Public acceptance is the primary concern for this type of re-use application. Advanced reclamation systems in combination with potable water supplies began in the City of Windhoek, Namibia as early as 1968 (Metcalf & Eddy, 2003).

Studies and evaluations have been performed using a combination of different applications, such as groundwater recharge and agriculture, industry and non-potable usage. An extensive groundwater recharge and re-use project in Israel uses a soil aquifer treatment (SAT) process as part of the municipal wastewater treatment system (Kanarek, et. al., 1996). Effluent water is spread into basins to allow for water to infiltrate the recharge zone. Collection wells are placed so that the water leaving the recharge zone is separate from that of the overall aquifer. Some of the major processes occurring throughout the whole process include: slow-sand filtration, chemical precipitation, adsorption, ion exchange, biological degradation, nitrification, denitrification and disinfection (Kanarek, et. al., 1996). Upon exit of the recharge zone, the effluent water is of high quality and suitable for many other non-potable uses described in the **APPLICATION** section.

HEALTH ASPECTS

Protection of the public's health is the greatest concern in reclaimed wastewater usage. Oftentimes pathogens are difficult to detect due to their low concentration and random distribution in the water (Toze, 2006). Most disease causing organisms found in water are enteric of origin. Enteric pathogens target the intestinal tract. Different types of waterborne enteric pathogens include viruses, bacteria, protozoans and helminths.

Viruses are the smallest organisms and require a host cell, such as humans, to survive. Humans who become infected with a virus can experience symptoms such as fever or diarrhea. Hepatitis A is a virus that can be transmitted through the fecal/oral route. Other waterborne viruses of interest are *Rotavirus* and *Norwalk virus*.

The most common pathogens found in reclaimed water are bacteria. Contaminated water has the potential to carry bacteria such as *Salmonella*, *Shigella*, *Escherichia coli* and *Campylobacter*. Many bacterial pathogens cause gastroenteritis or diarrhea and require a high dosage of cells to be ingested (Toze, 2006). Even though many bacterial pathogens are enteric, that which causes *Legionella pneumophilia* is not.

Protozoans are considered the most difficult organisms to remove since many of them produce cysts that are resistant to disinfection and can survive for long periods of time. Protozoan pathogens include *Giardia Lamblia*, *Cryptosporidium* and *Etamoeba histolytica* (Toze, 2006). Since the infectious dose of these pathogens is very low, awareness of these organisms in recycled wastewater streams is critical. Filtration technologies have the ability to remove protozoan cysts, oocyts and helminth ova (Metcalf & Eddy, 2003).

Helminths are parasitic worms that, like protozoans, are highly resistant to disinfection. Most helminths (nematodes and tapeworms) are transmitted through contaminated feces and urine. The World Health Organization (WHO) believes intestinal nematodes are of greatest concern in untreated wastewater (Toze, 2006). Due to the fact that recycled water has already been treated, these microorganisms do not pose a very large threat in water reclamation. The most common diseases caused by helminths are *Schistosomiasis* and *Ascariasis*.

A case study has been completed comparing the fecal contamination of greywater to the associated microbial risk. Greywater, wastewater absent of toilet water, is thought to have a higher chemical concentration and organic material and is oftentimes re-used for irrigation and recreation purposes (Ottoson, et. al., 2003). The organic matter may constitute an increased growth of enteric bacteria. Depending on the type of quantitative microbial risk assessment (QMRA), the risk for contamination of rotavirus, *Salmonella*, *Campylobactor, Cryptosporidium* and *Giardia* in the greywater were different (Ottoson, et. al., 2003). Overall, rotavirus and *Salmonella* present the greatest risk and must be monitored properly for health reasons.

TREATMENT TECHNOLOGIES

Membrane Biological Reactors

Biological processes preceding tertiary treatment procedures greatly impact effluent water quality. Higher quality effluent wastewater may be achieved by upgrading existing wastewater treatment plants with technologies such as membrane biological reactors (MBR). Membrane bioreactors are systems that consist of a membrane modules either integrated or used in addition to the activated sludge bioreactor stage of the wastewater treatment process. Integrated modules are fully submerged in the bioreactor, whereas modules used in addition to the bioreactor are situated in-line with biological treatment processes. Figure 4 shows the schematic layout of submerged (a.) and external (b.) bioreactors. Mixed liquor is re-circulated from the reactor to the membrane module before being sent to be disinfected (Metcalf & Eddy, 2003).

In effort to increase effluent water quality, research has been done on enhanced membrane biological reactors (eMBR). Enhanced MBR's involve the application of special microorganisms, called effective microorganisms (EM), in addition to the traditional activated sludge mixture. EM are bacteria which 'oxidize ammonia and nitrites and produce protease, amylase, and celluslase' and are expected to be responsible for degradation of organic material found in wastewater (Jin, et. al., 2005). The application of the eMBR has shown significant removal percentages of chemical oxygen demand (COD) and ammonia nitrogen, as well as, lower start-up times than conventional MBR's. More research is required in order for specific conclusions to be made about the efficiency of the EM.

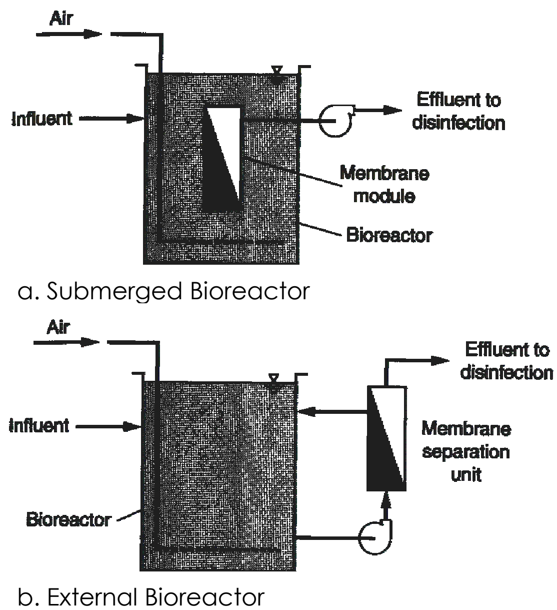

Figure 4: Membrane Bioreactors (Metcalf & Eddy, 2003)

The use of MBR systems combined with an activated sludge bioreactor result in higher quality effluent water than if secondary settling tanks were used alone. This concept introduces an important advantage in regard to the re-use of wastewater. If lower levels of turbidity, bacteria, total suspended solids (TSS) and biochemical oxygen demand (BOD) can be achieved from primary and secondary treatment steps of wastewater treatment, then tertiary treatment processes will operate more efficiently.

In order for water to be considered for re-use advanced tertiary treatment procedures must be employed in addition to preliminary, primary and secondary treatment. Below is a list of tertiary treatment procedures which can be used for water reclamation:

- Filtration
- Disinfection Processes

These tertiary treatment processes are important in working toward the removal of pathogens in wastewater and dependent on the water quality which precedes this step. Oftentimes in water reclamation facilities, both filtration and disinfection processes are employed. Due to the effect of these organisms on humans, removal through tertiary treatment processes is of key interest.

Filtration

Filtration for tertiary treatment purposes can be separated into three different types of membrane processes based on the membrane pore size which include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Microfiltration and UF processes are typically used as pretreatment step before NF and RO. Nanofiltration and RO are often used to treat water used for indirect re-use.

Filtration technologies have the ability to remove many constituents not able to be removed by sludge settling. The removal capabilities of bacteria, protozoans and viruses are of particular interest regarding health concerns of wastewater reclamation. Figure 5 shows how different membrane technologies perform in the removal of certain constituents.

Research has been done comparing macrofiltration, disk and sand filters, and membrane technologies, microfiltration and ultrafiltration. A study performed by M. Gomez compared the removal of nematode eggs, fecal coliform, *E. coli* and coliphages from wastewater subjected to macrofiltration and membrane treatment (2006). It was found that effluent water from both technologies was absent of nematode eggs (Gomez et. al., 2006). Low removal of *E. coli* and fecal coliform was observed for both the disk and sand filters (Gomez et. al., 2006). Membranes were able to remove all *E. coli* bacteria, but failed to remove all fecal contamination (Gomez et. al., 2006). Fecal contamination was found more frequently in microfiltration than ultrafiltration, probably due to the larger pore size. Removal capacities of macrofiltration processes are highly impacted by influent fecal contamination, whereas in membrane systems influent concentration does not impact removal capabilities. Macrofiltration resulted in low retention percentages for coliphage (Gomez et. al., 2006). Membranes showed efficient , not total, removal of coliphage with the ultrafiltration system producing higher removal percentages (Gomez et. al., 2006). Ultrafiltration systems produce the highest quality of water, but the quality must be weighed against the overall economic cost required to obtain it.

High quality water leaving the preceding treatment step is a key issue in filtration processes. Poor quality effluent can cause membrane fouling of filtration systems, especially in nanofiltration and reverse osmosis. Membrane fouling is the clogging of pores due to buildup occurring on the membrane surface. Fouling does not only cause inefficient operation of filtration systems, but also causes damage to the membranes (Metcalf & Eddy, 2003).

	Membrane technology				
Constituent	MF	UF	NF	RO	Comments
Biodegradable organics		✔	✔	✔	
Hardness			✔	✔	
Heavy metals			✔	✔	
Nitrate			✔	✔	
Priority organic pollutants		✔	✔	✔	
Synthetic organic compounds			✔	✔	
TDS			✔	✔	
TSS	✔	✔			TSS removed during pretreatment for NF and RO
Bacteria	✔[b]	✔	✔	✔	Used for membrane disinfection. Removed as pretreatment for NF and RO with MF and UF
Protozoan cysts and oocysts and helminth ova	✔	✔	✔	✔	
Viruses			✔	✔	Used for membrane disinfection

[a] Specific removal rates will depend on the composition and constituent concentrations in the treated wastewater.

[b] Variable performance.

Figure 5: Membrane Technology Performance (Metcalf & Eddy, 2003)

Disinfection Processes
Disinfection processes work to destroy pathogenic organisms and prevent outbreaks of waterborne diseases. It has been found that some parasitic pathogens, such as ova, cysts and certain viruses, are resistant to disinfection processes (Gomez et. al., 2006). The combination of filtration and disinfection allows for the discharge of water free of pathogens. Three common types of disinfection include:

- Ultraviolet Radiation
- Chlorination
- Ozone

Ultraviolet (UV) radiation is a physical process where the water flows through a closed chamber and is exposed to ultraviolet light. This disinfection method is expensive and does not provide any residual. An advantage of this process is that there is a short contact time and the UV rays do not interfere with any other compounds (Rowe, 1995).

Chlorination is a chemical process where chlorine (Cl^-), either liquid or gas, is added to the wastewater stream to remove pathogens. Primary advantages of chlorine disinfection include the long residual time and low cost. Even though chlorine is the most widely used chemical disinfectant, there are some precautions that must be taken. Chlorine has the potential to interact with organic compounds found in wastewater and produce disinfection by-products and undesirable odors (Metcalf & Eddy, 2003).

Ozonation is another chemical process where ozone (0_3) is used as a disinfectant. Complete removal of pathogenic microorganisms can be seen when there are high doses of ozone (Petala, 2006). Research has found that high dosages of ozone have the potential to cause adverse effects to aquatic life. Inhibition of the photobacterium *Vibrio fischeri* was found at high ozone dosages. This occurrence was most likely due to the formation of toxic by-products in the water from the interaction between the chemical and pollutants found in the water (Petala, 2006).

As mentioned in the previous **Filtration** section, water quality leaving each successive step of the treatment process impacts the next. Disinfection is no different. Poor water quality leaving secondary and tertiary processes impacts the effectiveness of disinfection. Wastewater turbidity has the ability to shield pathogens and interfere with disinfection and the detection of coliforms.

CASE STUDIES

Numerous cities across the United States engage in water conservation techniques such as the recycling of water. There is even more participation in other continents besides North America. Locations where there are large populations and/or drought conditions are more apt to employ reclamation technologies. San Diego, California and San Antonio, Texas are two cities where implementation of recycling facilities has been successful.

San Antonio, Texas
The Edwards Aquifer, which provides drinking water to the San Antonio residents, has been rapidly depleted over the past years (Hartley, 2006). In order to sustain the living conditions, water had to be conserved and the need for change was clear. The San Antonio Water System now includes three major water recycling facilities which produce approximately 130,000 acre-feet per year (SAWS, 2006). The water produced from these facilities is for recreational use, not drinking. Over the past years water recycling has contributed to the rising water level of the Edwards Aquifer.

Treatment processes at the San Antonio, Texas water recycling facility are similar to those of traditional wastewater treatment processes. Advanced treatment and disinfection processes include sand filters followed by chlorination. After the period of chlorination, dechlorination occurs through the addition of sulfur dioxide (SAWS, 2006). Dechlorination of the water occurs before being discharged in order to protect marine life. The water can also be re-used instead of being discharged. A schematic layout of the recycling process can be seen in Figure 7.

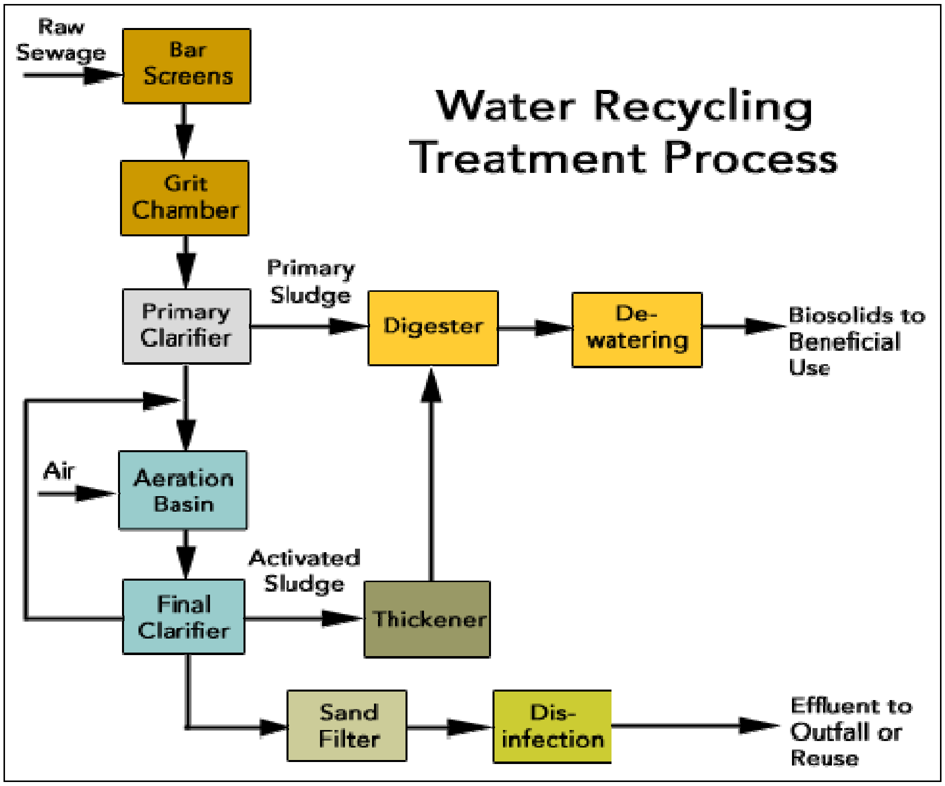

Figure 7: San Antonio Water Recycling Treatment Process (SAWS, 2006)

San Diego, California
The City of San Diego imports approximately 90% of their water from other regions in the United States (The City of San Diego, 2006). This demand has lead to the construction of two reclamation facilities, the North City Water Reclamation Plant Treatment Process and the South Bay Water Reclamation Treatment Process (Figure 6). The South Bay and North City facilities are capable of producing a combined total of 45 million gallons per day (mgd) of reclaimed water. Water discharged from these plants can be used for irrigation and industrial purposes, not for human consumption. Reclaimed water has cost of $0.80 for 748 gallons (hundred cubic feet) compared to $2.003 for potable water (The City of San Diego, 2006). State regulations and health agencies are active in making sure standards are upheld. The cost-effectiveness and regulation of treatment processes promotes the use of reclaimed water.

The South Bay Water Reclamation Plant Treatment Process begins with traditional treatment processes such as bar screens, grit chambers, primary clarifiers, aeration tanks and secondary clarifiers. Upon leaving the secondary clarifier the wastewater then enters tertiary treatment where it is filtered through a bed of anthracite coal. Ultraviolet disinfection is the last step before discharge in order to kill any remaining bacteria. The North City Water Reclamation Plant Treatment Process is similar to South Bay except that a demineralization process and chlorine-contact basins are present after the tertiary filters, not UV disinfection.

In the past there have been discussions to incorporate reclaimed wastewater into San Diego's public drinking supply. The reclaimed water would be treated even further before adding it to public drinking reservoirs. This issue has stirred public attention and been labeled the derogatory term, 'Toilet to tap' (Britton, 2006). The projected water demand is expected to increase by 25% by the year 2030, leading public officials to press for alternative action now (Britton, 2006). At the present time, no reclaimed wastewater is being circulated into public water supplies.

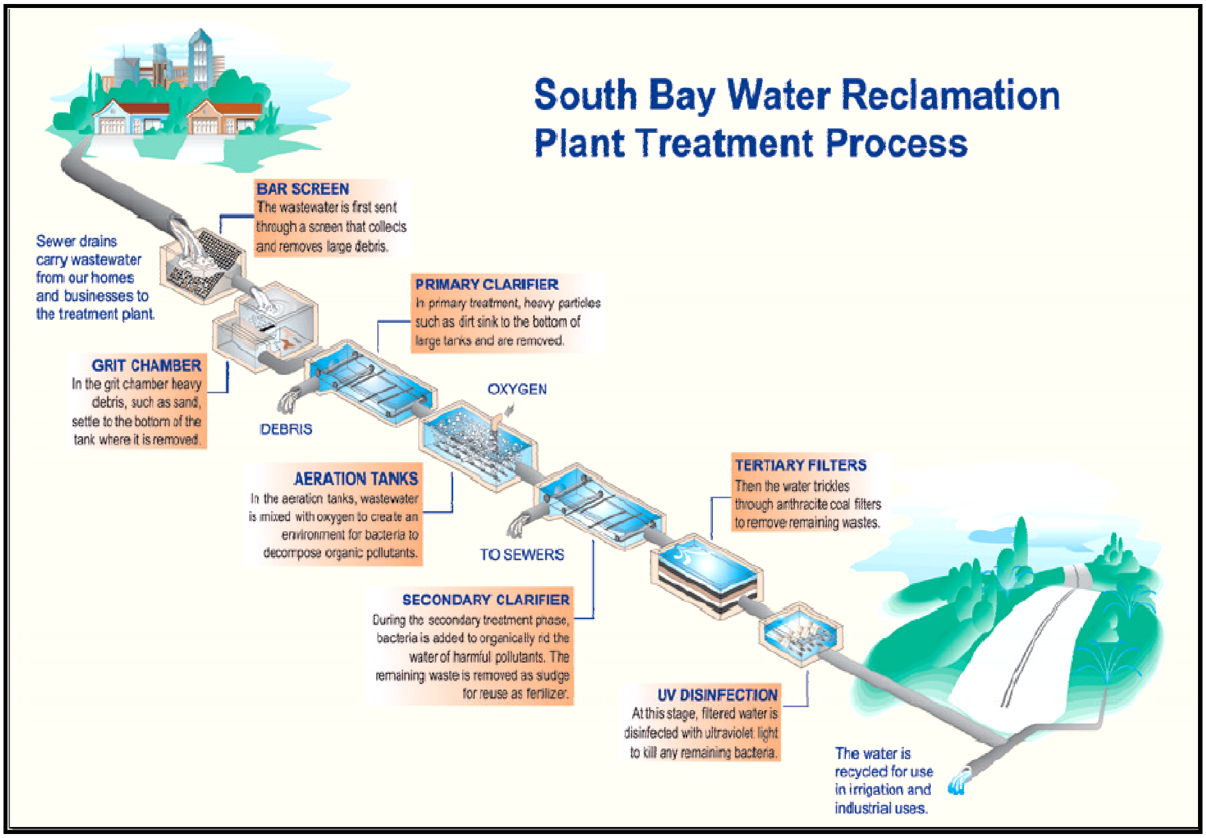

Figure 6: South Bay Water Reclamation Plant Treatment Process (The City of San Diego, 2006)

CONCLUSION

The need for water conservation is crucial due to a growing population and rapid usage of a precious limited resource. The re-use of water is a feasible alternative for many activities such as irrigation and industry applications. Proper treatment of wastewater is possible through membrane bioreactors, filtration processes and disinfection systems. These treatment processes are required to protect the public's heath and ensure pathogenic microorganisms like bacteria, viruses, protozoans and helminths are removed. Water reclamation treatment facilities are being implemented and used in many places across the United States. San Diego, California and San Antonio, Texas are examples of two places where water reclamation and re-use have been successful

Educating society about reclamation processes will help to encourage the movement towards sustainable technologies. Support from public and government agencies is necessary in order for water reclamation technologies to be successful. Communication, motivation, trust and credibility are qualities that decision-makers must possess in order for any new technology to gain acceptance by a controversial society. Much research has been done in the past and is also happening now to gain knowledge about the effects of reclaimed water and its impacts on the environment. The future of water conservation lies in developing technologies to enhance the sustainability of plant Earth.

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