University Curriculum Development for Decentralized Wastewater Treatment

Water Reuse

Module Text

Dr. Bruce Lesikar
Byonghi Lee
Dr. Donald Waller
Erin Lyons

December 2004

NDWRCDP Disclaimer

This work was supported by the National Decentralized Water Resources Capacity Development Project (NDWRCDP) with funding provided by the U.S. Environmental Protection Agency through a Cooperative Agreement (EPA No. CR827881-01-0) with Washington University in St. Louis. These materials have not been reviewed by the U.S. Environmental Protection Agency. These materials have been reviewed by representatives of the NDWRCDP. The contents of these materials do not necessarily reflect the views and policies of the NDWRCDP, Washington University, or the U.S. Environmental Protection Agency, nor does the mention of trade names or commercial products constitute their endorsement or recommendation for use.

CIDWT/University Disclaimer

These materials are the collective effort of individuals from academic, regulatory, and private sectors of the onsite/decentralized wastewater industry. These materials have been peer-reviewed and represent the current state of knowledge/science in this field. They were developed through a series of writing and review meetings with the goal of formulating a consensus on the materials presented. These materials do not necessarily reflect the views and policies of University of Arkansas, and/or the Consortium of Institutes for Decentralized Wastewater Treatment (CIDWT). The mention of trade names or commercial products does not constitute an endorsement or recommendation for use from these individuals or entities, nor does it constitute criticism for similar ones not mentioned.

Citation of Materials

The educational materials included in this module should be cited as follows:

Lesikar, B.J., B. Lee and D. Waller 2005. Water Reuse - PowerPoint Presentation. *in* (M.A. Gross and N.E. Deal, eds.) University Curriculum Development for Decentralized Wastewater Management. National Decentralized Water Resources Capacity Development Project. University of Arkansas, Fayetteville, AR.

Water Reuse

Table of Contents

Water Reuse

Wastewater as a Resource

Water is necessary for human consumption, food production, and many daily tasks, from toilet flushing to fire fighting. Human, agricultural, and industrial demands on the world's fresh water supplies are increasing as the world population continues to grow. In many parts of the United States, especially the Southwest, the demands for water in the near future will exceed the supplies of traditional sources like groundwater and surface water. This situation is forcing governmental agencies to look for alternative water sources and more efficient ways to use and reuse water.

The Hydrologic Cycle

The hydrologic cycle is the natural occurrence of water recycling (Figure 1). Water gathers on the Earth's surface – in oceans, lakes, streams, and other bodies of water, or on and in plants. This water is taken into the atmosphere through the processes of evaporation and transpiration, which are generally combined into the term evapotranspiration since it is extremely difficult to separate the two. As moist air cools, clouds form and the water returns to the Earth as precipitation. This water may end the journey as either surface water or groundwater, and the cycle begins again.

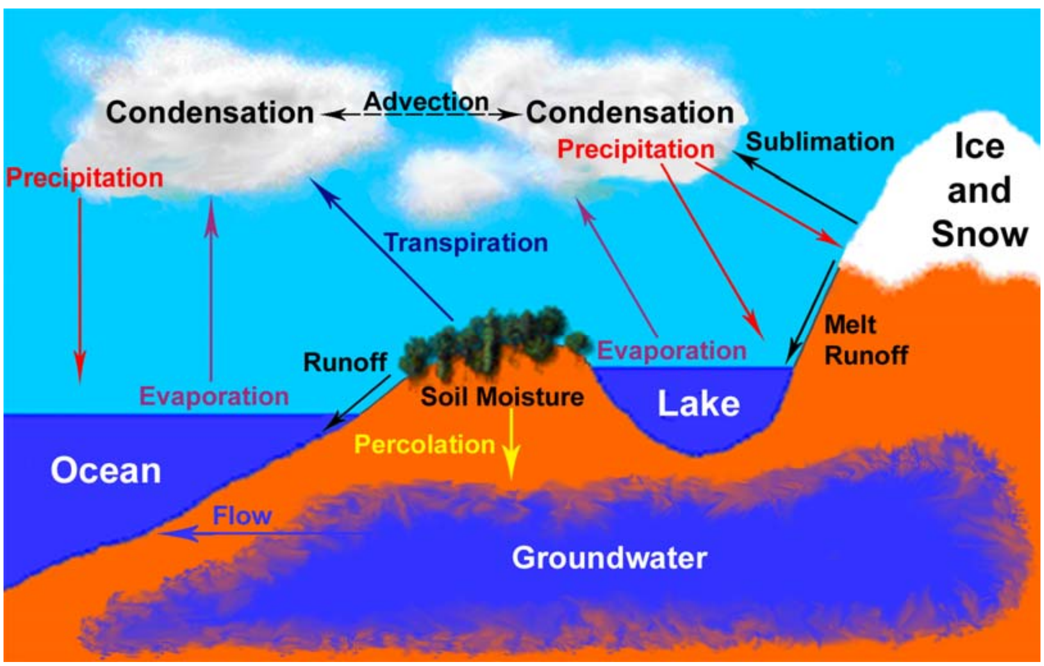

Figure 1: The Hydrologic Cycle

The United States receives enough rainfall annually to cover the entire country to a depth of 30 inches. However, this precipitation is not evenly distributed. The eastern region of the country receives significantly more precipitation. Much of this water – approximately twenty inches – returns to the hydrologic cycle through evaporation and transpiration. Of the remaining amount, approximately 8.9 inches reach the ocean after flowing overland in rivers, and only 0.1 inch reaches groundwater by percolation each year. (USEPA, 2002b)

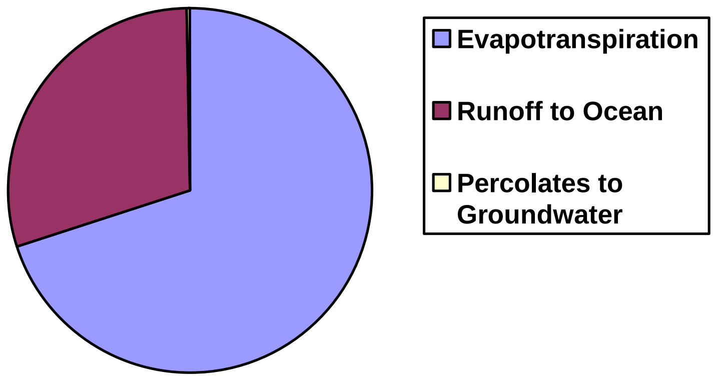

Figure 2: Fate of Water that Reaches Earth as Precipitation.

Fresh Water Supply and Demand

Fresh water is quickly becoming one of the most precious resources on Earth. It is necessary to sustain human life, but only approximately 3% of Earth's available water is fresh. Two-thirds of the total amount of fresh water is frozen in the polar ice caps, glaciers and icebergs, and the remaining third is in the form of either surface water or groundwater (Figure 3).

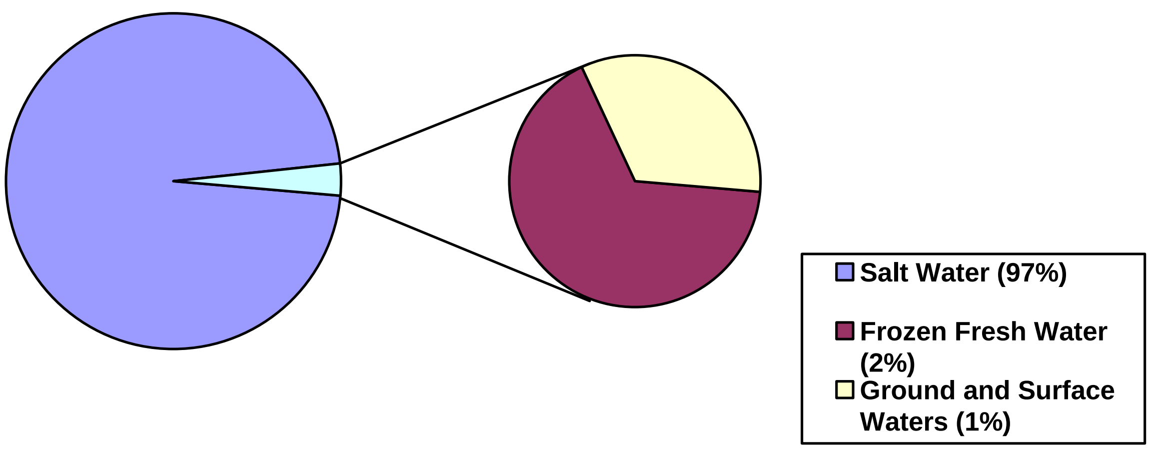

Figure 3: Earth's Water Resources

While the hydrologic cycle is continuous, the amount of water on Earth is finite, and as the world population continues to increase, more and more demands are being placed on the limited fresh water supply. Figure 4 shows the place of humans and water reclamation in the hydrologic cycle. Humankind is an intermediate step in the process, taking water from the groundwater and surface water supplies, treating it, using it, treating it again, and releasing it into the environment, generally into surface water supplies.

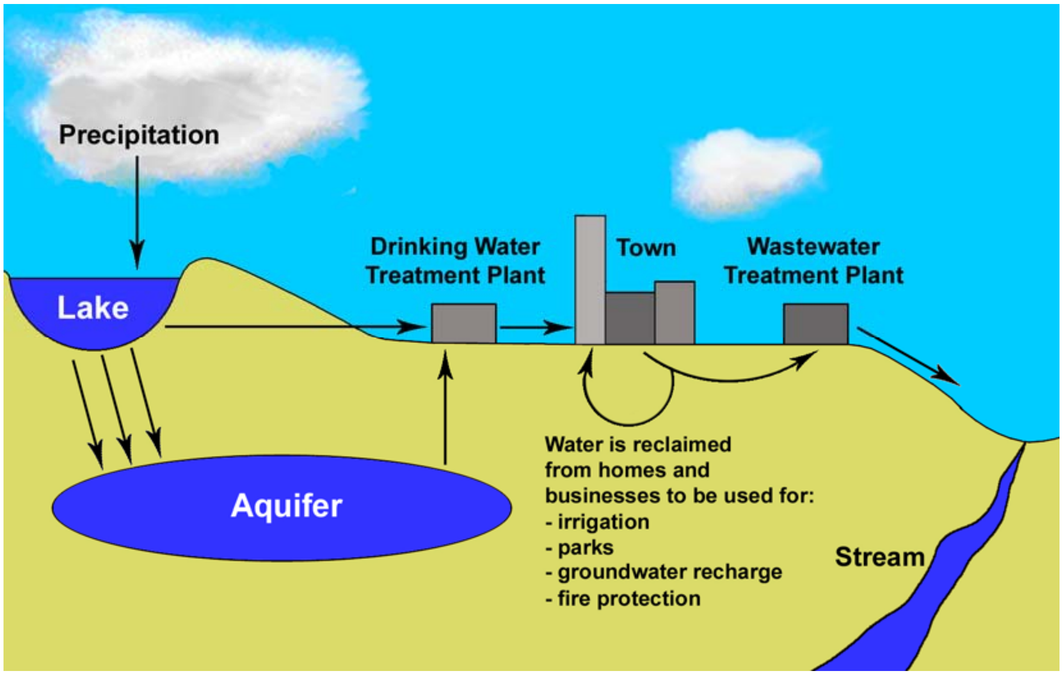

Figure 4: Humans in the Hydrologic Cycle.

According to the United States Geological Survey, in 1995, 402 billon gallons of water per day were withdrawn from fresh and saline sources for use within the United States. Ninety percent of the total withdrawal was used for agricultural and industrial purposes with irrigation accounting for 33% of the total. Household use accounted for 10% of the total amount withdrawn. On average, Americans use approximately 75 to 80 gallons of fresh water per person per day for household purposes. Figure 5 (below) shows the various destinations of household water. The washing machine and toilet alone use 50% of the water that enters the average household. Current rates of water use are not sustainable. Therefore, once fresh water is taken from surface water and groundwater sources it must be used in the most efficient ways possible to compensate for increasing demands from a growing population.

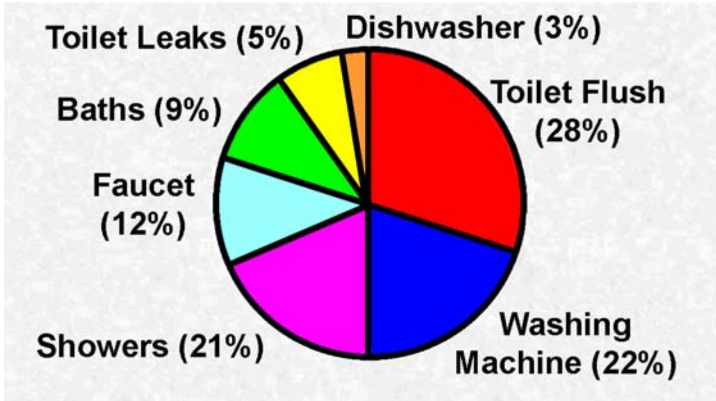

Figure 5: Average household water consumption. (USEPA, 2002b)

Water Recycling Possibilities

Humans already recycle water. After water is used, wastewater is processed through the wastewater treatment plant, where it is treated to meet certain standards, and released back into the environment. After release, the water flows into a body of water, or infiltrates through the soil to recharge groundwater. This water is eventually recaptured, retreated, and reused. The main idea behind water recycling is to make these existing processes more efficient at all levels. For example, an on-site system will allow people to capture and reuse water (at the residential or community level) before releasing it to the municipal water treatment plant. The captured water may be treated or untreated, with the possible uses varying based on the level of treatment.

Figure 6 shows the total water withdrawn and water reuse trend in billion gallons per day in the U.S. from 1950 to 1995. As shown in this figure, the total water withdrawn increased until 1980 and then leveled at approximately 400 billion gallons per day after 1985. From 1950 to 1980, the population increased from 150.7 million to 229.6 million people and in 1990, the population reached 252.3 million people. However, the reclaimed water volume increased dramatically after 1980, thus leveling water withdrawals at 400 billion gallons per day since 1985 (Solley, et al., 1998).

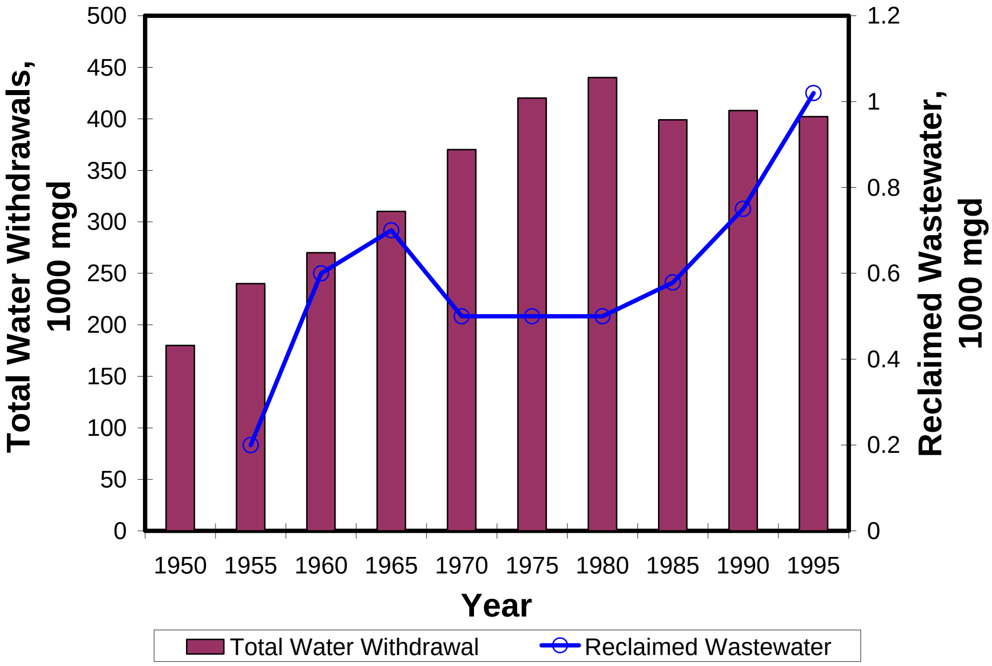

Figure 6: Trends in total water withdrawals and amounts of reclaimed wastewater used in the United States. (Solley, et al., 1998)

Applications for Reclaimed Water

Reclaimed water can be used wherever water is needed. Different uses require different levels of treatment, all of which are technologically possible. Greywater may be applied to plants with little to no treatment, while drinking water must be treated extensively to ensure public safety. Reclaimed water is being used for irrigation (one of the largest consumers of water) and many other tasks around the world. In the U.S., water reuse has been widely used in western states where the amount of rainfall is insufficient to meet demands. However, scarcity of water resources is forcing implementation of water reuse in eastern regions of the country as well. New Jersey and Georgia have recently published guidelines for water reuse (State of New Jersey, 2000, State of Georgia, 2002). However, regulations in the East are not yet as comprehensive as regulations or standards in California, Florida, and Washington.

Wastewater Recovery

Greywater Reuse

Greywater is water captured from sinks, showers, baths, spa baths, clothes washing machines, laundry tubs, and dishwashers. It does not include water from toilets or urinals, which is referred to as blackwater. (In some states, water from food processing areas is also considered blackwater.) This can perhaps be collected separately and used for beneficial purposes, but due to its high organic content black water is not mixed with greywater for reuse purposes. Greywater can be contaminated in three ways due to the addition of waste materials:

(1) Biologically contaminated by microorganisms which may be pathogenic,
(2) Chemically polluted by dissolved salts such as sodium, nitrogen, phosphates and chloride, or by organic chemicals such as oils, fats, milk, soap and detergents, or
(3) Physically polluted by soil sediment, food, lint, sand, etc.

The quantity of greywater generated in each household is determined by the number of occupants, the age distribution of the occupants, their lifestyle characteristics, and water usage patterns. According to a Canadian study, greywater typically represents 68% of the total wastewater from a household or about 61% when kitchen wastewater is excluded. (Waller, et al., 1998). Because the amount of greywater generated is variable, the amount must be estimated before designing and implementing any greywater reuse system. The state of New South Wales in Australia published guidelines for greywater reuse in sewered, single-family residences and recommended suitable greywater reuse application methods depending on applied treatment (New South Wales, 2000). Greywater is commonly used in subsurface irrigation, because subsurface application protects the public from pathogens in wastewater. When greywater receives adequate treatment, including disinfection, it can also be used for surface irrigation.

There are two types of greywater reuse practices. The first of these is using a greywater diversion device, which simply diverts greywater without treatment or storage. When greywater is reused directly in this manner, wastewater from the kitchen sink must be excluded, because it contains grease and solids from the garbage disposal that can block pipes. Storage of untreated greywater must be avoided to prevent the growth of pathogenic microorganisms. Greywater has a high organic content and microorganisms remove free oxygen in the process of consuming the organic matter. When the system has lost all free oxygen, the microbes begin to strip bonded oxygen, resulting in byproducts that have an offensive odor. Therefore, greywater should not be stored (other than temporarily in a surge tank) unless adequately treated. While greywater diversion devices do not treat greywater prior to application to soils, the greywater is filtered through a coarse screen to remove particulate matter that may clog pumps and block pipes, or place too great an organic load on the soil treatment system.

The second practice is that of using domestic greywater treatment systems which collect, treat to a higher standard, and store greywater (including kitchen wastewater) before

reuse.
Various treatment processes can be used in greywater treatment systems including

- Settling
- Floatation of lighter materials
- Anaerobic digestion in a septic tank
- Aeration
- Clarification
- Disinfection.

The first five of these treatment options remove mainly suspended particles and contaminants. They do not significantly remove dissolved chemical components such as nitrate, phosphate, boron and sodium that have the potential to cause environmental problems. Disinfection is only effective in a reuse system if greywater is first treated to reduce TSS and BOD levels. If there is any chance for human or vector contact with greywater, disinfection is essential. If disinfection is not used, a buffer zone must be established between the greywater application zone and the public. If a buffer zone is not established, greywater that has not been disinfected must be dispersed below ground level.

Sudsaver
A vertical axis washing machine uses approximately 40 gallons of water to wash and rinse clothes. Half of the water is used for the wash cycle and half for the rinse cycle. If an extra rinse cycle is used, an additional 20 gallons of water is consumed. Sudsaver is a setting on some washing machines that can be enabled to reduce water usage in washing machines. The Sudsaver feature returns rinse water from the previous wash cycle to the machine for the next wash cycle. Twenty gallons of water can be saved with each wash when this feature is used. One caution associated with Sudsaver is that it should not be used for washing pesticide-soiled clothes since pesticides can be transferred to clothes in the next wash cycle. For general purposes, however, Sudsaver is a safe and simple way to reduce household water consumption.

Wastewater Recycling

In-Facility Use
Instead of discharging greywater to sewers connected to centralized treatment plants, reclaimed water from in-facility treatment systems can be used for toilet and urinal flushing purposes within the facility. In highly populated urban areas with less available water such as Southern California, Tokyo (Japan), and Seoul (Korea), there are two kinds of in-facility water reuse systems: (1) individual building water reuse systems and (2) cluster water reuse systems.

Individual building water reuse systems are commonly used in high-rise buildings to conserve potable water. These buildings are equipped with two separate wastewater lines: (1) a line for sink wastewater and (2) a line for toilet and urinal wastewater. The collected sink wastewater is transferred to the on-site treatment system, usually located at the base of the building. This treatment system consists of chemical coagulation and filtration steps followed by a disinfection step, and generates reclaimed water. Because this wastewater does not contain high concentrations of organic materials, oxidizing units such as aeration tanks are not needed. The reclaimed water generated from this system is used for toilet and urinal flushing. As stated previously, blackwater from toilet and urinal flushing contains high concentrations of organic materials and is sent to the centralized municipal wastewater treatment plant.

A cluster water reuse system collects wastewater from several buildings and treats the wastewater at one location. The reclaimed water is distributed back to each individual building through a cluster distribution system for toilet and urinal flushing. The Irvine Ranch Water District in Irvine, California, is using this system to provide reclaimed water for toilet and urinal flushing in office buildings within the district. Both the Japanese and Korean governments have regulations on in-facility water reuse and the details for both countries can be found in reference (Korea Water Resource Corporation, 2003).

Most municipal wastewater treatment plants have filtration systems that remove total suspended solids (TSS) from treated effluent. This reclaimed water is used for in-facility uses such as pump seal water, equipment and road washing. There are two water lines in most wastewater treatment plants: (1) reclaimed and (2) drinking water. There is a sign at every hose bib where reclaimed water is connected with a message such as “Warning: non-potable water. Do not drink.”

Total Recycle/Non-Discharging/Closed Loop

In areas where freshwater supplies are limited, wastewater supplies can be used to augment these supplies. In this situation, discharges into the environment are eliminated becausewater is circulating in a closed loop. Reclaimed water can be used for many purposes such as irrigation, toilet flushing, and drinking water. One drawback to a closed loop system is the repeated passage of water through the consumption stage, which causes constituents that are not completely removed in reclamation processes to accumulate. This may cause adverse water quality in reclaimed water, such as salt buildup in irrigation water.

A demonstration project tested total recycle for direct potable water in Denver, Colorado, from 1985 to 1992; 0.1 Million gallons per day (MGD) of wastewater was treated to produce drinking water. The multiple-barrier approach, in which no one process is entirely responsible for the removal of a given contaminant, was utilized. The produced water met or exceeded standards of drinking water quality, and no adverse health effects were detected. This project demonstrated the potential for reclaimed water as a direct potable water source.

Water Reuse

Irrigation

Since 1960, irrigation with reclaimed water has been employed in the United Sates, especially in arid Western States. Reclaimed water can be used for irrigating agricultural crops and turf, in settings ranging from urban landscapes to golf courses and sports fields.

Although both quantity and quality issues of reclaimed water need to be addressed for use of reclaimed water for irrigation, this will focus on water quality issues. Information on the quantity issue can be found in reference (U.S. Environmental Protection Agency (USEPA), 1992). The physical and chemical characteristics of reclaimed water for irrigation are important, especially in arid zones where extreme temperature and low humidity result in high evapotranspiration rates. Where the evapotranspiration rate is high, chemical and physical constituents can accumulate in soils in a short time. Physical and mechanical soil properties, including dispersion of particles, stability of aggregates, soil structure, and permeability can also be adversely impacted due to irrigation with reclaimed water. Therefore, concern for crop yields and plant health, as well as the change of soil characteristics, has to be taken into consideration when reclaimed water is used for irrigation.

A number of guidelines for the quality of reclaimed water required for irrigation can be found in USEPA (1992). The most relevant reclaimed water qualities for irrigation are salinity, specific ion toxicity, and nutrients. Salinity in reclaimed water is the single most important parameter in irrigation, and is estimated using electrical conductivity (EC). Electrical conductivity is a measure of the ability of a solution to conduct an electrical current. EC may be used to determine salinity as shown in Equation 1.

$$\text{TDS (mg/L)} \cong \text{EC (dS/m or mmho/cm)} \times 640 \qquad \text{(Equation 1)}$$

where TDS = total dissolved solids, mg/L
EC = electrical conductivity, dS/m or mmho/cm
Salinity is expressed as mg TDS/L

There are three ways that salt in reclaimed water can affect the growth of plants: (1) osmotic pressure caused by high salt content in the soil water, (2) specific ion toxicity caused by individual ions, and (3) soil particle dispersion caused by high sodium and low salinity. The effect of salinity on crop production must be considered first when reclaimed water is used for irrigation.

When a high concentration of specific ions—not osmotic pressure alone—affects plant growth, it is referred as “specific ion toxicity.” The ions in this case are sodium, chloride and boron. The most prevalent toxicity is boron, which comes from household detergents and industrial sources. The quantities of chloride and sodium are also increased by household activities, especially when water softeners are used. Specific ions may accumulate in soil water, posing human and animal heath hazards. In addition, ions may impede the plants’ ability to photosynthesize..

When high quantities of sodium are present in reclaimed water, sodium toxicity can occur in plants, and the physical characteristics of soil can be deteriorated. Examples include formation of crusts, waterlogging and reduced soil permeability. This reduces reclaimed water infiltration and makes it virtually impossible to supply enough water to vegetation. The adverse changes of soil characteristics can occur within the top few centimeters and are related to structural stability. To predict the possible effects of sodium on infiltration, the sodium adsorption ratio (SAR) is often used.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \qquad \text{(Equation 2)}$$

The cation concentrations are expressed in milliequivalents per Liter (meq

To estimate the effects of sodium more accurately, the adjusted sodium adsorption ratio (adj R_{Na}), which includes changes in calcium solubility in the soil water, can be used. Details on the adjusted sodium adsorption ratio (adj R_{Na}) can be found in Metcalf and Eddy (2003).

$$adjR_{NA} = \frac{Na^{+}}{\sqrt{\frac{Ca_x^{2+} + Mg^{2+}}{2}}} \qquad \text{(Equation 3)}$$

Concentrations of Na^{+}, Mg^{2+}, and Ca_x^{2+} are expressed in meq/L and the value for Ca_x^{2+} is available from tables in Metcalf and Eddy (2003).

Agricultural Irrigation

Agricultural irrigation using reclaimed water to support crop production is a well-established practice in arid and semiarid regions. A significant portion of existing water reuse systems supplies reclaimed water for agricultural irrigation. In California, Florida, and Texas, the total volumes of reclaimed water used for agricultural irrigation are 150, 90, and 290 MGD, respectively. This is approximately 63% and 34% of the total volume of reclaimed water in California and Florida, respectively. If reclaimed water can meet a high demand of agricultural irrigation, a significant portion of fresh water resources can be saved for other beneficial uses.

When reclaimed water is used for agricultural irrigation, protecting the public from disease is the first priority. Regulations list the requirements according to the types of crops irrigated with reclaimed water. In Florida, reclaimed water used for irrigation of edible crops must have higher water quality than that applied to crops for cattle grazing. After reclaimed water is applied to pastures, a waiting period is required before allowing dairy cattle to graze when their milk is intended for human consumption. In addition, setbacks between irrigated and public access areas are specified depending on the type of irrigation, the degree of disinfection of the reclaimed water and the types of public access areas affected. The state of Washington specifies setback distances, and the quality of reclaimed water that can be applied depending on whether crops are food or nonfood.

California has similar regulations.

Landscape Irrigation
Landscape irrigation applies reclaimed water to decorative plants such as grasses, trees, and shrubs. Trees and shrubs are more desirable as landscape elements when reclaimed water is being used because they require less water than grasses. Irrigation systems that incorporate water-saving features are also advantageous because production and transportation of reclaimed water is a significant part of capital and operation/maintenance costs for water reuse systems.

Reclaimed water is used for landscape irrigation in two situations:

(1) Irrigation of restricted areas (e.g., freeway landscapes, other areas where the public has limited access or exposure to reclaimed water) and (2) irrigation of open access areas (e.g., golf courses, parks, playgrounds, schoolyards, residential landscapes or other areas where the public has similar access or exposure to reclaimed water). The quality of reclaimed is specified depending on the level of public access to the areas.

Washington, California and Florida have developed comprehensive regulations on landscape irrigation. The Standards of Washington define that Class C reclaimed water or better can be used in restricted areas, and Class A reclaimed water or better can be used in open-access areas. The classification of reclaimed water is based on processing and disinfection requirements (i.e., Class A has much more stringent standards than Class C). (State of Washington, 1997). California also requires that reclaimed water used in public-access areas meet requirements that are more stringent. In addition to disinfection requirements, these are related to turbidity, the length of time chlorine residual remains in water after chlorination and the presence of F-Specific Bacteriophage MS-2. These requirements can be found in Title 22, Division 4, Chapter 3, CCR. In Florida, the requirement of TSS concentration before disinfection is dictated by regulation along with process and disinfection requirements. Details can be found in Chapter 62-610, FAC. The details for each state's regulation can be found in the references.(State of Washington, 1997, State of Florida, 2000, State of California, 2000).

One well-known application of reclaimed water for landscape irrigation is the urban reuse system in St. Petersburg, Florida. This system has been operational since the 1970s. It features the use of reclaimed water to irrigate residential properties, golf course, parks, schoolyards, and other landscape areas. The city has dual water supply lines: (1) one is for potable water and (2) the other is for reclaimed water. Highly treated reclaimed water is distributed through a reclaimed water distribution system. Currently, more than 20 MGD of reclaimed water is supplied to customers each day. This project was studied by the State Virologist and provided the basis for Florida's high-level disinfection criteria.

Golf Courses
The number of applications of reclaimed wastewater for irrigation of golf courses is growing in the United States. In Florida, 419 golf courses were reported to use 110 MGD of reclaimed water for irrigation – accounting for 19% of reclaimed water used for

irrigation in Florida in 2001. Reuse systems featuring golf course irrigation represented about 43% of all reuse systems in Florida.

Use of reclaimed water for golf course irrigation is increasingly popular in Arizona, California, Hawaii, Nevada, South Carolina, Texas, and Washington. Additionally, Alabama, Colorado, Georgia, Illinois, Missouri, Maryland, Michigan, Montana, New Jersey, New Mexico, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Tennessee and Wisconsin report use of reclaimed water for irrigation of at least one golf course.

For example, the Experience at Ko‘ele golf course in Hawaii uses reclaimed water from the County of Maui/Lana‘i Water Company. In Orlando, Florida, the Water Conserv II reuse system provides reclaimed water to the Orange County National Golf Center.

Sport Fields

Reclaimed wastewater is being used to irrigate sport fields at community centers and schools where there is not enough fresh water for this purpose. Because of the possibility of human contact, reclaimed water for this purpose must be of the highest quality. Hawaii is one of several states that have specific water quality requirements for reclaimed water use on sports fields.

In Hawaii, fresh water is so scarce that subsurface irrigation must be used for irrigation of reclaimed water to maximize efficiency. “Guidelines for the Treatment and Reuse of Reclaimed Water” limits water application through overhead sprinkler irrigation systems. Subsurface irrigation supplies reclaimed water to a plant’s root zone, limiting water loss by evaporation. Reclaimed water is supplied to Brigham Young University-Hawaii and surrounding areas to irrigate its campus, baseball field, rugby field, tropical flowering trees, bananas, diversified crops and experimental turf and pasture grass. The required volume of reclaimed water is between 300,000 and 350,000 gallons per day. Approximately 1.3 million feet of drip tubing is used for this application. In the county of Maui, reclaimed water from Kihie wastewater reclamation facility provides water to irrigate the Kihei Community Center, Kihei Elementary and Lokelani Intermediate Schools, Haggai Institute and the Pi‘ilani Commercial Center through the Kihei Effluent Reuse Core System and the Kihie Effluent Reuse Distribution System, Phase I. These systems include open and closed reservoirs and transportation of reclaimed water.

Water Features

Wastewater can also be utilized in aesthetic features such as decorative pools, fountains, ponds, lagoons, and landscape impoundments. In Florida, reclaimed water for these purposes must also meet high standards. However, Washington has different requirements for reclaimed water qualities for landscape impoundments and decorative fountains. Because reclaimed water in decorative fountains has a greater possibility of human contact than water than landscape impoundments, reuse water used in the fountains require a higher level of treatment.

Parks

In arid and highly populated areas, such as Southern California, where the desire for green spaces is high, reclaimed water is being used to create parks. Grass banks and gardens are being built along lakes and streams to provide an oasis for communities, and effluent from water reclamation facilities is essential to maintain the parks. Some states have regulations on water qualities depending on human accessibility to these facilities.

The best-known application of reclaimed water for creating a park is the Japanese Garden in Los Angeles. This 6.5-acre garden and its 2.5-acre lake receive reclaimed water from Donald C. Tillman Water Reclamation Plant.

Snow Generation
Reclaimed water can be used to make artificial snow. Title 22, Division 4, CCR illustrates the reclaimed water quality requirements for snowmaking, which are high due to the likelihood of human contact. The Snow Valley Ski Resort, located in the San Bernardino Mountains, uses reclaimed water from the town of Running Spring to make snow. Reclaimed water is transported by a 9-mile long pipeline and stored in an aerated reservoir. The water is used for snowmaking in the winter and for maintenance of grass in the summer. Another benefit of snow generation using reclaimed water is the possibility of increased stream flow when the snow melts.

Groundwater Recharge
Reclaimed water can be used to replenish groundwater by direct injection, percolation, and the use of rapid infiltration basins. We generally associate groundwater recharge with rapid infiltration basins and direct injection. However, most final treatment and dispersal systems have a loading rate sufficient for a percolation component as well. Any loading rate greater than 0.1 gallons/ft^2/day will have a percolation component also.

The purposes of groundwater recharge by reclaimed water are: (1) to retard saltwater intrusion, (2) to provide further treatment for future use, (3) to augment potable or nonpotable aquifers, (4) to provide storage of reclaimed water, and (5) to control or prevent ground subsidence. The reclaimed water may also replenish groundwater through infiltration during irrigation. However, the total amount of reclaimed water that infiltrates through the soil should be insignificant due to high irrigation efficiency. When reclaimed water infiltrates and percolates through subsurface soils, filtration and biodegradation can occur. Thus, infiltration and percolation provide additional treatment in a wastewater treatment system. This treatment may eliminate the need for costly advanced pretreatment processes. The level of pretreatment depends on the method of recharge, hydrogeological conditions, requirements of downstream users, and other factors. After reclaimed water blends with groundwater, the mixed water may be indistinguishable from the original groundwater. Thus, the loss of identity of reclaimed water gives a positive psychological impact to users and allows more communities to accept reclaimed water as a valuable water source. Florida imposes limits on total organic carbon (TOC) and total organic halogen (TOX) in reclaimed water for groundwater recharge in order to reduce the risks related to non-conventional and emerging constituents.

Although recharge of groundwater with reclaimed water has obvious advantages for water management, some disadvantages are listed below:

(1) Large land surface requirement for percolation
(2) The cost associated with injection of reclaimed water to underground aquifers
(3) Potential contamination of aquifers by reclaimed water
(4) Incomplete recovery of injected water
(5) The requirement for an entity for aquifer oversight and management of inputs and withdrawals
(6) The potential inability to meet sudden high demand due to slow groundwater movement
(7) Water rights issues

Surface Spreading

Reclaimed water can be spread over the land surface for groundwater recharge. This method is the simplest, oldest, and most widely used for groundwater recharge. The reclaimed water percolates from a basin through an unsaturated (vadose) zone. Percolation through the soil and vadose zone can remove total suspended solids from reclaimed water. The infiltration basins are developed to accelerate percolation and are the favored methods of recharge. These basins allow the most efficient use of space and require little maintenance. The filtered reclaimed water moves down to the groundwater and then some distance through the aquifer. This reclaimed water can be extracted later for beneficial use.

Infiltration basins constructed on highly permeable soils that exhibit high hydraulic conductivity rates are called rapid infiltration basins (RIBs). The soil for RIBs must be fine enough to provide sufficient soil surfaces for biochemical and microbiological reactions. The best-known types of soils for RIBs are sandy loam, loamy sand, and fine sand range. A common management technique used to prevent clogging by soil accumulation is a wetting and drying cycle with periodic cleaning of the bottom. This practice maintains a high infiltration rate, sustains microbial populations to consume organic matter, and promotes biological nitrogen removal. The loading rate can be higher when nitrogen removal is not required in RIBs.

A well-known application of RIBs is Water Conserv II located in Orange County, Florida, which has been in operation for 15 years. The reclaimed water from two wastewater treatment plants is split between microsprinkler irrigation for citrus crops and water for RIBs. The average daily flow of reclaimed water is 30-35 MGD. Forty percent of this water goes into groundwater through RIBs. The network consists of 74 RIBs covering two thousand acres with each RIB containing one to five cells. The design capacity for this system is 22 MGD. Regulations in Florida specify the reclaimed water quality, physical characteristics of basins, setbacks from potable water supply wells, and design and operation requirements. The concentration of nitrate in reclaimed water used in RIBs may not exceed 12 mg/L (as nitrogen) to protect groundwater from nitrate contamination (FAC Ch. 62-610). Excess nitrate in water supplies is known to cause Methemoglobinemia (*"Blue Baby" Syndrome*). This limit also ensures that the concentration in groundwater is less than 10 mg/L nitrate (as nitrogen), which is the state of Florida drinking water standard.

Direct Injection

Reclaimed water can be injected into the groundwater zone, usually by means of a well in a confined aquifer. Direct injection is practiced where groundwater is deep or where hydrogeological conditions do not allow surface spreading of reclaimed water. In addition, the lack of available land for surface spreading may make direct injection the only option for groundwater recharge. Direct injection is an effective method for creating a fresh water barrier against seawater intrusion in coastal regions. High water quality is a necessity because this method of groundwater recharge injects reclaimed water directly into a groundwater zone without any soil treatment. The state of Florida imposes the potable water standard on water to be directly injected. The distance between injection wells and groundwater extraction wells must be maximized to increase the detention time of injected water under ground and allow mixing with natural groundwater. The most common problem in direct injection is clogging of the porous material surrounding the well screen at the bottom of the well. Even small amounts of organic and inorganic materials can cause clogging as the physical, chemical, and biological components in the water form a dense biomat. Dissolved air and gas can also contribute to clogging.

A well known reclaimed water injection project is Water Factory 21, located in Fountain Valley, California. This project provides a freshwater barrier to prevent saltwater encroachment into a potable water supply aquifer. It has been in operation for 26 years. Because injected water must be of the highest quality, Water Factory 21 employs a long series of advanced pretreatment processes. The produced reclaimed water is injected into a series of 23 multi-casing wells, providing 81 individual injection points into four aquifers to form a seawater barrier. The injection wells are located 3.5 miles inland from the Pacific Ocean. Before injection, reclaimed water is blended 2:1 with groundwater from a deep aquifer. Depending on hydrogeological conditions, the injected water flows toward the ocean to form a freshwater barrier or flows inland to augment potable groundwater supply. (USEPA, 1992)

Preventing Saltwater Intrusion

Under natural conditions, the movement of freshwater toward the sea prevents saltwater from encroaching upon coastal aquifers. The interface between freshwater and saltwater is maintained underneath coastal land. This interface is actually a diffuse zone where freshwater and saltwater mix, known as the zone of dispersion or transition zone (Figure 7A). When groundwater near the coastline is pumped, freshwater flowing toward the sea is reduced and saltwater can be drawn toward freshwater zones of the aquifer (Figure 7B). If groundwater withdrawal is continued, freshwater storage in the aquifer will decrease and, in extreme cases, wells supplying fresh water will have to be abandoned.

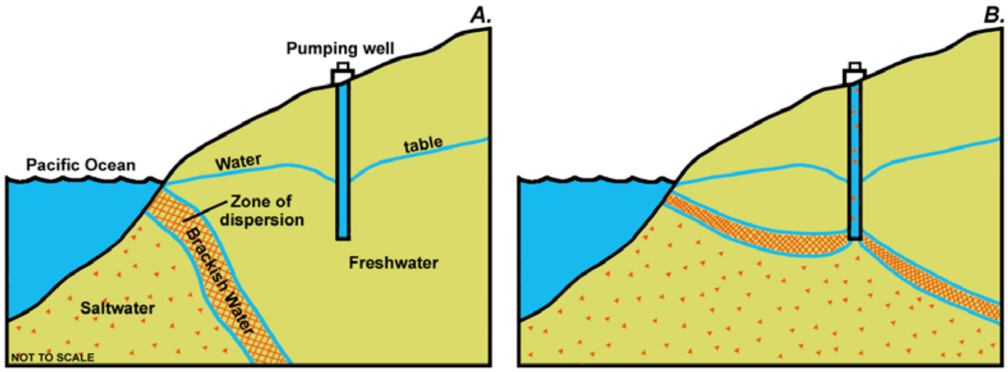

Figure 7: Interface between freshwater and salt water underneath costal land (A) before freshwater withdrawal, (B) after freshwater withdrawal.

Reclaimed water can be recharged to prevent saltwater intrusion toward freshwater in coastal regions (Figure 8). Because many coastal cities in Florida experience seawater intrusion, chapter 62-610, FAC (Florida Administrative Code) has detailed regulations on prevention of saltwater intrusion by reclaimed water injection under the title of salinity barrier systems. This rule specifies the quality of reclaimed water injected for this purpose and the distance between injection and public water supply wells.

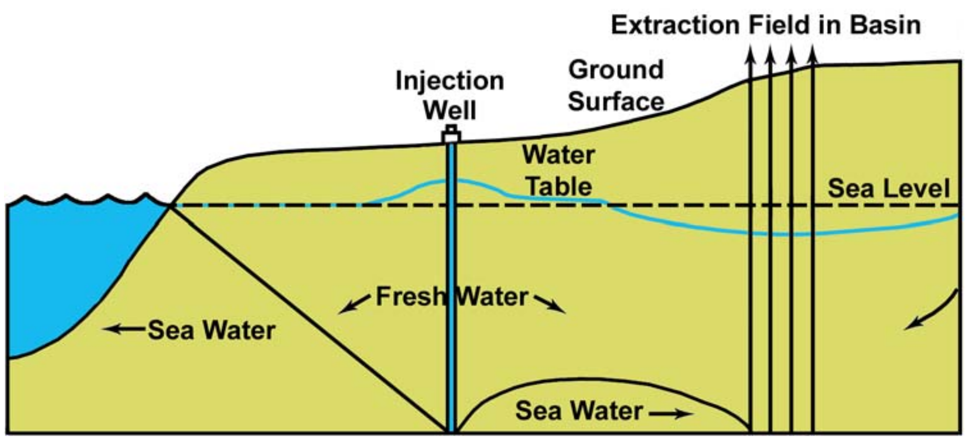

Figure 8: Prevention of salt-water intrusion by reclaimed water injection.

Aquifer Storage and Recovery (ASR)
Groundwater aquifers can provide a means of storage and transmission for reclaimed water. When reclaimed water is used for irrigation that has large seasonal demand, this water can be stored in groundwater aquifers during low demand periods, eliminating the need for large surface storage facilities that cause economic and environmental problems. In addition, aquifers can serve as natural distribution systems and reduce the need for surface transmission facilities.

ASR of reclaimed water involves injection into a subsurface formation for storage and recovery for beneficial purposes later. It is not considered ”reuse” until the water is withdrawn and utilized for beneficial use. Water reuse systems using ASR include groundwater recharge, storage, recovery, and use of reclaimed water. Because the characteristics of injected reclaimed water can change during aquifer storage, change must be predicted in the design stage. Additional treatment and disinfection upon recovery may be needed before beneficial use.

To protect groundwater from any possible contamination, reclaimed water must be highly treated. The treatment and disinfection upon recovery must include reliable filtration and chemical feed facilities. Because the recharged/reclaimed water can affect the quality of adjacent groundwater, extensive water quality monitoring programs must be implemented. Chapter 62-610, FAC provides the details on implementation and monitoring programs for ASR in Florida.

Construction Uses
Reclaimed water can be used for construction activities, including foundation compaction, dust control, water jetting for consolidation of backfill around pipelines and mixing concrete. Reclaimed water can also be used to dampen soil for compaction at landfills. Some constituents in reclaimed water have to be reduced or removed based upon individual application to ensure the safety of construction workers and the public.

Fire Protection
Reclaimed water can be used for fire fighting and prevention. Fire fighting may be either structural or nonstructural, and water standards for each purpose may vary. High water quality is required to fight structural fires due to the high likelihood of human contact. Reclaimed water may be supplied for fire fighting in hydrants or in sprinkler systems in commercial or industrial facilities, hotels, apartment buildings, and condominiums. However, in residential buildings, the residents must not have access to the reclaimed water plumbing system for repairs or modification. In Japan, reclaimed water from municipal wastewater treatment plants is pumped upstream into wooded areas and used to supply stream water for fire fighting. Reclaimed water may also be used for fire prevention. For example, it may be used to maintain an area of vegetation around a property to protect the property from encroaching fires.

When reclaimed water is used for fire protection throughout a community, potable water lines are reduced and drinking water quality is easily maintained. There is no need for redundancy in accommodating fire-fighting water in potable water systems. In conventional potable water systems, large pipes result in a water velocity too slow to maintain proper levels of chlorine residuals (Okun, 2002). One important consideration is that adequate storage is required to be sure that future fire fighting needs can be met, especially since potable lines are reduced in areas where reclaimed water is used for fire fighting.

Greenbelts
"Greenbelt" is the term used to describe a layer of vegetation surrounding a property that acts as a fire barrier. In the Western U.S., where the climate is arid and the risk of fire damage is high, property owners use reclaimed water to maintain a strip of vegetation

around their property. The strip is generally between five and ten feet thick and may consist of any green plants that will not burn quickly. Often, the greenbelt is enough to protect the property until the fire burns around it and away.

Storage

Reclaimed water may be held on-site to be used for fire fighting should the need arise. Storage facilities are generally located uphill of the property, and may be open ponds or enclosed tanks. The storage facility must be large enough to meet any demands placed on it, which may not be limited to fire fighting and protection. There are daily and seasonal imbalances between reclaimed water supply and demand that must be taken into account. In addition to operational storage, seasonal storage or disposal may be needed when reclaimed water is used as the primary source of supply. Reclaimed water is continuously produced while most reuse applications, such as agricultural irrigation, are seasonal. These seasonal and operational storage facilities may meet emergency storage requirements such as fire fighting depending on the storage capacity. If the system cannot meet the emergency demand, a reliable supply system (such as potable water) must be provided.

When open ponds are used for storage, the following problems can occur:

(1) Release of odors, principally hydrogen sulfide
(2) Temperature stratification
(3) Loss of chlorine residual
(4) Low dissolved oxygen resulting in odors and fish kills
(5) Excessive growth of algae and phytoplankton
(6) High levels of turbidity and color
(7) Regrowth of microorganisms
(8) Water quality deterioration due to bird and rodent populations.

Temperature stratification induces the production of sulfide odors. The runoff carrying materials can cause turbidity and color. The result is that the stored reclaimed water cannot be used when there is demand. The most effective method for solving the above problem is aeration. Some chemicals such as copper sulfate can be added to control the growth of plankton.

Enclosed reservoirs may be used to avoid the problems that occur in open ponds. However, enclosed reservoirs have the following problems:

(1) Stagnation,
(2) Release of odors, principally hydrogen sulfide,
(3) Loss of chlorine residual (much slower than open ponds),
(4) Regrowth of microorganisms (much slower than open ponds).

Recirculation of content and addition of chlorine can be effective methods for controlling problems associated with enclosed reservoirs.

Design Considerations

The purpose of any water reuse system is to take used water and use it for another purpose. Reclaimed water systems remove contaminants from wastewater so that it can be used to meet our water needs. Because of potential environmental and health risks, the process must address the necessary water quality. System design issues are: contaminant removal, reliability, and redundancy; each is influenced by the intended use for the treated water. For example, water to be used for drinking, direct injection into groundwater, or RIB discharge must meet the highest water quality standards to protect the health and well being of the public. In these situations, reliability and redundancy must be at high levels to yield a virtually 100% guarantee of clean, safe water.

System Reliability and Redundancy

The treatment plant producing reclaimed water must have reliability and redundancy to ensure uninterrupted operation under any circumstances. The design of process piping, equipment arrangement and unit structures in the reclamation plant must allow for efficient and flexible operations and maintenance to permit the highest possible degree of treatment under varying circumstances. This includes alarms warning of power failure, automatic standby power sources, emergency storage, and provisions for each process having an alarm, multiple units, and standby units. The USEPA published guidelines to ensure system reliability and redundancy in reclamation plants (USEPA, 1973). California and Washington have their own regulations and standards (State of California, 2000, State of Washington, 1997).

Florida established a minimum system size for treatment facilities to ensure continuous production of high-quality reclaimed water. The minimum size for producing reclaimed water for slow-rate land application system, public access areas, residential irrigation and edible crops is 0.1

Site Loading

When reclaimed water is used for agricultural irrigation, the following design criteria have to be considered: (1) hydraulic loading, (2) organic loading, (3) nutrient loading, and (4) salinity. When regulations specify a hydraulic loading rate for land application, they pertain to land application systems that are used to treat wastewater for disposal rather than water reuse. When a land treatment system is developed, the objective is generally to minimize the land area required. In this practice, the hydraulic loading rate is far greater than irrigation demand, and limits are set for the maximum hydraulic loading. On the other hand, when reclaimed water is used to meet the irrigation requirements of crops, irrigation needs establish the hydraulic loading rates. Many states do not specify the hydraulic loading rates when reclaimed water is used in agricultural irrigation. The rates are generally set by site conditions. However, some states set the maximum hydraulic loading rate at 2.0 to 2.5 inches per week. The state of Nebraska sets the maximum rate at 4.0 inches per week.

Six major factors that affect the decomposition of organic materials applied to soils are: (1) carbon-nitrogen ratio, (2) oxygen supply, (3) soil water content, (4) temperature, (5) pH, and (6) salinity. If the carbon-nitrogen ratio in applied reclaimed water is appropriate for optimum biological denitrification, the carbon and nitrogen will be removed simultaneously. Soil must not be saturated for extended periods so that high oxygen levels are maintained, but some soil moisture must be preserved for optimum decomposition. The rate of decomposition increases with increasing temperature. This rate is very slow at 38^{o}F, with the maximum rate occurring at 80 ^{o}F. Bacteria (the major decomposers in soil) are most active within a pH range of 6.5 – 8.5. High salinity in soil will impede the activity of bacteria and reduce organic material decomposition.

When wastewater with high organic content is applied to the land surface, the topsoil layer has a tendency to clog due to the development of a biological mat. This biomat prevents oxygen transfer and creates anaerobic conditions underneath the topsoil layer, causing odors and other problems. In order to maintain aerobic conditions and prevent such problems, Idaho specifies the yearly average organic loading rate must not exceed 50 pounds chemical oxygen demand (COD) per acre per day when wastewater is used for irrigation (State of Idaho, 1996). Chemical oxygen demand is the unit of organic content, based on the amount of chemicals consumed in order to oxidize organic materials. Because wastewater has to be oxidized to become reclaimed water, organic loading is not usually a factor for irrigation with reclaimed water.

Because wastewater contains nitrogen (N), phosphorus (P) and other nutrients, reclaimed water can serve as a source of these nutrients for crops. However, excess supplies of nutrients can cause many problems. From the standpoint of crop nutrition, the macronutrients Nitrogen (N) and Phosphorous (P) and micronutrients calcium (Ca), zinc (Zn), boron (B) and sulfur (S) can be found in wastewater. When reclaimed water is used for agricultural irrigation, the most important nutrient (and the one most frequently occurring in excessive amounts) is nitrogen. Because wastewater has high nitrogen content, reclaimed water can meet the nitrogen demand for crop growth during the early to mid-season crop-growing periods. However, excessive nitrogen supply during the later part of growing period (when plant demand for nitrogen decreases) can cause excessive vegetative growth, delayed or uneven maturity, or reduced crop quality. If an alternative water source with low nitrogen content is available, a switch in water supplies or blending of reclaimed water with other water supplies can be used to keep nitrogen levels under control. Otherwise, nitrogen removal processes have to be implemented in water reclamation. Nitrogen has four different forms in water: (1) organic nitrogen, (2) ammonia nitrogen, (3) nitrite nitrogen, and (4) nitrate nitrogen. Because nitrite is unstable in nature, it is quickly oxidized to nitrate. Nitrogen-loading rates will depend on a number of factors. The main factor is that nitrate causes Methemoglobinemia (*"Blue Baby" Syndrome*). In Florida, the concentration of nitrate in groundwater must not exceed the state water quality standard of 10 mg/L as nitrogen. Idaho recommends nitrogen-loading rates based on crop utilization plus 50%. The extra 50% accounts for normal losses. However, nutrient-loading rates are not a major concern when reclaimed water is used for irrigation, because hydraulic loading rate is generally the limiting factor.

Soluble salts, particularly sodium, in reclaimed water can cause a number of potential problems as explained in *Section 2.3.1 Irrigation*. The effects of salt on soil structure and texture and plant growth have to be considered. Idaho recommends an electrical conductivity less than 2 mmho/cm on average per year for irrigated water. The sodium adsorption ratio (SAR) is a water quality parameter that helps to predict possible infiltration problems based on cation concentrations. Sodium Adsorption Ratio values of less than 10 are acceptable. Problems may be encountered where SAR is more than 10.

Management

Record Keeping

All operational data have to be recorded to ensure the quality of reclaimed water. These data include all analyses specified by regulatory agencies, records of operational problems, unit process and equipment breakdowns, diversions to emergency storage or disposal, and corrective or preventive actions taken. Process or equipment failures that trigger an alarm must be recorded and the records maintained and stored as a separate record file. Some states require submittal of monthly summaries of operating record to proper authorities. In addition, other states require that anytime untreated or partially treated water is discharged, proper authorities must be informed immediately.

Signage

The public and employees must be informed that reclaimed water is being used in an area by the posting of advisory signs, by distribution of written notices to residents or employees, or by other means. All reclaimed water valves, storage facilities, and outlets must be tagged or labeled to warn that the water is not intended for drinking. The signage or advisory notification is often colored purple with white or black lettering. Sign wording generally reads “DO NOT DRINK.” Purple color-coding is an industry standard used to denote reclaimed water.

Cross-Connection Control

No cross-connection between the reclaimed water and the potable water system is allowed. Every possible measure to prevent cross-connection has to be exercised. Where both reclaimed water and potable water are supplied in a use area, back flow prevention devices and air gap separation must be installed at the potable water service connection. Where potable water is used to supplement a reclaimed water system, air gap separation must also be provided. Reclaimed water must not be used in residential buildings unless the residents cannot access the plumbing system. The criteria issued by Washington State provide detailed requirements for cross-connection prevention (State of Washington, 1997).

Operation

To produce reliable and high-quality reclaimed water, capable operators must be stationed in treatment plants, and the quality must be continuously monitored.

Certified Operators

Many states require a sufficient number of qualified operators to achieve the required level of treatment at all times in reclamation plants. Florida requires staffing by certified operators 24 hours/day, seven days/week. This requirement can be reduced to six hours/day, seven days/week if acceptable quality reclaimed water is delivered to the use area only during periods of operator presence, or other reliability features are provided. The classes of operators and lead/chief operator for treatment plants are specified by Florida regulations.

Sampling and Testing

In order to protect the public in the use area from untreated or partially treated wastewater, many states have regulations on sampling frequencies and analyses according to the type of reuse.

Monitoring requirements for reclaimed water vary greatly from state to state and depend on the type of reuse. Arizona requires daily sampling for fecal coliform for unrestricted urban reuse, while monthly sampling is required for agricultural reuse on non-food crops. Continuous turbidity monitoring of reclaimed water is required when a limit on turbidity is specified.

California, Florida, and Washington also require on-line monitoring of turbidity in reclaimed water. Oregon, however, requires that the turbidity be monitored hourly for unrestricted urban, recreational, and agricultural reuse. Daily or weekly sampling for total coliform is required depending on the type of reuse area.

Florida requires a TSS limit that must be achieved before disinfection. Daily samples for coliform must be taken for treatment plants with capacities greater than 0.5 MGD. An annual analysis of reclaimed water used in irrigation based on primary and secondary drinking water standards is required. Concentrations of TOC and TOX must be monitored when reclaimed water is used for either groundwater recharge or indirect potable reuse.

Public Health Considerations

Inorganic and Organic Constituents in Wastewater

Despite development and implementation of advanced wastewater treatment technologies that produce high quality water, there are still concerns about long-term safety of reclaimed water. Since any quality of reclaimed water can be produced, the degree of

treatment must be addressed (i.e., what constituents have to be removed and what quality is acceptable?)
Constituents in municipal wastewater which cause concern for public health can be classified into three groups: (1) Conventional, (2) Nonconventional and (3) Emerging (Metcalf and Eddy, 2003). The typical constituents in each class are presented in Table 1. Conventional constituents can be treated with most conventional wastewater treatment processes. Nonconventional constituents may have to be removed or reduced using advanced wastewater treatment processes, and emerging constituents pose health concerns when wastewater is beneficially reused. The concentrations of nonconventional and emerging constituents are in the micro- or nanogram/L range. In some cases, constituents cannot be removed effectively with advanced wastewater treatment processes. When beneficial reuse of wastewater is considered, the effect of these constituents to public health must be addressed.

Table 1: Classification of typical constituents found in wastewater.

Classification	Constituents
Conventional	Total suspended solids (TSS)
	Colloidal solids
	Biochemical oxygen demand (BOD)
	Total organic carbon (TOC)
	Ammonia
	Nitrate
	Nitrite
	Total nitrogen
	Phosphorus
	Bacteria
	Protozoan cysts and oocysts
	Total dissolved solids
	Viruses
Nonconventional	Refractory organics
	Volatile organic compounds
	Surfactants
	Metals
Emerging	Prescription and nonprescription drugs
	Home care products
	Veterinary and human antibiotics
	Industrial and household products
	Sex and steroidal hormones
	Other endocrine disrupters

Emerging Organics

The advancement of organic material synthesis has made possible the production of a variety of synthetic chemicals. Some scientists believe that these chemicals may disrupt the endocrine system of humans and wildlife. The endocrine system—also referred to as the hormone system—is comprised of glands, hormones, and receptors. The glands located throughout the body produce and secrete the hormones, and the receptors in the various target organs and tissues recognize and react to the secreted hormones. This system regulates a wide range of biological processes such as: control of blood sugar, function of the reproductive system, regulation of metabolism, development of the brain and nervous system, and development of an organism from conception through adulthood.

Endocrine disruptors are defined by the USEPA as “chemicals which interfere with endocrine system function” in any organism (2003). These chemicals are classified as emerging organic compounds (EOCs) and are derived from (1) veterinary and human antibiotics, (2) human prescription and nonprescription drugs, (3) industrial and household wastewater products, and (4) sex and steroidal hormones. The detailed list of chemicals is presented in Metcalf and Eddy (2003).

Several studies have reported on the effects of endocrine disruptors on wildlife in the environment (Trussell, 2001). However, the effects of these chemicals in humans are scientifically controversial. The USEPA is developing a program to provide methods and procedures for detecting and characterizing endocrine activities of synthetic chemicals such as pesticides, commercial chemicals, and environmental contaminants.

Although the effects of EOCs on humans are still being debated in the scientific community, they are a concern when reclaimed water is used for any potable purpose. Over 30 million organic compounds are known to exist, and even if a small percentage of those are found to act as endocrine disruptors, it will be virtually impossible to monitor all the levels in treated water. Some states have selected TOC and TOX as surrogate measures for endocrine disruptors. Florida requires monthly average values for TOC and TOX levels below 3.0 mg/L and 0.2 mg/L, respectively, and below 5.0 mg/L and 0.3 mg/L for a monthly period when reclaimed water is used for either groundwater recharge or indirect potable reuse (FAC, Ch. 62-610.563).

Pathogenic Organisms

One of most critical issues for water reuse is protection of the public from infectious diseases. The principal infectious agents that may be found in untreated wastewater and their corresponding diseases are presented in Table 2. The microorganisms causing diseases can be classified into three groups: (1) bacteria, (2) parasites (protozoa and helminthes), and (3) viruses. A detailed explanation on each group can be found in USEPA manual (USEPA, 1992). The human immunodeficiency virus (HIV) that causes the acquired immunodeficiency syndrome (AIDS) in wastewater has been studied. This virus could be transmitted via a waterborne route, but the survival rate was significantly less than poliovirus survival under similar conditions (USEPA, 1992).
Although viruses and other pathogens could exist in wastewater used for irrigation, these

pathogens do not readily penetrate fruits or vegetables unless skin is broken. In a study in which soil was inoculated with poliovirus, the virus was detected in the leaves of the plant only when the roots were damaged or cut (USEPA, 1992). Another study indicated that the possibility of transferring the virus through the roots to the fruit was very low. Therefore, the possibility of translocation of pathogens through roots, trees, or vines to the edible portion of crops is very low, and the health risk associated with eating these crops is negligible.

Table 2: Infectious agents potentially present in untreated wastewater.

Pathogen	**Disease**
Protozoa	
Entamoeba histolytica	Amebiasis(amebic dysentery)
Giardia lamblia	Giardiasis
Balantidium coli	Balantisasis (dysentery)
Cryptosporidium	Cryptosporidiosis, diarrhea, fever
Helminths	
Ascaris Lumbricoides (roundworm)	Ascariasis
Ancylostoma duodenale (hookworm)	Ancylostomiasis
Necator americanus (roundworm)	Necatoriasis
Ancylostma (spp.) (hookworm)	Cutaneous larva migrams
Strongloides stercoralis (threadworm)	Strongyloidiasis
Trichuris trichiura (whipworm)	Trichuriasis
Tanenia (spp.) (tapeworm)	Taeniasis
Enterobius vermicularis (pinworm)	Enterobiasis
Echinococcus granulosus (spp.) (tapeworm)	Hydatidosis
Bacteria	
Shigella (4 spp.)	Shigellosis (dysentery)
Salmonella typhi	Typhoid fever
Salmonella (1700 serotypes)	Salmonellosis
Vibro Cholerae	Cholera
Escherichia coli (enteropathogenic)	Gastroenteritis
Yersinia enterocolitica	Yersiniosis
Leptospira (spp.)	Leptospirosis
Legionella	Legionnaire’s disease
Campylobacter jejune	Gastroenteritis

Table 2. Infectious agents potentially present in untreated wastewater. (continued)

Pathogen	Disease
Viruses	
Enteroviruses (72 types) (polio, echo, Coxsackie, new enteroviruses)	Gastroenteritis, heart anomalies, meningitis, others
Hepatitis A virus	Infectious hepatitis
Adenovirus (47 types)	Respiratory disease, eye infection
Rotavirus (4 types)	Gastroenteritis
Parvovirus (3 types)	Gastroenteritis
Norwalk agent	Diarrhea, vomiting, fever
Reovirus (3 types)	Not clearly established
Astrovirus (5 types)	Gastroenteritis
Callcivirus (2 types)	Gastroenteritis
Coronavirus	Gastroenteritis

Infective Doses

Occurrence of illness is the result of complex interrelationships between the host and the infectious agents. The typical variables are: (1) the number of microorganisms getting into the host (dose), (2) the minimum number of microorganisms starting the infection (infective dose), and (3) the microorganism's ability to cause disease (pathogenicity). Because infective dose is defined as the dosed number of microorganisms starting immunological response by a host, the actual number of microorganisms showing signs of disease could be higher than the infective dose. In addition, susceptibility is highly dependent on the host. Infants, elderly persons, malnourished persons, and persons with illness are more susceptible than healthy adults. Table 3 presents the infective doses of selected pathogens. For beneficial water reuse, especially for potable reuse, the number of microorganisms in reclaimed water must be low, and processes for reducing and eliminating microorganisms must be implemented to protect the public.

Table 3: Infectious doses of selected pathogens.

Organisms	Infectious Dose
Escherichia coli (enteropathogenic)	$10^6 - 10^{10}$
Clostridium perfringens	1×10^{10}
Salmonella typhi	$10^4 – 10^7$
Vibrio cholerae	$10^3 – 10^7$
Shigella flexneri 2A	180
Entameoba histolytica	20
Shigella dysnetariae 1	10
Giardia lamblia	<10
Viruses	1-10
Ascaris Lumbricoides	1-10

Inactivation of Pathogens

To protect the public from infectious diseases, destruction of microorganisms must occur during the reclamation process. In the U.S., the most common disinfection method for water and wastewater is chlorine injection. Ozone and ultraviolet are other prominent disinfectants, especially in European countries.

Several factors for disinfection must be evaluated:

- Disinfection effectiveness and reliability,
- Capital, operating and maintenance costs,
- Practicality (e.g., ease of transport and storage, on-site generation, ease of application and control, flexibility, complexity, safety), and
- Potential adverse effects (e.g., toxicity to aquatic life), or formation of toxic and carcinogenic substances.

Chlorine has been used to disinfect water and wastewater for years. The chlorine disinfection efficiency is dependent on the water temperature, pH, degree of mixing, time of contact, presence of interfering substances, concentration and form of chlorine, and nature and concentration of the target microorganisms. Bacteria are known to be less resistant to chlorine than viruses, which are, in turn, less resistant than parasite ova and cysts. The required dosing amount to disinfect to any desired level varies depending on the presence of constituents that interfere with the effectiveness of chlorine. Typical interfering constituents are organic materials, suspended solids, and ammonia. Organic material in water can reduce availability of chorine for disinfection due to oxidation of organics by chlorine. A greater chlorine dosage is required when water has total suspended solids (TSS) that protect microorganisms from chlorine. The less effective combined-chlorine forms, such as chloramines, are produced when ammonia in water reacts with injected free chlorine. When organic acids (known as humic acids) are present in water, undesirable disinfection byproducts (DBPs) are produced. Classified as probable human carcinogens by USEPA, the typical DBPs are trihalomethanes (THMs) and haloacetic acids (HAAs). The details for chlorine disinfection and related issues are found in Metcalf and Eddy (2003).

Ozone (O_3) is a powerful oxidant for inorganic and organic materials. This high-oxidizing power can destroy any microorganism in a matter of minutes. However, ozone has to be generated on-site; it cannot be stored or transferred due to its unstable nature. Generation of ozone requires a great amount of electricity and more complex operations than chlorination systems. Unlike chlorine, ozone does not result in a residual in water, which may be a safety problem if the water has a long detention time, or will be transported over large distances. It is used for disinfection, color, and odor removal, and for increasing dissolved oxygen concentrations.

Ultraviolet (UV) light is a physical disinfectant with a wavelength of 254 nm. It penetrates microorganisms’ cell walls and is absorbed by cellular nucleic acids, stopping the replication of cells and killing the microorganisms. Because UV disinfection does not create any byproducts and is cheaper than chlorine disinfection, it is gaining popularity in wastewater reclamation plants. Prior to UV disinfection, water must be filtered for TSS, which can block UV rays. It is recommended that water receive treatment to reduce the number of particles with associated coliform bacteria, or simply remove the particles themselves with some type of upstream treatment (Metcalf and Eddy, 2003). In some places, chlorination is practiced after UV disinfection to maintain a chlorine residual that prevents microbial contamination during transportation and storage.

Because disinfection is the last barrier to protect the public from pathogens, many states specify disinfection requirements based on water reuse purposes. Average total numbers of coliforms and the maximum total coliforms for a single sample per 100 mL of reclaimed water are usually specified. In addition, the total residue of chlorine and the contact time between water and chlorine are specified. California has the most comprehensive regulations on disinfection and specifies requirements, including contact time between chlorine and treating wastewater, in Title 22, CCR (California Code of Regulation). Reclaimed water is classified as (1) disinfected tertiary reclaimed water, (2) disinfected secondary-2.2 reclaimed water, (3) disinfected secondary-23 reclaimed water, and (4) undisinfected secondary reclaimed water based upon disinfection. The details for these reclaimed waters can be found in Title 22, Division 4, CCR.

Public Education

The successful implementation of a water reuse program requires that the public must be informed. There are many successful cases of water reuse programs with public involvement and education.

The public must acknowledge that the additional supply of water is being provided to accommodate continuous growth of the community. In addition, options and consequences for new water sources must be explained. When new water sources are developed, the public must be aware of the environmental impact and cost. When a water reuse program is introduced, the public must be informed that this program could save and even replenish existing water resources for future. In addition, the ability of current technologies to produce high-quality reclaimed water must to be presented to the public. Reliability and redundancy of water reuse systems (including multiple barriers and extensive monitoring) must be addressed. The public must be notified that the injected reclaimed water can be blended with natural groundwater, increasing groundwater

availability.

Definitions

There are quite a few definitions of water reuse in regulations of many states and countries such as Canada and Australia. The most comprehensive definitions are provided by Title 22 in California Code of Regulation (CCR), chapter 62-610 in Florida Administrative Code (FAC) and Water Reclamation and Reuse Standards issued by the State of Washington. Although it is impossible to present all definitions and explain all related issues, the important definitions that can give answers for "what is water reuse?" will be presented
here.

Biochemical Oxygen Demand (BOD): A measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. The greater the BOD measurement, the greater the degree of pollution.

Color-coding: To warn the public and employees that reclaimed water is not intended for drinking. All piping, pipelines, valves, and outlets are color-coded or otherwise marked to differentiate from potable or other water. Purple color—Pantone 512 or 522—is used for this purpose.

Example: White or black "DO NOT DRINK" letters on purple-colored plate wherever the warning is necessary.

Direct potable reuse: A method of water reuse that supplies reclaimed water directly to the water supply system. This implies the pipe-to-pipe system that connects reclaimed water lines directly to water treatment plants without intervening discharge to a natural water body.

Example: Supplying well-treated wastewater to a water treatment plant by a pipe as a drinking water source.

Direct reuse: The use of reclaimed water that has been transported from a wastewater treatment plant to the point of use without intervening discharge to a natural water body, such as agricultural and landscape irrigation.

Example: Transferring reclaimed water directly to house for turf irrigation from water reclamation plant.

Dual distribution system: A situation where there are two water supply lines: one is for potable water and another is for reclaimed water. The reclaimed water line is usually colored purple or embossed with a warning.

Example: A city having two water lines: one for drinking water and another for reclaimed water.

Direct recharge: The controlled subsurface addition of reclaimed water directly to the groundwater basin that results in the replenishment of groundwater. Direct recharge is typically accomplished via injection wells but may be accomplished by other methods that directly recharge into the saturated zone by a subsurface means.
Example: Injecting reclaimed water underground.

Disinfected wastewater: Wastewater in which pathogenic organisms have been destroyed by chemical, physical, and biological means.
Example: Wastewater treated with chemicals to kill all germs.

Filtered wastewater: This term is defined as oxidized wastewater that has been coagulated and passed through natural undisturbed soil or a bed of filter media, or has been passed through a microfiltration, ultrafiltration, nanofiltration, or reverse osmosis membrane. The quality of filtered wastewater is defined in Title 22, Division 4, CCR.
Example: Wastewater passing through filters to remove most of solid components.

F-Specific Bacteriophage MS-2: A strain of a specific type of virus that infects coliform bacteria, traceable to the American Type Culture Collection (ATCC 1559B1) and grown on lawns of E. Coli (ATTC 15997).
Example: A specific virus existing in wastewater if it is not properly disinfected.

Indirect potable reuse: Use reclaimed water to augment potable water supply. This includes the discharge of reclaimed water to potable water reservoirs or groundwater to allow mixing with natural water.
Example: Taking water to produce drinking water where treated wastewater is being discharged. No direct connection between wastewater treatment plant and water treatment plant.

Indirect reuse: Use of reclaimed water indirectly such as taking water from a natural water body or groundwater where reclaimed water has been discharged or recharged.
Example: Taking groundwater for irrigation where reclaimed water is being directly injected. No direct connection between wastewater reclamation plant and final users.

Irrigation: Application of reclaimed water to land. This includes spray irrigation done by spraying reclaimed water from sprinklers or orifices in piping, and subsurface irrigation done by dripping reclaimed water from drippers or emitters.
Example: Providing water to grass in turf.

Unplanned reuse: A situation where downstream supplies are drawn from sources to which wastewater is discharged, and source water quantity and quality is not controlled by the user. This is common worldwide for water reuse.
Example: Location on the Mississippi River with upstream wastewater discharge and downstream drinking water withdrawals.

Planned reuse: A situation where reclaimed water is used either directly or indirectly, without losing control of quantity and quality. This includes planned direct and indirect reuse.

Example: Producing reclaimed wastewater after determining the place to use it.

Potable wastewater reuse: The augmentation of drinking water supplies by highly treated
reclaimed water. This includes direct and indirect potable wastewater reuse.

Example: Discharging reclaimed water to a lake where a water treatment plant is taking raw water or directly transferring highly treated wastewater to produce drinking water.

Reclamation plant: An arrangement of devices, structure, equipment, processes and controls that produce reclaimed water suitable for the intended reuse.

Example: Wastewater treatment plant producing reclaimed water.

Reclaimed water: Effluent derived in any part from wastewater processed in a wastewater treatment system that has been adequately and reliably treated. As a result of that treatment, it is suitable for a beneficial use or a controlled use that would not otherwise occur. In CCR, the term recycled water is used, instead of reclaimed water.

Example: Produced water from water reclamation plants

Recycled water: Except for California and Canada, the term *recycled water* is used synonymously with *reclaimed water*. In CCR, recycled water is defined as reclaimed water, and the term reclaimed water is not used in CCR. In Canada, the term recycled water is defined as return of reclaimed water to be used again for the purpose that generates wastewater, e.g., treatment and recycling of all household wastewater for toilet flushing and other non-potable uses.

Example: Greywater being used for toilet flushing.

Reliability: The ability of a treatment system or components to perform a required function under stated conditions for a stated period of time.

Example: Providing equipment that can produce reclaimed water continuously.

Total suspended solids (TSS): A measure of the suspended solids in wastewater, effluent, or water bodies, determined by tests for "total suspended non-filterable solids."

Wastewater reclamation: Treatment or processing of wastewater to produce reclaimed water. Also, this term includes delivery of reclaimed water to a point of use and its use.

Example: Producing and delivering reclaimed water to final users.

Wastewater recycling: The use of wastewater that is collected, reclaimed and returned into the same water use scheme. Manufacturing industries are usually practicing water recycling on an individual plant basis.

Example: Using greywater to flush toilets.

Wastewater reuse: The use of treated wastewater for a beneficial use, such as agricultural irrigation and industrial cooling.

Example: Providing treated wastewater for irrigation.

References

Stephen J. Coonan and Alan H. Plummer, Jr. (2001) Water Reclamation as a Water Management Strategy in Texas, Presented in Texas Water Conservation Association – Fall Meeting 2001

Mackenzie L. David and David A. Cornell (1991) Introduction to Environmental Engineering, McGraw-Hill, N.Y., N.Y.

D.A. Okun (2002) Water reuse introduces the need to integrate both water supply and wastewater management at local and regulatory levels, Water Science and Technology, Vol. 46, No. 6-7, pp 273-280

R.R. Trussell (2001) Endocrine Disruptors, Journal American Water Works Association, Vol. 93, Iss. 2, pp 58-65

Korea Water Resource Corporation, Waste water reuse system, www.water.or.kr/engwater/general/ewk_gel_dev_heavy.html

Metcalf and Eddy (2003) Wastewater Engineering-Treatment and Reuse-4th ed., McGraw-Hill, New York, New York.

New South Wales (2000) Greywater Reuse in Sewered Single Domestic Premises, New South Wales Health Department, Australia.

G. Stuart Pettygrove and Takashi Asano (1985) Irrigation with Reclaimed Municipal Wastewater: A Guidance Manual, Lewis Publishers, Chelsea, MI.

State of California (2000) Code of Regulations, Title 22, Division 4, Chapter 3. Water Recycling Criteria, Sections 60301 et seq., Dec. 2, 2000.

State of Florida (2000) Florida Administrative Code, Chapter 62-610. Reuse of Reclaimed Water and Land Application.

State of Georgia (2002) Guidelines for Water Reclamation and Urban Reuse, Georgia Department of Natural Resources, Atlanta, Georgia.

State of Idaho (1996) Handbook for Land Application of Municipal and Industrial Wastewater, Division of Environmental Quality, Boise, Idaho.

State of New Jersey (2000) Reclaimed Water for Beneficial Reuse, New Jersey Department of Environmental Protection.

State of Washington (1997) Water Reclamation and Reuse Standards, Washington State Department of Health and Washington State Department of Ecology, September, 1997

Wayne B. Solley, Robert R. Pierce and Howard A. Perlman (1998) Estimated Use of Water in the United States in 1995, U.S. Geology Survey, U.S. Department of Interior.

USEPA (1973) Design Criteria for Mechanical. Electric, and Fluid system and component reliability, EPA-430-99-74-001, U.S. Environmental Protection Agency, Washington D.C

USEPA (1992) Manual-Guidelines for Water Reuse, EPA/625/R-92/004, U.S. Environmental Protection Agency and U.S. Agency for International Development, Washington D.C.

USEPA (2002a) On-site Wastewater Treatment System Manual, EPA/625/R-00/008, U.S. Environmental Protection Agency and U.S. Agency for International Development, Washington D.C.

USEPA (2002b)Water Supply and Demand in the United States, www.epa.gov/seahome/groundwater/src/supply.htm

USEPA (2003) Endocrine Disruptor Screening Program Web Site, www.epa.gov/scipoly/oscpendo/

D.H. Waller, J.D. Mooers, A. Samosite and B. Sahely (1998) Research Report – Innovative Residential Water and Wastewater Management, Canada Mortgage and Housing Corporation, Canada.

Water Environment Federation (1998) Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association, Washington, D.C.