CHAPTER 2

Types of Reuse Applications

Chapter 2 provides detailed explanations of major reuse application types. These include:

- Urban
- Industrial
- Agricultural
- Environmental and recreational
- Groundwater recharge
- Augmentation of potable supplies

Quantity and quality requirements are considered for each reuse application, as well as any special considerations necessary when reclaimed water is substituted for more traditional sources of water. Case studies of reuse applications are provided in Section 2.7. Key elements of water reuse that are common to most projects (i.e., supply and demand, treatment requirements, storage, and distribution) are discussed in Chapter 3.

2.1 Urban Reuse

Urban reuse systems provide reclaimed water for various nonpotable purposes including:

- Irrigation of public parks and recreation centers, athletic fields, school yards and playing fields, highway medians and shoulders, and landscaped areas surrounding public buildings and facilities
- Irrigation of landscaped areas surrounding single-family and multi-family residences, general wash down, and other maintenance activities
- Irrigation of landscaped areas surrounding commercial, office, and industrial developments
- Irrigation of golf courses
- Commercial uses such as vehicle washing facilities, laundry facilities, window washing, and mixing water for pesticides, herbicides, and liquid fertilizers
- Ornamental landscape uses and decorative water features, such as fountains, reflecting pools, and waterfalls
- Dust control and concrete production for construction projects
- Fire protection through reclaimed water fire hydrants
- Toilet and urinal flushing in commercial and industrial buildings

Urban reuse can include systems serving large users. Examples include parks, playgrounds, athletic fields, highway medians, golf courses, and recreational facilities. In addition, reuse systems can supply major water-using industries or industrial complexes as well as a combination of residential, industrial, and commercial properties through "dual distribution systems." A 2-year field demonstration/research garden compared the impacts of irrigation with reclaimed versus potable water for landscape plants, soils, and irrigation components. The comparison showed few significant differences; however, landscape plants grew faster with reclaimed water (Lindsey *et al.,* 1996). But such results are not a given. Elevated chlorides in the reclaimed water provided by the City of St. Petersburg have limited the foliage that can be irrigated (Johnson, 1998).

In dual distribution systems, the reclaimed water is delivered to customers through a parallel network of distribution mains separate from the community's potable water distribution system. The reclaimed water distribution system becomes a third water utility, in addition to wastewater and potable water. Reclaimed water systems are operated, maintained, and managed in a manner similar to the potable water system. One of the oldest municipal dual distribution systems in the U.S., in St. Petersburg, Florida, has been in operation since 1977. The system provides reclaimed water for a mix of residential properties, commercial developments, industrial parks, a resource recovery power plant, a baseball stadium, and schools. The City of Pomona, California, first began distributing reclaimed water in 1973 to California Polytechnic University and has since added 2 paper mills, roadway landscaping, a regional park and a landfill with an energy recovery facility.

During the planning of an urban reuse system, a community must decide whether or not the reclaimed water system will be interruptible. Generally, unless reclaimed water is used as the only source of fire protection in a community, an interruptible source of reclaimed water is acceptable. For example, the City of St. Petersburg, Florida, decided that an interruptible source of reclaimed water would be acceptable, and that reclaimed water would provide backup only for fire protection.

If a community determines that a non-interruptible source of reclaimed water is needed, then reliability, equal to that of a potable water system, must be provided to ensure a continuous flow of reclaimed water. This reliability could be ensured through a municipality having more than one water reclamation plant to supply the reclaimed water system, as well as additional storage to provide reclaimed water in the case of a plant upset. However, providing the reliability to produce a non-interruptible supply of reclaimed water will have an associated cost increase. In some cases, such as the City of Burbank, California, reclaimed water storage tanks are the only source of water serving an isolated fire system that is kept separate from the potable fire service.

Retrofitting a developed urban area with a reclaimed water distribution system can be expensive. In some cases, however, the benefits of conserving potable water may justify the cost. For example, a water reuse system may be cost-effective if the reclaimed water system eliminates or forestalls the need to:

- Obtain additional water supplies from considerable distances
- Treat a raw water supply source of poor quality (e.g., seawater desalination)
- Treat wastewater to stricter surface water discharge requirements

In developing urban areas, substantial cost savings may be realized by installing a dual distribution system as developments are constructed. A successful way to accomplish this is to stipulate that connecting to the system is a requirement of the community's land development code. In 1984, the City of Altamonte Springs, Florida, enacted the requirement for developers to install reclaimed water lines so that all properties within a development are provided service. This section of the City's land development code also stated, "The intent of the reclaimed water system is not to duplicate the potable water system, but rather to complement each other and thereby provide the opportunity to reduce line sizes and looping requirements of the potable water system" (Howard, Needles, Tammen, and Bergendoff, 1986a).

The Irvine Ranch Water District in California studied the economic feasibility of expanding its urban dual distribution system to provide reclaimed water to high-rise buildings for toilet and urinal flushing. The study concluded that the use of reclaimed water was feasible for flushing toilets and urinals and priming floor drain traps for buildings of 6 stories and higher (Young and Holliman, 1990). Following this study, an ordinance was enacted requiring all new buildings over 55 feet (17 meters) high to install a dual distribution system for flushing in areas where reclaimed water is available (Irvine Ranch Water District, 1990).

The City of Avalon, California, conducted a feasibility study to assess the replacement of seawater with reclaimed water in the City's nonpotable toilet flushing/fire protection distribution system. The study determined that the City would save several thousand dollars per year in amortized capital and operation and maintenance costs by switching to reclaimed water (Richardson, 1998).

2.1.1 Reclaimed Water Demand

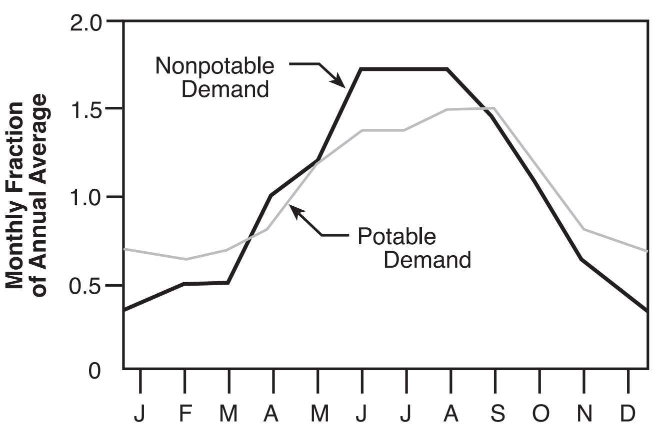
The daily irrigation demand for reclaimed water generated by a particular urban system can be estimated from an inventory of the total irrigable acreage to be served by the reclaimed water system and the estimated weekly irrigation rates. These rates are determined by such factors as local soil characteristics, climatic conditions, and type of landscaping. In some states, recommended weekly irrigation rates may be available from water management agencies, county or state agricultural agents, or irrigation specialists. Reclaimed water demand estimates must also take into account any other permitted uses for reclaimed water within the system.

An estimate of the daily irrigation demand for reclaimed water can also be made by evaluating local water billing records. For example, in many locations, second water meters measure the volume of potable water used outside the home, primarily for irrigation. An evaluation of the water billing records in Orlando, Florida, showed the average irrigation demand measured on the residential second meter was approximately 506 gpd (1.9 m^3/d), compared to 350 gpd (1.3 m^3/d) on the first meter, which measured the amount of water for in-house use (CDM, 2001). This data indicates that a 59 percent reduction in residential potable water demand could be accomplished if a dual distribution system were to provide irrigation service.

Water use records can also be used to estimate the seasonal variation in reclaimed water demand. **Figure 2-1** and **Figure 2-2** show the historic monthly variation in the potable and nonpotable water demand for the Irvine Ranch Water District in California and St. Petersburg, Florida, respectively. Although the seasonal variation in demand is different between the 2 communities, both show a similar trend in the seasonal variation between potable and nonpotable demand. Even though St. Petersburg and Irvine Ranch meet much of the demand for irrigation with reclaimed water, the influence of these uses can still be seen in the potable water demands.

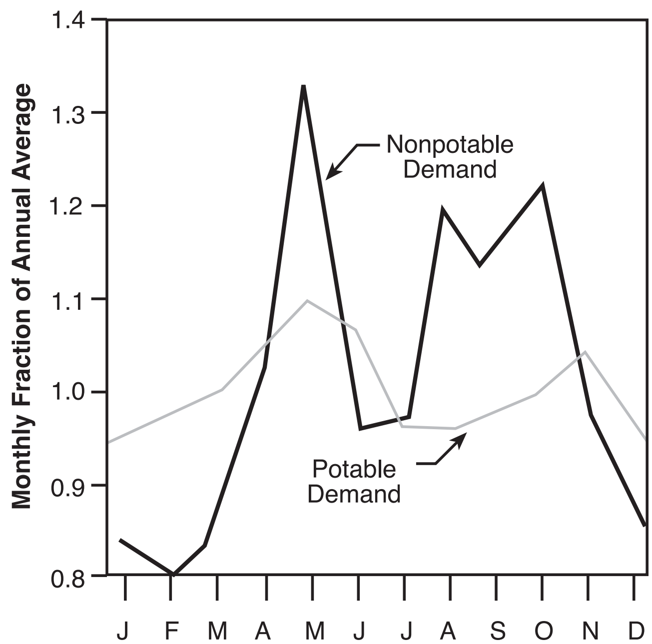
For potential reclaimed water users, such as golf courses, that draw irrigation water from onsite wells, an evaluation of the permitted withdrawal rates or pumping records can be used to estimate their reclaimed water needs.

Figure 2-1. Potable and Nonpotable Water Use - Monthly Historic Demand Variation, Irvine Ranch Water District, California



In assessing the reuse needs of an urban system, demands for uses other than irrigation must also be considered. These demands are likely to include industrial, commercial, and recreational uses. Demands for industrial users, as well as commercial users, such as car washes, can be estimated from water use or billing records. Demands for recreational impoundments can be

Figure 2-2. Potable and Nonpotable Water Use - Monthly Historic Demand Variation, St. Petersburg, Florida



estimated by determining the volume of water required to maintain a desired water elevation in the impoundment.

For those systems using reclaimed water for toilet flushing as part of their urban reuse system, water use records can again be used to estimate demand. According to Grisham and Fleming (1989), toilet flushing can account for up to 45 percent of indoor residential water demand. In 1991, the Irvine Ranch Water District began using reclaimed water for toilet flushing in high-rise office buildings. Potable water demands in these buildings have decreased by as much as 75 percent due to the reclaimed water use (IRWD, 2003).

2.1.2 Reliability and Public Health Protection

In the design of an urban reclaimed water distribution system, the most important considerations are the reliability of service and protection of public health. Treatment to meet appropriate water quality and quantity requirements and system reliability are addressed in Section 3.4. The following safeguards must be considered during the design of any dual distribution system:

- Assurance that the reclaimed water delivered to the customer meets the water quality requirements for the intended uses

- Prevention of improper operation of the system
- Prevention of cross-connections with potable water lines
- Prevention of improper use of nonpotable water

To avoid cross connections, all above-ground appurtenances and equipment associated with reclaimed water systems must be clearly marked. National color standards have not been established, but most manufacturers, counties, and cities have adopted the color purple for reclaimed water lines. The State of Florida has accepted Pantone 522C as the color of choice for reclaimed water material designation. Florida also requires signs to be posted with specific language in both English and Spanish identifying the resource as nonpotable. Additional designations include using the international symbol for "Do Not Drink" on all materials, both surface and subsurface, to minimize potential cross connections. A more detailed discussion of distribution safeguards and cross connection control measures is presented in Section 3.6.1, Conveyance and Distribution Facilities.

2.1.3 Design Considerations

Urban water reuse systems have 2 major components:

1. Water reclamation facilities
2. Reclaimed water distribution system, including storage and pumping facilities

2.1.3.1 Water Reclamation Facilities

Water reclamation facilities must provide the required treatment to meet appropriate water quality standards for the intended use. In addition to secondary treatment, filtration, and disinfection are generally required for reuse in an urban setting. Because urban reuse usually involves irrigation of properties with unrestricted public access or other types of reuse where human exposure to the reclaimed water is likely, reclaimed water must be of a higher quality than may be necessary for other reuse applications. In cases where a single large customer needs a higher quality reclaimed water, the customer may have to provide additional treatment onsite, as is commonly done with potable water. Treatment requirements are presented in Section 3.4.2.

2.1.3.2 Distribution System

Reclaimed water operational storage and high-service pumping facilities are usually located onsite at the water reclamation facility. However, in some cases, particularly for large cities, operational storage facilities may be located at appropriate locations in the system and/or near the reuse sites. When located near the pumping facilities, ground or elevated tanks may be used; when located within the system, operational storage is generally elevated.

Sufficient storage to accommodate diurnal flow variation is essential to the operation of a reclaimed water system. The volume of storage required can be determined from the daily reclaimed water demand and supply curves. Reclaimed water is normally produced 24 hours per day in accordance with the diurnal flow at the water reclamation plant and may flow to ground storage to be pumped into the system or into a clear well for high-lift pumping to elevated storage facilities. In order to maintain suitable water quality, covered storage is preferred to preclude biological growth and maintain chlorine residual. Refer to Section 3.5.2 for a discussion of operational storage.

Since variations in the demand for reclaimed water occur seasonally, large volumes of seasonal storage may be needed if all available reclaimed water is to be used, although this may not be economically practical. The selected location of a seasonal storage facility will also have an effect on the design of the distribution system. In areas where surface storage may be limited due to space limitations, aquifer storage and recovery (ASR) could prove to be a viable enhancement to the system. Hillsborough County, Florida has recovered ASR water, placed it into the reuse distribution system, and is working to achieve a target storage volume of 90 million gallons (340,700 m^3) (McNeal, 2002). A detailed discussion of seasonal storage requirements is provided in Section 3.5.

The design of an urban distribution system is similar in many respects to a municipal potable water distribution system. Materials of equal quality for construction are recommended. System integrity should be assured; however, the reliability of the system need not be as stringent as a potable water system unless reclaimed water is being used as the only source of fire protection. No special measures are required to pump, deliver, and use the water. No modifications are required because reclaimed water is being used, with the exception that equipment and materials must be clearly identified. For service lines in urban settings, different materials may be desirable for more certain identification.

The design of distribution facilities is based on topographical conditions as well as reclaimed water demand requirements. If topography has wide variations, multi-level systems may have to be used. Distribution mains must be sized to provide the peak hourly demands at a pressure adequate for the user being served. Pressure requirements for a dual distribution system vary depending on the type of user being served. Pressures for irrigation systems can be as low as 10 psi (70 kPa) if additional booster pumps are provided at the point of delivery, and maximum pressures can be as high as 100 to 150 psi (700 to 1,000 kPa).

The peak hourly rate of use, which is a critical consideration in sizing the delivery pumps and distribution mains, may best be determined by observing and studying local urban practices and considering time of day and rates of use by large users to be served by the system. The following design peak factors have been used in designing urban reuse systems:

System	Peaking Factor
Altamonte Springs, Florida (HNTB, 1986a)	2.90
Apopka, Florida (Godlewski *et al.*, 1990)	4.00
Aurora, Colorado (Johns *et al.*, 1987)	2.50
Boca Raton, Florida (CDM, 1990a)	2.00
Irvine Ranch Water District, California (IRWD, 1991)	
- Landscape Irrigation	6.80
- Golf Course and Agricultural Irrigation	2.00
San Antonio Water System (SAWS), Texas (SAWS Website, 2004)	1.92
Sea Pines, South Carolina (Hirsekorn and Ellison, 1987)	2.00
St. Petersburg, Florida (CDM, 1987)	2.25

The wide range of peaking factors reflects the nature of the demands being served, the location of the reuse system (particularly where irrigation is the end use), and the experience of the design engineers. San Antonio's low peaking factor was achieved by requiring onsite storage for customer demands greater than 100 acre-feet per year (62 gpm). These large customers were allowed to receive a peak flow rate based on a 24-hour delivery of their peak month demand in July. This flat rate delivery and number of large irrigation customers resulted in a low system peaking factor.

For reclaimed water systems that include fire protection as part of their service, fire flow plus the maximum daily demand should be considered when sizing the distribution system. This scenario is not as critical in sizing the delivery pumps since it will likely result in less pumping capacity, but is critical in sizing the distribution mains because fire flow could be required at any point in the system, resulting in high localized flows.

The Irvine Ranch Water District Water Resources Master Plan recommends a peak hourly use factor of 6.8 when reclaimed water is used for landscape irrigation and a peak factor of 2.0 for agricultural and golf course irrigation systems (IRWD, 1991). The peak factor for landscape irrigation is higher because reclaimed water use is restricted to between 9 p.m. and 6 a.m. This restriction may not apply to agricultural or golf course use.

Generally, there will be "high-pressure" and "low-pressure" users on an urban reuse system. The high-pressure users receive water directly from the system at pressures suitable for the particular type of reuse. Examples include residential and landscape irrigation, industrial processes and cooling water, car washes, fire protection, and toilet flushing in commercial and industrial buildings. The low-pressure users receive reclaimed water into an onsite storage pond to be repumped into their reuse system. Typical low-pressure users are golf courses, parks, and condominium developments that use reclaimed water for irrigation. Other low-pressure uses include the delivery of reclaimed water to landscape or recreational impoundments, or industrial or cooling tower sites that have onsite tanks for blending and/or storing water.

Typically, urban dual distribution systems operate at a minimum pressure of 50 psi (350 kPa), which will satisfy the pressure requirements for irrigation of larger landscaped areas such as multi-family complexes, and offices, commercial, and industrial parks. A minimum pressure of 50 psi (350 kPa) should also satisfy the requirements of car washes, toilet flushing, construction dust control, and some industrial uses. Based on requirements of typical residential irrigation equipment, a minimum delivery pressure of 30 psi (210 kPa) is used for the satisfactory operation of in-ground residential irrigation systems.

For users who operate at higher pressures than other users on the system, additional onsite pumping will be required to satisfy the pressure requirements. For example, golf course irrigation systems typically operate at higher pressures (100 to 200 psi or 700 kPa to 1,400 kPa), and if directly connected to the reclaimed water system, will likely require a booster pump station. Repumping may be required in high-rise office buildings using reclaimed water for toilet flushing. Additionally, some industrial users may operate at higher pressures.

The design of a reuse transmission system is usually accomplished through the use of computer modeling, with portions of each of the sub-area distribution systems representing demand nodes in the model. The demand of each node is determined from the irrigable acreage tributary to the node, the irrigation rate, and the daily irrigation time period. Additional demands for uses other than irrigation, such as fire flow protection, toilet flushing, and industrial uses must also be added to the appropriate node.

The 2 most common methods of maintaining system pressure under widely varying flow rates are: (1) constant-speed supply pumps and system elevated storage tanks, which maintain essentially consistent system pressures, or (2) constant-pressure, variable-speed, high-service supply pumps, which maintain a constant system pressure while meeting the varying demand for reclaimed water by varying the pump speed. While each of these systems has advantages and disadvantages, either system will perform well and remains a matter of local choice. The dual distribution system of the City of Altamonte Springs, Florida operates with constant-speed supply pumps and 2 elevated storage tanks, and pressures range between 55 and 60 psi (380 kPa and 410 kPa). The urban system of the Marin Municipal Water District, in California, operates at a system pressure of 50 to 130 psi (350 kPa and 900 kPa), depending upon elevation and distance from the point of supply, while Apopka, Florida operates its reuse system at a pressure of 60 psi (410 kPa).

The system should be designed with the flexibility to institute some form of usage control when necessary and provide for the potential resulting increase in the peak hourly demand. One such form of usage control would be to vary the days per week that schools, parks, golf courses, and residential areas are irrigated. In addition, large users, such as golf courses, will have a major impact on the shape of the reclaimed water daily demand curve, and hence on the peak hourly demand, depending upon how the water is delivered to them. The reclaimed water daily demand curve may be "flattened" and the peak hourly demand reduced if the reclaimed water is discharged to golf course ponds over a 24-hour period or during the daytime hours when demand for residential landscape irrigation is low. These methods of operation can reduce peak demands, thereby reducing storage requirements, pumping capacities, and pipe diameters. This in turn, can reduce construction cost.

2.1.4 Using Reclaimed Water for Fire Protection

Reclaimed water may be used for fire protection, but this application requires additional design efforts (Snyder *et al*., 2002). Urban potable water distribution systems are typically sized based on fire flow requirements. In residential areas, this can result in 6-inch diameter pipes to support fire demands where 2-inch diameter pipes may be sufficient to meet potable needs. Fire flow requirements also increase the volume of water required to be in storage at any given time. While this results in a very robust distribution system, the increased pipe size and storage required for fire flows results in increased residence time within the distribution system, and a corresponding potential reduction in reclaimed water quality. In Rouse Hill, an independent community near Sydney, Australia, reclaimed water lines are being sized to handle fire flows, allowing potable line sizes to be reduced. Due to a shortage of potable water supplies, the City of Cape Coral, Florida, designed a dual distribution system supplied by reclaimed water and surface water that provides for fire protection and urban irrigation. This practice was possible due to the fact that nonpotable service, including the use of reclaimed water for fire protection, was part of the planning of the development before construction. However, these benefits come at the cost of elevating the reclaimed water system to an essential service with reliability equal to that of the potable water system. This in turn, requires redundancy and emergency power with an associated increase in cost. For these reasons, the City has decided to not include fire protection in its future reclaimed water distribution systems. This decision was largely based on the fact that the inclusion of fire protection limited operations of the reclaimed water distribution system. Specifically, the limited operations included the lack of ability to reduce the operating pressure and to close valves in the distribution system.

In some cases, municipalities may be faced with replacing existing potable water distribution systems, because the pipe material is contributing to water quality problems. In such instances, consideration could be given to converting the existing network into a nonpotable distribution system capable of providing fire protection and installing a new, smaller network to handle potable demands. Such an approach would require a comprehensive cross connection control process to ensure all connections between the potable and nonpotable system were severed. Color-coding of below-ground piping also poses a challenge. To date, no community has attempted such a conversion. More often, the primary means of fire protection is the potable water system, with reclaimed water systems providing an additional source of water for fire flows. In the City of St. Petersburg, Florida, fire protection is shared between potable and reclaimed water. In San Francisco, California, reclaimed water is part of a dual system for fire protection that includes high-rise buildings. Reclaimed water is also available for fire protection in the Irvine Ranch Water District, California. In some cases, site-specific investigations may determine that reclaimed water is the most cost-effective means of providing fire protection. The City of Livermore, California, determined that using reclaimed water for fire protection at airport hangers and a wholesale warehouse store would be less expensive than upgrading the potable water system (Johnson and Crook, 1998).

2.2 Industrial Reuse

Industrial reuse has increased substantially since the early 1990s for many of the same reasons urban reuse has gained popularity, including water shortages and increased populations, particularly in drought areas, and legislation regarding water conservation and environmental compliance. To meet this increased demand, many states have increased the availability of reclaimed water to industries and have installed the necessary reclaimed water distribution lines. As a result, California, Arizona, Texas, Florida, and Nevada have major industrial facilities using reclaimed water for cooling water and process/boiler-feed requirements. Utility power plants are ideal facilities for reuse due to their large water requirements for cooling, ash sluicing, rad-waste dilution, and flue gas scrubber requirements. Petroleum refineries, chemical plants, and metal working facilities are among other industrial facilities benefiting from reclaimed water not only for cooling, but for process needs as well.

2.2.1 Cooling Water

For the majority of industries, cooling water is the largest use of reclaimed water because advancements in water treatment technologies have allowed industries to successfully use lesser quality waters. These advancements have enabled better control of deposits, corrosion, and biological problems often associated with the use of reclaimed water in a concentrated cooling water system.

There are 2 basic types of cooling water systems that use reclaimed water: (1) once-through and (2) recirculating evaporative. The recirculating evaporative cooling water system is the most common reclaimed water system due to its large water use and consumption by evaporation.

2.2.1.1 Once-Through Cooling Water Systems

As implied by the name, once-through cooling water systems involve a simple pass of cooling water through heat exchangers. There is no evaporation, and therefore, no consumption or concentration of the cooling water. Very few once-through cooling systems use reclaimed water and, in most instances, are confined to locations where reuse is convenient, such as where industries are located near an outfall. For example, Bethlehem Steel Company in Baltimore, Maryland, has used 100 mgd (4,380 l/s) of treated wastewater effluent from Baltimore's Back River Wastewater Treatment Facility for processes and once-through cooling water system since the early 1970s. The Rawhide Energy Station utility power plant in Fort Collins, Colorado, has used about 245 mgd (10,753 l/s) of reclaimed water for once through cooling of condensers since the 1980s. The reclaimed water is added to a body of water and the combined water is used in the once-through cooling system. After one-time use, the water is returned to the original water source (lake or river).

2.2.1.2 Recirculating Evaporative Cooling Water Systems

Recirculating evaporative cooling water systems use water to absorb process heat, and then transfer the heat by evaporation. As the cooling water is recirculated, makeup water is required to replace water lost through evaporation. Water must also be periodically removed from the cooling water system to prevent a buildup of dissolved solids in the cooling water. There are 2 common types of evaporative cooling systems that use reclaimed water: (1) cooling towers and (2) spray ponds.

2.2.1.2a Cooling Tower Systems

Like all recirculating evaporative systems, cooling water towers are designed to take advantage of the absorption and transfer of heat through evaporation. Over the past 10 years, cooling towers have increased in efficiency so that only 1.75 percent of the recirculated water is evaporated for every 10 °F (6 °C) drop in process water heat, decreasing the need to supplement with makeup water. Because water is evaporated, the dissolved solids and minerals will remain in the recirculated water. These solids must be removed or treated to prevent accumulation on the cooling equipment as well as the cooling tower. This removal is accomplished by discharging a portion of the cooling water, referred to as blow-down water. The blow-down water is usually treated by a chemical process and/or a filtration/softening/clarification process before disposal. Buildup of total dissolved solids can occur within the reclamation/industrial cooling system if the blow-down waste stream, with increased dissolved solids, is recirculated between the water reclamation plant and the cooling system.

The Curtis Stanton Energy Facility in Orlando, Florida, receives reclaimed water from an Orange County wastewater facility for cooling water. Initially, the blow-down water was planned to be returned to the wastewater facility. However, this process would eventually increase the concentration of dissolved solids in the reclaimed water to a degree that it could not be used as cooling water in the future. So, as an alternative, the blow-down water is crystallized at the Curtis Stanton facility and disposed of at a landfill. The City of San Marcos, Texas, identified the following indirect impacts associated with receiving the blow-down water back at their wastewater treatment plant: reduced treatment capacity, impact to the biological process, and impact to the plant effluent receiving stream (Longoria *et al.,* 2000). To avoid the impacts to the wastewater treatment plant, the City installed a dedicated line to return the blow-down water directly to the UV disinfection chamber. Therefore, there was no loss of plant capacity or impact to the biological process. The City has provided increased monitoring of the effluent-receiving stream to identify any potential stream impacts.

Cooling tower designs vary widely. Large hyperbolic concrete structures, as shown in **Figure 2-3**, range from 250 to 400 feet (76 to 122 meters) tall and 150 to 200 feet (46 to 61 meters) in diameter, and are common at utility power plants. These cooling towers can recirculate approximately 200,000 to 500,000 gpm (12,600 to 31,500 l/s) of water and evaporate approximately 6,000 to 15,000 gpm (380 to 950 l/s) of water.

Smaller cooling towers can be rectangular boxes constructed of wood, concrete, plastic, and/or fiberglass reinforced plastic with circular fan housings for each cell. Each cell can recirculate (cool) approximately 3,000 to 5,000 gpm (190 to 315 l/s). Petroleum refineries, chemical plants, steel mills, smaller utility plants, and other processing industries can have as many as 15 cells in a single cooling tower, recirculating approximately 75,000 gpm (4,700 l/s). Commercial air conditioning cooling tower systems can recirculate as little as 100 gpm (6 l/s) to as much as 40,000 gpm (2,500 l/s).

The cycles of concentration (COC) are defined as the ratio of a given ion or compound in the cooling tower water compared to the identical ion or compound in the makeup water. For example, if the sodium chloride level in the cooling tower water is 200 mg/l, and the same compound in the makeup water is 50 mg/l, then the COC is 200 divided by 50, or 4, often referred to as 4 cycles. Industries often operate their cooling towers at widely different cycles of concentration as shown in **Table 2-1**. The reason for such variations is that the cooling water is used for different applications such as wash water, ash sluicing, process water, etc.

2.2.1.2b Spray Ponds

Spray ponds are usually small lakes or bodies of water where warmed cooling water is directed to nozzles that

Table 2-1. Typical Cycles of Concentration (COC)

Industry	Typical COC
Utilities	
Fossil	5-8
Nuclear	6-10
Petroleum Refineries	6-8
Chemical Plants	8-10
Steel Mills	3-5
HVAC	3-5
Paper Mills	5-8

Figure 2-3. Cooling Tower

spray upward to mix with air. This spraying causes evaporation, but usually only produces a 3 to 8 °F drop in temperature. Spray ponds are often used by facilities, such as utility power plants, where minimal cooling is needed and where the pond can also be incorporated into either decorative fountains or the air conditioning system. Reclaimed water has some application related to spray ponds, usually as makeup water, since there are often restrictions on discharging reclaimed water into lakes or ponds. In addition, there is a potential for foaming within the spray pond if only reclaimed water is used. For example, the City of Ft. Collins, Colorado, supplies reclaimed water to the Platte River Power Authority for cooling its 250 megawatt (MW) Rawhide Energy Station. The recirculation cooling system is a 5.2-billion-gallon (20-million-m^3) lake used to supply 170,000 gpm (107,000 l/s) to the condenser and auxiliary heat exchangers. Reclaimed water is treated to reduce phosphate and other contaminants, and then added to the freshwater lake.

2.2.1.3 Cooling Water Quality Requirements

The most frequent water quality problems in cooling water systems are corrosion, biological growth, and scaling. These problems arise from contaminants in potable water as well as in reclaimed water, but the concentrations of some contaminants in reclaimed water may be higher than in potable water. **Table 2-2** provides some reclaimed water quality data from Florida and California.

In Burbank, California, about 5 mgd (219 l/s) of municipal secondary effluent has been successfully utilized for cooling water makeup in the City's power generating plant since 1967. The reclaimed water is of such good quality that with the addition of chlorine, acid, and corrosion inhibitors, the reclaimed water quality is nearly equal to that of freshwater. There are also numerous petroleum refineries in the Los Angeles area in California that have used reclaimed water since 1998 as 100 percent of the makeup water for their cooling systems.

The City of Las Vegas and Clark County Sanitation District uses 90 mgd (3,940 l/s) of secondary effluent to supply 35 percent of the water demand in power generating stations operated by the Nevada Power Company. The power company provides additional treatment consisting of 2-stage lime softening, filtration, and chlorination prior to use as cooling tower makeup. A reclaimed water reservoir provides backup for the water supply. The Arizona Public Service 1,270-MW Palo Verde nuclear power plant is located 55 miles from Phoenix, Arizona, and uses almost all of the City of Phoenix and area cities' reclaimed water at an average rate of 38,000 gpm (2,400 l/s).

In a partnership between the King County Department of Metropolitan Services (Seattle, Washington), the Boeing Company, and Puget Sound Power and Light Company, a new 600,000-square-foot (55,740-m^2) Customer Service Training Center is cooled using chlorinated secondary effluent (Lundt, 1996).

In Texas, The San Antonio Water System (SAWS) has a provision in its service agreement that allows for adjustment in the reclaimed water rates for cooling tower use if the use of reclaimed water results in fewer cycles of concentration.

2.2.1.3a Corrosion Concerns

The use of any water, including reclaimed water, as makeup in recirculating cooling tower systems will result in the concentration of dissolved solids in the heat exchange system. This concentration may or may not cause serious corrosion of components. Three requirements should be considered to identify the cooling system corrosion potential:

1. Calculation of the concentrated cooling water quality – most often "worst" case but also "average expected" water quality

Table 2-2. Florida and California Reclaimed Water Quality

Water Constituents	Orlando	Tampa	Los Angeles	San Francisco
Conductivity	1200 – 1800	600 – 1500	2000 – 2700	800 – 1200
Calcium Hardness	180 – 200	100 – 120	260 – 450	50 – 180
Total Alkalinity	150 – 200	60 – 100	140 – 280	30 – 120
Chlorides	20 – 40	30 – 80	250 – 350	40 – 200
Phosphate	18 – 25	10 – 20	300 – 400	20 – 70
Ammonia	10 – 15	5 – 15	4 – 20	2 – 8
Suspended Solids	3 – 5	3 – 5	10 – 45	2 – 10

2. Identification of metal alloys in the process equipment that will contact cooling water– primarily heat exchanger/cooler/condenser tubing but also all other metals in the system, including lines, water box, tube sheet, and cooling tower

3. Operating conditions (temperatures and water flow) of the cooling tower – primarily related to the heat exchanger tubing but also the other metals in the system

Depending upon its level of treatment, the quality of reclaimed water can vary substantially. The amount of concentration in the cooling system will also vary substantially, depending on the cycles of concentration within the system. Certainly, any contamination of the cooling water through process in-leakage, atmospheric conditions, or treatment chemicals will impact the water quality.

2.2.1.3b Biological Concerns

Biological concerns associated with the use of reclaimed water in cooling systems include:

- Microbiological organisms that contribute to the potential for deposits and microbiologically induced corrosion (MIC)

- Nutrients that contribute to microbiological growth

Microbiological organisms (bacteria, fungus, or algae) that contribute to deposits and corrosion are most often those adhering to surfaces and identified as “sessile” microorganisms. The deposits usually occur in low flow areas (2 feet per second [0.6 m/s] or less) but can stick to surfaces even at much greater flow rates (5 to 8 feet per second [1.5 to 2 m/s]). The deposits can create a variety of concerns and problems. Deposits can interfere with heat transfer and can cause corrosion directly due to acid or corrosive by-products. Indirectly, deposits may shield metal surfaces from water treatment corrosion inhibitors and establish under-deposit corrosion. Deposits can grow rapidly and plug heat exchangers, cooling tower film fill, or cooling tower water distribution nozzles/sprays.

Reclaimed water generally has a very low level of microbiological organisms due to the treatment requirements prior to discharge. Chlorine levels of 2.0 mg/l (as free chlorine) will kill most sessile microorganisms that cause corrosion or deposits in cooling systems.

Nutrients that contribute to microbiological growth are present in varying concentrations in reclaimed water. However, even when freshwater is used in cooling towers, chemicals added during the treatment process can contribute a considerable concentration of nutrients. It is also important to have a good biological control program in place before reclaimed water is used. Ammonia and organics are typical nutrients found in reclaimed water that can reduce or negate some commonly used biocides (particularly cationic charged polymers).

2.2.1.3c Scaling Concerns

The primary constituents for scale potential from reclaimed water are calcium, magnesium, sulfate, alkalinity, phosphate, silica, and fluoride.

Combinations of these minerals that can produce scale in the concentrated cooling water generally include calcium phosphate (most common), silica (fairly common), calcium sulfate (fairly common), calcium carbonate (seldom found), calcium fluoride (seldom found), and magnesium silicate (seldom found).

All constituents with the potential to form scale must be evaluated and controlled by chemical treatment and/or by adjusting the cycles of concentration. Reclaimed water quality must be evaluated, along with the scaling potential to establish the use of specific scale inhibitors. Guidelines for selection and use of scale inhibitors are available as are scale predictive tools.

2.2.2 Boiler Make-up Water

The use of reclaimed water for boiler make-up water differs little from the use of conventional public water supply; both require extensive additional treatment. Quality requirements for boiler make-up water depend on the pressure at which the boiler is operated. Generally, the higher the pressure, the higher the quality of water required. Very high pressure (1500 psi [10,340 kPa] and above) boilers require make-up water of very high quality.

In general, both potable water and reclaimed water used for boiler water make-up must be treated to reduce the hardness of the boiler feed water to close to zero. Removal or control of insoluble scales of calcium and magnesium, and control of silica and alumina, are required since these are the principal causes of scale buildup in boilers. Depending on the characteristics of the reclaimed water, lime treatment (including flocculation, sedimentation, and recarbonation) might be followed by multi-media filtration, carbon adsorption, and nitrogen removal. High-purity boiler feed water for high-pressure boilers might also require treatment by reverse osmosis or ion exchange. High alkalinity may contribute to foaming, resulting in deposits in the superheater, reheater, or turbines. Bicarbonate alkalinity, under the influence of boiler heat, may lead to the release of carbon dioxide, which is a source of corrosion in steam-using equipment. The considerable treatment and relatively small amounts of make-up water required normally make boiler make-up water a poor candidate for reclaimed water.

Since mid-2000, several refineries located in southern Los Angeles, California, have used reclaimed water as their primary source of boiler make-up water. Through the use of clarification, filtration, and reverse osmosis, high-quality boiler make-up water is produced that provides freshwater, chemical, and energy savings. The East Bay Municipal Utility District in California provides reclaimed water to the Chevron Refinery for use as boiler feed water. **Table 2-3** shows the sampling requirements and expected water quality for the reclaimed water.

2.2.3 Industrial Process Water

The suitability of reclaimed water for use in industrial processes depends on the particular use. For example, the electronics industry requires water of almost distilled quality for washing circuit boards and other electronic components. On the other hand, the tanning industry can use relatively low-quality water. Requirements for textiles, pulp and paper, and metal fabricating are intermediate. Thus, in investigating the feasibility of industrial reuse with reclaimed water, potential users must be contacted to determine the specific requirements for their process water.

A full-scale demonstration plant, operated at Toppan Electronics, in San Diego, California, has shown that reclaimed water can be used for the production of circuit boards (Gagliardo *et al.,* 2002). The reclaimed water used for the demonstration plant was pretreated with microfiltration. **Table 2-4** presents industrial process water quality requirements for a variety of industries.

2.2.3.1 Pulp and Paper Industry

The historical approach of the pulp and paper industry has been to internally recycle water to a very high degree. The pulp and paper industry has long recognized the potential benefits associated with water reuse. At the turn of the century, when the paper machine was being developed, water use was approximately 150,000 gallons per ton (625 liters per kilogram). By the 1950s, the water usage rate was down to 35,000 gallons per ton (145 liters per kilogram) (Wyvill *et al*., 1984). An industry survey conducted in 1966 showed the total water use for a bleached Kraft mill to be 179,000 gallons per ton (750 liters per kilogram) (Haynes, 1974). Modern mills approach a recycle ratio of 100 percent, using only 16,000 to 17,000 gallons of freshwater per ton (67 to 71 liters per kilogram) (NCASI, 2003).

About a dozen pulp and paper mills use reclaimed water. Less than half of these mills use treated municipal wastewater. Tertiary treatment is generally required. The driver is usually an insufficient source of freshwater. SAPPI's Enstra mill in South Africa has been using treated municipal wastewater since the early 1940s. In Lake Tahoe, California, the opportunities for using treated wastewater in pulping and papermaking arose with the construction of tertiary wastewater facilities (Dorica *et al.*,1998).

Some of the reasons that mills choose not to use treated municipal wastewater include:

- Concerns about pathogens
- Product quality requirements that specifically preclude its use
- Possibly prohibitive conveyance costs
- Concerns about potentially increased corrosion, scaling, and biofouling problems due to the high degree of internal recycling involved

Table 2-5 shows the water quality requirements for several pulp and paper processes in New York City.

2.2.3.2 Chemical Industry

The water quality requirements for the chemical industry vary greatly according to production requirements. Generally, waters in the neutral pH range (6.2 to 8.3) that are also moderately soft with low turbidity, suspended solids (SS), and silica are required; dissolved solids and chloride content are generally not critical (Water Pollution Control Federation, 1989).

2.2.3.3 Textile Industry

Waters used in textile manufacturing must be non-staining; hence, they must be low in turbidity, color, iron, and manganese. Hardness may cause curds to deposit on the textiles and may cause problems in some of the processes that use soap. Nitrates and nitrites may cause problems in dyeing.

In 1997, a local carpet manufacturer in Irvine, California, retrofitted carpet-dyeing facilities to use reclaimed water year-round (IRWD, 2003). The new process is as effective as earlier methods and is saving up to 500,000 gallons of potable water per day (22 l/s).

Table 2-3. North Richmond Water Reclamation Plant Sampling Requirements

Location[1]	Sample Type	Parameter	Frequency	Target Value[2]
Samples Required for Compliance with RWQCB Order 90-137				
Chevron Tie-In	Grab	Turbidity, Total Chlorine Residual[1], Total Coliform[2]	Daily	Max. 2 NTU, Min. 300 CT, 2.2 MPN/100 ml
Reclaimed Water Effluent	24-hour composite[3]	Flow	Continuous	NA
Samples Required for Compliance with EBMUD-Chevron Agreement; Chevron's NPDES Permit				
Filter Influent, Filter Effluent, Chlorine Contact Basin Effluent	Online Analyzers[3]	pH, Turbidity, Free Chlorine Residual	Continuous	6.5-7.5, 2 NTU, <4.0 mg/l
Reclaimed Water Effluent	24-hour composite	Orthophosphate (PO_4)	Daily	<1.4 mg/l
Reclaimed Water Effluent	24-hour composite	Calcium, Total Iron, Magnesium, Silica, TSS Ammonia (NH_3-N), Chloride	Daily	50 mg/l, 0.1 mg/l, 20 mg/l, 10 mg/l, <1.0 mg/l, <175 mg/l
Reclaimed Water Effluent	96-hour flow through	Rainbow trout acute bioassay	Weekly	>90% Survival
Reclaimed Water Effluent	24-hour composite	COD, TOC (Grab), Selenium, Surfactants	Weekly	<50 mg/l, Report Only <1.0 mg/l
Reclaimed Water Effluent	24-hour composite	Total Chromium, Hexavalent Cr, Ag, As, TOC, Cd, Cyanide, Cu, Hg, Pb, Ni, Zn – mg/l	Monthly	Report Only[4]
Reclaimed Water Effluent	24-hour composite	Total Phenolics, PAHs	Quarterly	Report Only[4]
Reclaimed Water Effluent	Grab	Oil and Grease, Total Sulfides	Quarterly	Report Only[4]
Reclaimed Water Effluent	Grab	Volatile Organics, Halogenated Volatile Organics	Twice/Year	Report Only[4]
Reclaimed Water Effluent	Grab	TCDD Equivalents, Tributyltin, Halogenated Volatile Organics, Polychlorinated Biphenyls, Pesticides	Once/Year	Report Only[4]

NOTES:
1. Chlorine residual may vary based on CT calculation (contact time x residual = 300 CT); 90 minute minimum contact time.
2. Sample must be collected at reclaimed water metering station at pipeline tie-in to Chevron Refinery cooling towers; 90 minute chlorine contact time requirement.
3. Readouts for online analyzers are on graphic panel in Operations Center.
4. "Report Only" parameters are used for pass-through credit for reclaimed water constituents as provided for in Chevron's National Pollutant Discharge Elimination System (NPDES) permit.

Source: Yologe, 1996

Table 2-4. Industrial Process Water Quality Requirements

Parameter*	Pulp & Paper			Chemical	Petrochem & Coal	Textiles		Cement
	Mechanical Piping	Chemical, Unbleached	Pulp & Paper Bleached			Sizing Suspension	Scouring, Bleach & Dye	
Cu	-	-	-	-	0.05	0.01	-	-
Fe	0.3	1.0	0.1	0.1	1.0	0.3	0.1	2.5
Mn	0.1	0.5	0.05	0.1	-	0.05	0.01	0.5
Ca	-	20	20	68	75	-	-	-
Mg	-	12	12	19	30	-	-	-
Cl	1,000	200	200	500	300	-	-	250
HCO_3	-	-	-	128	-	-	-	-
NO_3	-	-	-	5	-	-	-	-
SO_4	-	-	-	100	-	-	-	250
SiO_2	-	50	50	50	-	-	-	35
Hardness	-	100	100	250	350	25	25	-
Alkalinity	-	-	-	125	-	-	-	400
TDS	-	-	-	1,000	1,000	100	100	600
TSS	-	10	10	5	10	5	5	500
Color	30	30	10	20	-	5	5	-
pH	6-10	6-10	6-10	6.2-8.3	6-9	-	-	6.5-8.5
CCE	-	-	-	-	-	-	-	-

*All values in mg/l except color and pH.

Source: Water Pollution Control Federation, 1989.

Table 2-5. Pulp and Paper Process Water Quality Requirements

Parameter [(a)]	Mechanical Pulping	Chemical, Unbleached	Pulp and Paper, Bleached
Iron	0.3	1	0.1
Manganese	0.1	0.5	0.05
Calcium	-	20	20
Magnesium	-	12	12
Chlorine	1,000	200	200
Silicon Dioxide	-	50	50
Hardness	-	100	100
TSS	-	10	10
Color	30	30	10
pH	6 - 10	6 - 10	6 - 10

[(a)] All values in mg/l except color and pH.

Source: Adamski *et al.,* 2000

2.2.3.4 Petroleum and Coal

Processes for the manufacture of petroleum and coal products can usually tolerate water of relatively low quality. Waters generally must be in the 6 to 9 pH range and have moderate SS of no greater than 10 mg/l.

2.3 Agricultural Reuse

This section focuses on the following specific considerations for implementing a water reuse program for agricultural irrigation:

- Agricultural irrigation demands
- Reclaimed water quality
- Other system considerations

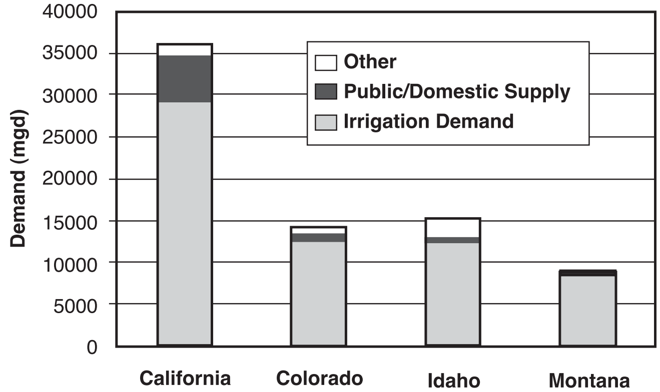
Technical issues common to all reuse programs are discussed in Chapter 3, and the reader is referred to the following subsections for this information: 3.4 – Treatment Requirements, 3.5 – Seasonal Storage Requirements, 3.6 – Supplemental Facilities (conveyance and distribution, operational storage, and alternative disposal).

Agricultural irrigation represents a significant percentage of the total demand for freshwater. As discussed in Chapter 3, agricultural irrigation is estimated to represent 40 percent of the total water demand nationwide (Solley *et al*., 1998). In western states with significant agricultural production, the percentage of freshwater used for irrigation is markedly greater. For example, **Figure 2-4** illustrates the total daily freshwater withdrawals, public water supply, and agricultural irrigation usage for Montana, Colorado, Idaho, and California. These states are the top 4 consumers of water for agricultural irrigation, which accounts for more than 80 percent of their total water demand.

The total cropland area in the U.S. and Puerto Rico is estimated to be approximately 431 million acres (174 million hectares), of which approximately 55 million acres (22 million hectares) are irrigated. Worldwide, it is estimated that irrigation water demands exceed all other categories of water use and make up 75 percent of the total water usage (Solley *et al.,* 1998).

A significant portion of existing water reuse systems supply reclaimed water for agricultural irrigation. In Florida, agricultural irrigation accounts for approximately 19 percent of the total volume of reclaimed water used within the state (Florida Department of Environmental Protection, 2002b). In California, agricultural irrigation accounts for approximately 48 percent of the total volume of reclaimed water used within the state (California State Water Resources Control Board, 2002). **Figure 2-5** shows the percentages of the types of crops irrigated with reclaimed water in California.

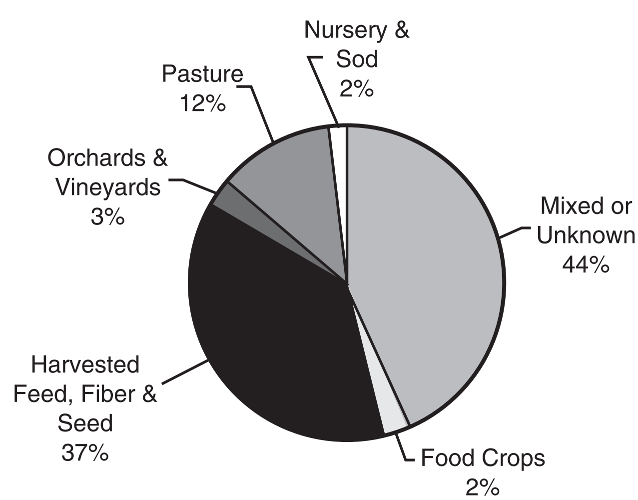
Figure 2-4. Comparison of Agricultural Irrigation, Public/Domestic, and Total Freshwater Withdrawals



Agricultural reuse is often included as a component in water reuse programs for the following reasons:

- Extremely high water demands for agricultural irrigation

Figure 2-5. Agricultural Reuse Categories by Percent in California



Source: California State Water Control Board, 2000

- Significant water conservation benefits associated with reuse in agriculture

- Ability to integrate agricultural reuse with other reuse applications

Due to saltwater intrusion to its agricultural wells, the City of Watsonville, California, is looking to develop 4,000 acre-feet per year (2,480 gpm) of reuse for the irrigation of strawberries, artichokes, and potentially certified organic crops (Raines *et al.,* 2002). Reclaimed water will make up 25 percent of the estimated new water required for irrigation.

2.3.1 Estimating Agricultural Irrigation Demands

Because crop water requirements vary with climatic conditions, the need for supplemental irrigation will vary from month to month throughout the year. This seasonal variation is a function of rainfall, temperature, crop type, stage of plant growth, and other factors, depending on the method of irrigation being used.

The supplier of reclaimed water must be able to quantify these seasonal demands, as well as any fluctuation in the reclaimed water supply, to assure that the demand for irrigation water can be met. Unfortunately, many agricultural users are unable to provide sufficient detail about irrigation demands for design purposes. This is because the user's seasonal or annual water use is seldom measured and recorded, even on land surfaces where water has been used for irrigation for a number of years. However, expert guidance is usually available through state colleges and universities and the local soil conservation service office.

To assess the feasibility of reuse, the reclaimed water supplier must be able to reasonably estimate irrigation demands and reclaimed water supplies. To make this assessment in the absence of actual water use data, evapotranspiration, percolation and runoff losses, and net irrigation must be estimated, often through the use of predictive equations.

2.3.1.1 Evapotranspiration

Evapotranspiration is defined as water either evaporated from the soil surface or actively transpired from the crop. While the concept of evapotranspiration is easily described, quantifying the term mathematically is difficult. Evaporation from the soil surface is a function of the soil moisture content at or near the surface. As the top layer of soil dries, evaporation decreases. Transpiration, the water vapor released through the plants' surface membranes, is a function of available soil moisture, season, and stage of growth. The rate of transpiration may be further impacted by soil structure and the salt concentration in the soil water. Primary factors affecting evaporation and transpiration are relative humidity, wind, and solar radiation.

Practically every state in the U.S. and Canada now has access to weather information from the Internet. California has developed the California Irrigation Management Information System (CIMIS), which allows growers to obtain daily reference evapotranspiration information. Data are made available for numerous locations within the state according to regions of similar climatic conditions. State publications provide coefficients for converting these reference data for use on specific crops, location, and stages of growth. This allows users to refine irrigation scheduling and conserve water. Other examples of weather networks are the Michigan State University Agricultural Weather Station, the Florida Automated Weather Network, and the Agri-Food Canada Lethbridge Research Centre Weather Station Network.

Numerous equations and methods have been developed to define the evapotranspiration term. The Thornthwaite and Blaney-Criddle methods of estimating evapotranspiration are 2 of the most cited methods. The Blaney-Criddle equation uses percent of daylight hours per month and average monthly temperature. The Thornthwaite method relies on mean monthly temperature and daytime hours. In addition to specific empirical equations, it is quite common to encounter modifications to empirical equations for use under specific regional conditions. In selecting an empirical method of estimating evapotranspiration, the potential user is encouraged to solicit input from local agencies familiar with this subject.

2.3.1.2 Effective Precipitation, Percolation, and Surface Water Runoff Losses

The approach for the beneficial reuse of reclaimed water will, in most cases, vary significantly from land application. In the case of beneficial reuse, the reclaimed water is a resource to be used judiciously. The prudent allocation of this resource becomes even more critical in locations where reclaimed water is assigned a dollar value, thereby becoming a commodity. Where there is a cost associated with using reclaimed water, the recipient of reclaimed water will seek to balance the cost of supplemental irrigation against the expected increase in crop yields to derive the maximum economic benefit. Thus, percolation losses will be minimized because they represent the loss of water available to the crop and wash fertilizers out of the root zone. An exception to this occurs when the reclaimed water has a high salt concentration and excess application is required to prevent the accumulation of salts in the root zone.

Irrigation demand is the amount of water required to meet the needs of the crop and also overcome system losses. System losses will consist of percolation, surface water runoff, and transmission and distribution losses. In addition to the above losses, the application of water to crops will include evaporative losses or losses due to wind drift. These losses may be difficult to quantify individually and are often estimated as single system efficiency. The actual efficiency of a given system will be site specific and vary widely depending on management practices followed. Irrigation efficiencies typically range from 40 to 98 percent (Vickers, 2001). A general range of efficiencies by type of irrigation system is shown in **Table 2-6**.

Since there are no hard and fast rules for selecting the most appropriate method for projecting irrigation demands and establishing parameters for system reliability, it may be prudent to undertake several of the techniques and to verify calculated values with available records. In the interest of developing the most useful models, local irrigation specialists should be consulted.

2.3.2 Reclaimed Water Quality

The chemical constituents in reclaimed water of concern for agricultural irrigation are salinity, sodium, trace elements, excessive chlorine residual, and nutrients. Sensitivity is generally a function of a given plant's tolerance to constituents encountered in the root zone or deposited on the foliage. Reclaimed water tends to have higher concentrations of these constituents than the groundwater or surface water sources from which the water supply is drawn.

The types and concentrations of constituents in reclaimed wastewater depend upon the municipal water supply, the influent waste streams (i.e., domestic and industrial contributions), amount and composition of infiltration in the wastewater collection system, the wastewater treatment processes, and type of storage facilities. Conditions that can have an adverse impact on reclaimed water quality may include:

- Elevated TDS levels
- Industrial discharges of potentially toxic compounds into the municipal sewer system
- Saltwater (chlorides) infiltration into the sewer system in coastal areas

Table 2-6. Efficiencies for Different Irrigation Systems

Irrigation System	Potential On-Farm Efficiency[1] (Percent)
Gravity (Surface)	
Improved gravity[2]	75-85
Furrow	55-70
Flood	40-50
Sprinklers	
Low energy precision application (LEPA)	80-90
Center pivot[3]	70-85
Sideroll	60-80
Solid set	65-80
Hand-move	60-65
Big gun	60-65
Microirrigation	
Drip	80-95

[1]Efficiencies shown assume appropriate irrigation system selection, correct irrigation design, and proper management.
[2]Includes tailwater recovery, precision land leveling, and surge flow systems.
[3]Includes high- and low-pressure center pivot.

Source: Vickers, 2001.

For example, reclaimed water is used mostly for ridge and furrow irrigation at the High Hat Ranch in Sarasota, Florida, although a portion of the reclaimed water is used for citrus irrigation via microjet irrigation. To achieve successful operation of the microjet irrigation system, filters were installed to provide additional solids removal treatment to the reclaimed water used for citrus irrigation.

2.3.2.1 Salinity

Salinity is the single most important parameter in determining the suitability of the water to be used for irrigation. Salinity is determined by measuring the electrical conductivity (EC) and/or the total dissolved solids (TDS) in the water. Estimates indicate that 23 percent of irrigated farmland has been damaged by salt (Postel, 1999). The salinity tolerance of plants varies widely. Crops must be chosen carefully to ensure that they can tolerate the salinity of the irrigation water, and even then the soil must be properly drained and adequately leached to prevent salt build-up. Leaching is the deliberate over-application of irrigation water in excess of crop needs to establish a downward movement of water and salt away from the root zone.

The extent of salt accumulation in the soil depends on the concentration of salts in the irrigation water and the rate at which salts are removed by leaching. Salt accumulation can be especially detrimental during germination and when plants are young (seedlings). At this stage, damage can occur even with relatively low salt concentrations. Concerns with salinity relate to possible impacts to the following: the soil's osmotic potential, specific ion toxicity, and degradation of soil physical conditions. These conditions may result in reduced plant growth rates, reduced yields, and, in severe cases, total crop failure.

The concentration of specific ions may cause one or more of these trace elements to accumulate in the soil and in the plant. Long-term build-up may result in animal and human health hazards or phytotoxicity in plants. When irrigating with municipal reclaimed water, the ions of most concern are sodium, chloride, and boron. Household detergents are usually the source of boron and water softeners contribute sodium and chloride. Plants vary greatly in their sensitivity to specific ion toxicity. Toxicity is particularly detrimental when crops are irrigated with overhead sprinklers during periods of high temperature and low humidity. Highly saline water applied to the leaves results in direct absorption of sodium and/or chloride and can cause leaf injury.

Salinity reduces the water uptake in plants by lowering the osmotic potential of the soil. This, in turn, causes the plant to use a large portion of its available energy to adjust the salt concentration within its tissue in order to obtain adequate water. This results in less energy available for plants to grow. The problem is more severe in hot and dry climatic conditions because of increased water demands by plants and is even more severe when irrigation is inadequate.

One location where subsurface drainage is being evaluated is in California's San Joaquin Valley. The drainage management process is called "integrated on-farm drainage management" and involves reusing the drainage water and using it to irrigate more salt-tolerant crops. The final discharge water goes into solar evaporators that collect the dry agricultural salt.

Further complications of salinity problems can occur in geographic locations where the water table is high. A high water table can cause a possible upward flow of high salinity water into the root zone. Subsurface drainage offers a viable solution in these locations. Older clay tiles are often replaced with fabric-covered plastic pipe to prevent clogging. This subsurface drainage technique is one salinity-controlling process that requires significant changes in irrigation management. There are other techniques that require relatively minor changes including more frequent irrigation schedules, selection of more salt-tolerant crops, seed placement, additional leaching, bed forming, and pre-plant irrigation.

2.3.2.2 Sodium

The potential influence sodium may have on soil properties is indicated by the sodium-adsorption-ratio (SAR), which is based on the effect of exchangeable sodium on the physical condition of the soil. SAR expresses the concentration of sodium in water relative to calcium and magnesium. Excessive sodium in irrigation water (when sodium exceeds calcium by more than a 3:1 ratio) contributes to soil dispersion and structural breakdown, where the finer soil particles fill many of the smaller pore spaces, sealing the surface and greatly reducing water infiltration rates (AWWA, 1997). For reclaimed water, it is recommended that the calcium ion concentration in the SAR equation be adjusted for alkalinity to include a more correct estimate of calcium in the soil water following irrigation, specifically adj RNa. Note that the calculated adj RNa is to be substituted for the SAR value.

Sodium salts influence the exchangeable cation composition of the soil, which lowers the permeability and affects the tilth of the soil. This usually occurs within the first few inches of the soil and is related to high sodium or very low calcium content in the soil or irrigation water. Sodium hazard does not impair the uptake of water by plants but does impair the infiltration of water into the soil. The growth of plants is thus affected by an unavailability of soil water (Tanji, 1990). Calcium and magnesium act as stabilizing ions in contrast to the destabilizing ion, sodium, in regard to the soil structure. They offset the phenomena related to the distance of charge neutralization for soil particles caused by excess sodium. Sometimes the irrigation water may dissolve sufficient calcium from calcareous soils to decrease the sodium hazard appreciably. Leaching and dissolving the calcium from the soil is of little concern when irrigating with reclaimed water because it is usually high enough in salt and calcium. Reclaimed water, however, may be high in sodium relative to calcium and may cause soil permeability problems if not properly managed.

2.3.2.3 Trace Elements

The elements of greatest concern at elevated levels are cadmium, copper, molybdenum, nickel, and zinc. Nickel and zinc have visible adverse effects in plants at lower concentrations than the levels harmful to animals and humans. Zinc and nickel toxicity is reduced as pH increases. Cadmium, copper, and molybdenum, however, can be harmful to animals at concentrations too low to impact plants.

Copper is not toxic to monogastric animals, but may be toxic to ruminants. However, their tolerance to copper increases as available molybdenum increases. Molybdenum can also be toxic when available in the absence of copper. Cadmium is of particular concern as it can accumulate in the food chain. It does not adversely affect ruminants due to the small amounts they ingest. Most milk and beef products are also unaffected by livestock ingestion of cadmium because the cadmium is stored in the liver and kidneys of the animal, rather than the fat or muscle tissues.

In addition, it was found that the input of heavy metals from commercial chemical fertilizer impurities was far greater than that contributed by the reclaimed water (Engineering Science, 1987).

Table 2-7 shows EPA's recommended limits for constituents in irrigation water.

The recommended maximum concentrations for "long-term continuous use on all soils" are set conservatively to include sandy soils that have low capacity to leach (and so to sequester or remove) the element in question. These maxima are below the concentrations that produce toxicity when the most sensitive plants are grown in nutrient solutions or sand cultures to which the pollutant has been added. This does not mean that if the suggested limit is exceeded that phytotoxicity will occur. Most of the elements are readily fixed or tied up in soil and accumulate with time. Repeated applications in excess of suggested levels might induce phytotoxicity. The criteria for short-term use (up to 20 years) are recommended for fine-textured neutral and alkaline soils with high capacities to remove the different pollutant elements.

2.3.2.4 Chlorine Residual

Free chlorine residual at concentrations less than 1 mg/l usually poses no problem to plants. However, some sensitive crops may be damaged at levels as low as 0.05 mg/l. Some woody crops, however, may accumulate chlorine in the tissue to toxic levels. Excessive chlorine has a similar leaf-burning effect as sodium and chloride when sprayed directly on foliage. Chlorine at concentrations greater than 5 mg/l causes severe damage to most plants.

2.3.2.5 Nutrients

The nutrients most important to a crop's needs are nitrogen, phosphorus, potassium, zinc, boron, and sulfur. Reclaimed water usually contains enough of these nutrients to supply a large portion of a crop's needs.

The most beneficial nutrient is nitrogen. Both the concentration and form of nitrogen need to be considered in irrigation water. While excessive amounts of nitrogen stimulate vegetative growth in most crops, it may also delay maturity and reduce crop quality and quantity. The nitrogen in reclaimed water may not be present in concentrations great enough to produce satisfactory crop yields, and some supplemental fertilizer may be necessary. In addition, excessive nitrate in forages can cause an imbalance of nitrogen, potassium, and magnesium in grazing animals. This is a concern if the forage is used as a primary feed source for livestock; however, such high concentrations are usually not expected with municipal reclaimed water.

Soils in the western U.S. may contain enough potassium, while many sandy soils of the southern U.S. do not. In either case, the addition of potassium with reclaimed water has little effect on crops. Phosphorus contained in reclaimed water is usually at too low a level to meet a crop's needs. Yet, over time, it can build up in the soil and reduce the need for phosphorus supplementation. Excessive phosphorus levels do not appear to pose any problems to crops, but can be a problem in runoff to surface waters.

Table 2-7. Recommended Limits for Constituents in Reclaimed Water for Irrigation

Constituent	Long-Term Use (mg/l)	Short-Term Use (mg/l)	Remarks
Aluminum	5.0	20	Can cause nonproductiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
Beryllium	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Boron	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/L in nutrient solutions. Toxic to many sensitive plants (e.g., citrus) at 1 mg/L. Usually sufficient quantities in reclaimed water to correct soil deficiencies. Most grasses are relatively tolerant at 2.0 to 10 mg/L.
Cadmium	0.01	0.05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L in nutrient solution. Conservative limits recommended.
Chromium	0.1	1.0	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt	0.05	5.0	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.
Fluoride	1.0	15.0	Inactivated by neutral and alkaline soils.
Iron	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.
Lead	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium	2.5	2.5	Tolerated by most crops at concentrations up to 5 mg/L; mobile in soil. Toxic to citrus at low doses - recommended limit is 0.075 mg/L.
Manganese	0.2	10.0	Toxic to a number of crops at a few-tenths to a few mg/L in acidic soils.
Molybdenum	0.01	0.05	Nontoxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Selenium	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium.
Tin, Tungsten, & Titanium	-	-	Effectively excluded by plants; specific tolerance levels unknown
Vanadium	0.1	1.0	Toxic to many plants at relatively low concentrations.
Zinc	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.
Constituent	**Recommended Limit**		**Remarks**
pH	6.0		Most effects of pH on plant growth are indirect (e.g., pH effects on heavy metals' toxicity described above).
TDS	500 - 2,000 mg/l		Below 500 mg/L, no detrimental effects are usually noticed. Between 500 and 1,000 mg/L, TDS in irrigation water can affect sensitive plants. At 1,000 to 2,000 mg/L, TDS levels can affect many crops and careful management practices should be followed. Above 2,000 mg/L, water can be used regularly only for tolerant plants on permeable soils.
Free Chlorine Residual	<1 mg/l		Concentrations greater than 5 mg/l causes severe damage to most plants. Some sensitive plants may be damaged at levels as low as 0.05 mg/l.

Source: Adapted from Rowe and Abdel-Magid, 1995.

Numerous site-specific studies have been conducted regarding the potential water quality concerns associated with reuse irrigation. The overall conclusions from the Monterey (California) Wastewater Reclamation Study for Agriculture (Jaques, 1997) are as follows:

- Irrigation with filtered effluent (FE) or Title-22 effluent (T-22) appears to be as safe as well water.
- Few statistically significant differences were found in soil or plant parameters, and none were found to

be attributable to different types of water. None of the differences had important implications for public health.

- Yields of annual crops were often significantly higher with reclaimed water.

- No viruses were detected in any of the reclaimed waters, although viruses were often detected in the secondary effluent prior to the reclamation process.

- The T-22 process was somewhat more efficient than the FE process in removing viruses when the influent was seeded at high levels of virus concentration. However, both processes demonstrated the ability to remove more than 5 logs of viruses during the seeding experiments. (Jaques, 1997)

This and other investigations suggest that reclaimed water is suitable for most agricultural irrigation needs.

2.3.3 Other System Considerations

In addition to irrigation supply and demand and reclaimed water quality requirements, there are other considerations specific to agricultural water reuse that must be addressed. Both the user and supplier of reclaimed water may have to consider modifications in current practice that may be required to use reclaimed water for agricultural irrigation. The extent to which current irrigation practices must be modified to make beneficial use of reclaimed water will vary on a case-by-case basis. Important considerations include:

- System reliability
- Site use control
- Monitoring requirements
- Runoff controls
- Marketing incentives
- Irrigation equipment

2.3.3.1 System Reliability

System reliability involves 2 basic issues. First, as in any reuse project that is implemented to reduce or eliminate surface water discharge, the treatment and distribution facilities must operate reliably to meet permit conditions. Second, the supply of reclaimed water to the agricultural user must be reliable in quality and quantity for successful use in a farming operation.

Reliability in quality involves providing the appropriate treatment for the intended use, with special consideration of crop sensitivities and potential toxicity effects of reclaimed water constituents (See Sections 3.4 and 2.3.2). Reliability in quantity involves balancing irrigation supply with demand. This is largely accomplished by providing sufficient operational and seasonal storage facilities (See Sections 3.5 and 3.5.2.) It is also necessary to ensure that the irrigation system itself can reliably accept the intended supply to minimize the need for discharge or alternate disposal.

2.3.3.2 Site Use Control

Many states require a buffer zone around areas irrigated with reclaimed water. The size of this buffer zone is often associated with the level of treatment the reclaimed water has received and the means of application. Additional controls may include restrictions on the times that irrigation can take place and restrictions on the access to the irrigated site. Such use area controls may require modification to existing farm practices and limit the use of reclaimed water to areas where required buffer zones cannot be provided. See Chapter 4 for a discussion of the different buffer zones and use controls specified in state regulations. Signs specifying that reclaimed water is being used may be required to prevent accidental contact or ingestion.

2.3.3.3 Monitoring Requirements

Monitoring requirements for reclaimed water use in agriculture differ by state (See Chapter 4). In most cases, the supplier will be required to sample the reclaimed water quality at specific intervals for specific constituents. Sampling may be required at the water reclamation plant and, in some cases, in the distribution system.

Groundwater monitoring is often required at the agricultural site, with the extent depending on the reclaimed water quality and the hydrogeology of the site. Groundwater monitoring programs may be as simple as a series of surficial wells to a complex arrangement of wells sampling at various depths. Monitoring must be considered in estimating the capital and operating costs of the reuse system, and a complete understanding of monitoring requirements is needed as part of any cost/benefit analysis.

2.3.3.4 Runoff Controls

Some irrigation practices, such as flood irrigation, result in a discharge of irrigation water from the site (tail water). Regulatory restrictions of this discharge may be few or none when using surface water or groundwater sources;

however, when reclaimed water is used, runoff controls may be required to prevent discharge or a National Pollutant Discharge Elimination System (NPDES) permit may be required for a surface water discharge.

2.3.3.5 Marketing Incentives

In many cases, an existing agricultural site will have an established source of irrigation water, which has been developed by the user at some expense (e.g., engineering, permitting, and construction). In some instances, the user may be reluctant to abandon these facilities for the opportunity to use reclaimed water. Reclaimed water use must then be economically competitive with existing irrigation practices or must provide some other benefits. For example, in arid climates or drought conditions where potable irrigation is restricted for water conservation purposes, reclaimed water could be offered as a dependable source of irrigation. Reclaimed water may also be of better quality than that water currently available to the farmer, and the nutrients may provide some fertilizer benefit. In some instances, the supplier of reclaimed water may find it cost effective to subsidize reclaimed water rates to agricultural users if reuse is allowing the supplier to avoid higher treatment costs associated with alternative means of disposal.

2.3.3.6 Irrigation Equipment

By and large, few changes in equipment are required to use reclaimed water for agricultural irrigation. However, some irrigation systems do require special considerations.

Surface irrigation systems (ridge and furrow, graded borders) normally result in the discharge of a portion of the irrigation water from the site. Where reclaimed water discharge is not permitted, some method of tail water return or pump-back may be required.

In sprinkler systems, dissolved salts and particulate matter may cause clogging, depending on the concentration of these constituents as well as the nozzle size. Because water droplets or aerosols from sprinkler systems are subject to wind drift, the use of reclaimed water may necessitate the establishment of buffer zones around the irrigated area. In some types of systems (i.e., center pivots), the sprinkler nozzles may be dropped closer to the ground to reduce aerosol drift and thus minimize the buffer requirements. In addition, some regulatory agencies restrict the use of sprinkler irrigation for crops to be eaten raw, because it results in the direct contact of reclaimed water with the fruit.

When reclaimed water is used in a micro-irrigation system, a good filtration system is required to prevent complete or partial clogging of emitters. Close, regular inspections of emitters are required to detect emitter clogging. In-line filters of an 80 to 200 mesh are typically used to minimize clogging. In addition to clogging, biological growth within the transmission lines and at the emitter discharge may be increased by nutrients in the reclaimed water. Due to low volume application rates with micro-irrigation, salts may accumulate at the wetted perimeter of the plants and then be released at toxic levels to the crop when leached via rainfall.

2.4 Environmental and Recreational Reuse

Environmental reuse includes wetland enhancement and restoration, creation of wetlands to serve as wildlife habitat and refuges, and stream augmentation. Uses of reclaimed water for recreational purposes range from landscape impoundments, water hazards on golf courses, to full-scale development of water-based recreational impoundments, incidental contact (fishing and boating) and full body contact (swimming and wading). As with any form of reuse, the development of recreational and environmental water reuse projects will be a function of a water demand coupled with a cost-effective source of suitable quality reclaimed water.

As discussed in Chapter 4, many states have regulations that specifically address recreational and environmental uses of reclaimed water. For example, California's recommended treatment train for each type of recreational water reuse is linked to the degree of body contact in that use (that is, to what degree swimming and wading are likely). Secondary treatment and disinfection to 2.2 total coliforms/100 ml average is required for recreational water bodies where fishing, boating, and other non-body contact activities are permitted. For nonrestricted recreational use that includes wading and swimming, treatment of secondary effluent is to be followed by coagulation, filtration, and disinfection to achieve 2.2 total coliforms/100 ml and a maximum of 23 total coliforms/100 ml in any one sample taken during a 30-day period.

In California, approximately 10 percent (47.6 mgd) (2080 l/s) of the total reclaimed water use within the state was associated with recreational and environmental reuse in 2000 (California State Water Resources Control Board, 2002). In Florida, approximately 6 percent (35 mgd or 1530 l/s) of the reclaimed water currently produced is being used for environmental enhancements, all for wetland enhancement and restoration (Florida Department of Environmental Protection, 2002). In Florida, from 1986 to 2001, there was a 53 percent increase (18.5 mgd to 35 mgd or 810 l/s to 1530 l/s) in the reuse flow used for environmental enhancements (wetland enhancement and restoration).

Two examples of large-scale environmental and recreational reuse projects are the City of West Palm Beach, Florida, wetlands-based water reclamation project (see case study 2.7.17) and the Eastern Municipal Water District multipurpose constructed wetlands in Riverside County, California.

The remainder of this section provides an overview of the following environmental and recreational uses:

- Natural and man-made wetlands
- Recreational and aesthetic impoundments
- Stream augmentation

The objectives of these reuse projects are typically to create an environment in which wildlife can thrive and/or develop an area of enhanced recreational or aesthetic value to the community through the use of reclaimed water.

2.4.1 Natural and Man-made Wetlands

Over the past 200 years, approximately 50 percent of the wetlands in the continental United States have been destroyed for such diverse uses as agriculture, mining, forestry, and urbanization. Wetlands provide many worthwhile functions, including flood attenuation, wildlife and waterfowl habitat, productivity to support food chains, aquifer recharge, and water quality enhancement. In addition, the maintenance of wetlands in the landscape mosaic is important for the regional hydrologic balance. Wetlands naturally provide water conservation by regulating the rate of evapotranspiration and, in some cases, by providing aquifer recharge. The deliberate application of reclaimed water to wetlands can provide a beneficial use, and therefore reuse, by fulfilling any of the following objectives:

1. To create, restore, and/or enhance wetlands systems
2. To provide additional treatment of reclaimed water prior to discharge to a receiving water body
3. To provide a wet weather disposal alternative for a water reuse system (See Section 3.6.4.)

For wetlands that have been altered hydrologically, application of reclaimed water serves to restore and enhance the wetlands. New wetlands can be created through application of reclaimed water, resulting in a net gain in wetland acreage and functions. In addition, man-made and restored wetlands can be designed and managed to maximize habitat diversity within the landscape.

The application of reclaimed water to wetlands provides compatible uses. Wetlands are often able to enhance the water quality of the reclaimed water without creating undesirable impacts to the wetlands system. This, in turn, enhances downstream natural water systems and provides aquifer recharge.

A great deal of research has been performed documenting the ability of wetlands, both natural and constructed, to provide consistent and reliable water quality improvement. With proper execution of design and construction elements, constructed wetlands exhibit characteristics that are similar to natural wetlands, in that they support similar vegetation and microbes to assimilate pollutants. In addition, constructed wetlands provide wildlife habitat and environmental benefits that are similar to natural wetlands. Constructed wetlands are effective in the treatment of BOD, TSS, nitrogen, phosphorus, pathogens, metals, sulfates, organics, and other toxic substances.

Water quality enhancement is provided by transformation and/or storage of specific constituents within the wetland. The maximum contact of reclaimed water within the wetland will ensure maximum treatment assimilation and storage. This is due to the nature of these processes. If optimum conditions are maintained, nitrogen and BOD assimilation in wetlands will occur indefinitely, as they are primarily controlled by microbial processes and generate gaseous end products. In contrast, phosphorus assimilation in wetlands is finite and is related to the adsorption capacity of the soil and long-term storage within the system. The wetland can provide additional water quality enhancement (polishing) to the reclaimed water product.

In most reclaimed water wetland projects, the primary intent is to provide additional treatment of effluent prior to discharge from the wetland. However, this focus does not negate the need for design considerations that will maximize wildlife habitats, and thereby provide important ancillary benefits. For constructed wetlands, appropriate plant species should be selected based on the type of wetland to be constructed as well as the habitat goals. Treatment performance information is available regarding certain wetland species as well as recommendations regarding species selection (Cronk and Fennessy, 2001).

Wetlands do not provide treatment of total suspended solids. In addition, a salinity evaluation may be necessary because effluent with a high salt content may cause impacts to wetland vegetation. In some cases, salt tolerant vegetation may be appropriate. Design considerations will need to balance the hydraulic and constituent loadings with impacts to the wetland. Impacts to groundwater quality should also be evaluated.

The benefits of a wetland treatment system include:

- Improve water quality through the use of natural systems
- Protect downstream receiving waters
- Provide wetland creation, restoration, or enhancement
- Provide wildlife and waterfowl habitat
- Offer relatively low operating and maintenance costs
- A reasonable development cost
- Maintain "green space"
- Attenuate peak flows
- One component of a "treatment train"; can be used in areas with high water table and/or low permeable soils
- Aesthetic and educational opportunities

Potential limitations of a wetland treatment systems include:

- Significant land area requirements
- May have limited application in urban settings
- Potential for short-circuiting, which will lead to poor performance
- Potential for nuisance vegetation and algae
- May need to be lined to maintain wetland hydroperiod

A number of cities have developed wetlands enhancement systems to provide wildlife habitats as well as treatment. In Arcata, California, one of the main goals of a city wetland project was to enhance the beneficial use of downstream surface waters. A wetlands application system was selected because the wetlands: (1) serve as nutrient sinks and buffer zones, (2) have aesthetic and environmental benefits, and (3) can provide cost-effective treatment through natural systems. The Arcata wetlands system was also designed to function as a wildlife habitat. The Arcata wetlands system, consisting of three 10-acre (4-hectare) marshes, has attracted more than 200 species of birds, provided a fish hatchery for salmon, and contributed directly to the development of the Arcata Marsh and Wildlife Sanctuary (Gearheart, 1988).

Due to a 20-mgd (877-L/s) expansion of the City of Orlando, Florida, Iron Bridge Regional Water Pollution Control Facility in 1981, a wetland system was created to handle the additional flow. Since 1981, reclaimed water from the Iron Bridge plant has been pumped 16 miles (20 kilometers) to a wetland that was created by berming approximately 1,200 acres (480 hectares) of improved pasture. The system is further divided into smaller cells for flow and depth management. The wetland consists of 3 major vegetative areas. The first area, approximately 410 acres (166 hectares), is a deep marsh consisting primarily of cattails and bulrush with nutrient removal as the primary function. The second area consists of 380 acres (154 hectares) of a mixed marsh composed of over 60 submergent and emergent herbaceous species used for nutrient removal and wildlife habitat. The final area, 400 acres (162 hectares) of hardwood swamp, consists of a variety of tree species providing nutrient removal and wildlife habitat. The reclaimed water then flows through approximately 600 acres (240 hectares) of natural wetland prior to discharge to the St. Johns River (Jackson, 1989).

EPA (1999a) indicated that little effort had been made to collect or organize information concerning the habitat functions of treatment wetlands. Therefore, the Treatment Wetland Habitat and Wildlife Use Assessment document (U.S. EPA, 1999a) was prepared. The document was the first comprehensive effort to assemble wide-ranging information concerning the habitat and wildlife use data from surface flow treatment wetlands. The data have been gathered into an electronic format built upon the previous existing North American Treatment Wetland Database funded by the EPA. The report indicates that both natural and constructed treatment wetlands have substantial plant communities and wildlife populations. There are potentially harmful substances in the water, sediments, and biological tissues of treatment wetlands. However, contaminant concentration levels are generally below published action levels. There is apparently no documentation indicating that harm has occurred in any wetland intentionally designed to improve water quality.

The Yelm, Washington, project in Cochrane Memorial Park, is an aesthetically pleasing 8-acre (3-hectare) city park featuring constructed surface and submerged wetlands designed to polish the reclaimed water prior to recharging groundwater. In the center of the park, a fish pond uses the water to raise and maintain rainbow trout for catch and release (City of Yelm, 2003).

A number of states including Florida, South Dakota, and Washington, provide regulations to specifically address the use of reclaimed water in wetlands systems. Where specific regulations are absent, wetlands have been constructed on a case-by-case basis. In addition to state requirements, natural wetlands, which are considered waters of the U.S., are protected under EPA's NPDES Permit and Water Quality Standards programs. The quality of reclaimed water entering natural wetlands is regulated by federal, state and local agencies and must be treated to at least secondary treatment levels or greater to meet water quality standards. Constructed wetlands, on the other hand, which are built and operated for the purpose of treatment only, are not considered waters of the U.S.

Wetland treatment technology, using free water surface wetlands, has been under development, with varying success, for nearly 30 years in the U.S. (U.S. EPA, 1999b). Several key documents that summarize the available information and should be used to assist in the design of wetland treatment systems are: Treatment Wetlands (Kadlec and Kngith, 1996), Free Water Surface Wetlands for Wastewater Treatment (U.S. EPA, 1999b), Constructed Wetlands for Pollution Control: Process, Performance, Design and Operation (IWA, 2000), and the Water Environment Federation Manual of Practice FD-16 Second Edition. Natural Systems for Wastewater Treatment, Chapter 9; Wetland Systems, (WEF, 2001).

2.4.2 Recreational and Aesthetic Impoundments

For the purposes of this discussion, an impoundment is defined as a man-made water body. The use of reclaimed water to augment natural water bodies is discussed in Section 3.4.3. Impoundments may serve a variety of functions from aesthetic, non-contact uses, to boating and fishing, as well as swimming. As with other uses of reclaimed water, the required level of treatment will vary with the intended use of the water. As the potential for human contact increases, the required treatment levels increase. The appearance of the reclaimed water must also be considered when used for impoundments, and treatment for nutrient removal may be required as a means of controlling algae. Without nutrient control, there is a high potential for algae blooms, resulting in odors, an unsightly appearance, and eutrophic conditions.

Reclaimed water impoundments can be easily incorporated into urban developments. For example, landscaping plans for golf courses and residential developments commonly integrate water traps or ponds. These same water bodies may also serve as storage facilities for irrigation water within the site.

In Lubbock, Texas, approximately 4 mgd (175 l/s) of reclaimed water is used for recreational lakes in the Yellowhouse Canyon Lakes Park (Water Pollution Control Federation, 1989). The canyon, which was formerly used as a dump, was restored through the use of reclaimed water to provide water-oriented recreational activities. Four lakes, which include man-made waterfalls, are used for fishing, boating, and water skiing; however, swimming is restricted.

Lakeside Lake is a 14-acre (6-hectare) urban impoundment in Tucson, Arizona. The lake was constructed in the 1970s in the Atterbury Wash to provide fishing, boating, and other recreational opportunities. The lake is lined with soil/cement layers and has a concrete shelf extending 6 feet (2 meters) from the shore around the perimeter. A berm crosses the lake from east to west, creating a north and south bay. The Arizona Game and Fish Department (AGFD) stock the lake with channel catfish, rainbow trout, bluegill, redear and hybrid sunfish, crappie, and large mouth bass on a seasonal basis. The lake was initially supplied by groundwater and surface runoff but began receiving reclaimed water from the Roger Road Treatment Plant in 1990 (up to 45,000 gpd) (170 m^3/d). A mechanical diffuser was installed on the lake bottom in 1992 to improve dissolved oxygen concentrations (PBS&J, 1992).

2.4.3 Stream Augmentation

Stream augmentation is differentiated from a surface water discharge in that augmentation seeks to accomplish a beneficial end, whereas discharge is primarily for disposal. Stream augmentation may be desirable to maintain stream flows and to enhance the aquatic and wildlife habitat as well as to maintain the aesthetic value of the water courses. This may be necessary in locations where a significant volume of water is drawn for potable or other uses, largely reducing the downstream volume of water in the river.

As with impoundments, water quality requirements for stream augmentation will be based on the designated use of the stream as well as the aim to maintain an acceptable appearance. In addition, there may be an emphasis on creating a product that can sustain aquatic life.

The San Antonio Water System in Texas releases its high quality (Type 1) reclaimed water to the San Antonio River. Reclaimed water is used instead of pumped groundwater to sustain the river flow through a city park, zoo, and downtown river walk. A second stream augmentation flows to Salado Creek, where reclaimed water replaces the flow from an abandoned artesian well. Also, reclaimed water is used in a decorative fountain at the City Convention Center with the fountain discharging into a dead-end channel of the downtown river walk waterway.

Several agencies in southern California are evaluating the process in which reclaimed water would be delivered to streams in order to maintain a constant flow of high-quality water for the enhancement of aquatic and wildlife habitat as well as to maintain the aesthetic value of the streams.

2.5 Groundwater Recharge

This section addresses planned groundwater recharge using reclaimed water with the specific intent to replenish groundwater. Although practices such as irrigation may contribute to groundwater augmentation, the replenishment is an incidental byproduct of the primary activity and is not discussed in this section.

The purposes of groundwater recharge using reclaimed water may be: (1) to establish saltwater intrusion barriers in coastal aquifers, (2) to provide further treatment for future reuse, (3) to augment potable or nonpotable aquifers, (4) to provide storage of reclaimed water for subsequent retrieval and reuse, or (5) to control or prevent ground subsidence.

Pumping of aquifers in coastal areas may result in saltwater intrusion, making them unsuitable as sources for potable supply or for other uses where high salt levels are intolerable. A battery of injection wells can be used to create a hydraulic barrier to maintain intrusion control. Reclaimed water can be injected directly into an aquifer to maintain a seaward gradient and thus prevent inland subsurface saltwater intrusion. This may allow for the additional development of inland withdrawals or simply the protection of existing withdrawals.

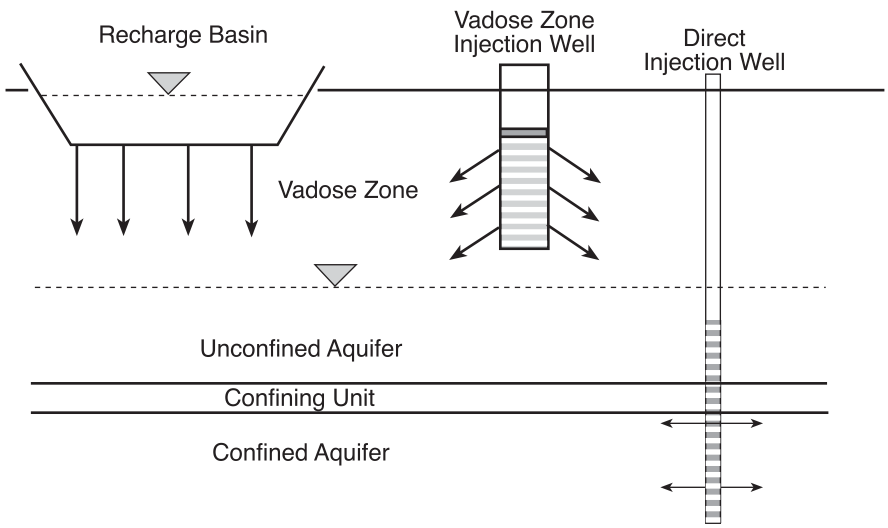
Infiltration and percolation of reclaimed water takes advantage of the natural removal mechanisms within soils, including biodegradation and filtration, thus providing additional *in situ* treatment of reclaimed water and additional treatment reliability to the overall wastewater management system. The treatment achieved in the subsurface environment may eliminate the need for costly advanced wastewater treatment processes. The ability to implement such treatment systems will depend on the method of recharge, hydrogeological conditions, requirements of the downgradient users, as well as other factors.

Aquifers provide a natural mechanism for storage and subsurface transmission of reclaimed water. Irrigation demands for reclaimed water are often seasonal, requiring either large storage facilities or alternative means of disposal when demands are low. In addition, suitable sites for surface storage facilities may not be available, economically feasible, or environmentally acceptable. Groundwater recharge eliminates the need for surface storage facilities and the attendant problems associated with uncovered surface reservoirs, such as evaporation losses, algae blooms resulting in deterioration of water quality, and creation of odors. Aquifer storage and recovery (ASR) systems are being used in a number of states to overcome seasonal imbalances in both potable and reclaimed water projects. The tremendous volumes of storage potentially available in ASR systems means that a greater percentage of the resource, be it raw water or reclaimed water, can be captured for beneficial use.

While there are obvious advantages associated with groundwater recharge, possible limitations include (Oaksford, 1985):

- Extensive land areas may be needed for spreading basins.
- Costs for treatment, water quality monitoring, and injection/infiltration facilities operations may be prohibitive.
- Recharge may increase the danger of aquifer contamination due to inadequate or inconsistent pretreatment.
- Not all recharged water may be recoverable due to movement beyond the extraction well capture zone or mixing with poor-quality groundwater.
- The area required for operation and maintenance of a groundwater supply system (including the groundwater reservoir itself) is generally larger than that required for a surface water supply system. The fact that the aquifer does not compete with overlying land uses provides a significant advantage. However, this reservoir cannot adversely impact existing uses of the aquifer.

Figure 2-6. Three Engineered Methods for Groundwater Recharge



- Hydrogeologic uncertainties, such as transmissivity, faulting, and aquifer geometry, may reduce the effectiveness of the recharge project in meeting water supply demand.

- Inadequate institutional arrangements or groundwater laws may not protect water rights and may present liability and other legal problems.

The degree to which these factors might limit implementation of a groundwater recharge system is a function of the severity of the site specific impediments balanced against the need to protect existing water sources or expand raw water supplies.

2.5.1 Methods of Groundwater Recharge

Groundwater recharge can be accomplished by surface spreading, vadose zone injection wells, or direct injection. These methods of groundwater recharge use more advanced engineered systems as illustrated in **Figure 2-6** (Fox, 1999). With the exception of direct injection, all engineered methods require the existence of an unsaturated aquifer.

Table 2-8 provides a comparison of major engineering factors that should be considered when installing a groundwater recharge system, including the availability and cost of land for recharge basins (Fox, 1999). If such costs are excessive, the ability to implement injection wells adjacent to the reclaimed water source tends to decrease the cost of conveyance systems for injection wells. Surface spreading basins require the lowest degree of pretreatment while direct injection systems require water quality comparable to drinking water, if potable aquifers are affected. Low-technology treatment options for surface spreading basins include primary and secondary wastewater treatment with the possible use of lagoons and natural systems. Reverse osmosis is commonly used for direct injection systems to prevent clogging, however, some ASR systems have been operating successfully without membrane treatment when water was stored for irrigation. The cost of direct injection systems can be greatly reduced from the numbers presented in Table 2-8 if the aquifer is shallow and nonpotable. Vadose zone injection wells are a relatively new technology, and there is uncertainty over maintenance methods and requirements; however, it is clear that the removal of solids and disinfection is necessary to prevent clogging.

2.5.1.1 Surface Spreading

Surface spreading is a direct method of recharge whereby the water moves from the land surface to the aquifer by infiltration and percolation through the soil matrix.

An ideal soil for recharge by surface spreading would have the following characteristics:

- Rapid infiltration rates and transmission of water

- No layers that restrict the movement of water to the desired unconfined aquifer

- No expanding-contracting clays that create cracks when dried that would allow the reclaimed water to

Table 2-8. Comparison of Major Engineering Factors for Engineered Groundwater Recharge

	Recharge Basins	Vadose Zone Injection Wells	Direct Injection Wells
Aquifer Type	Unconfined	Unconfined	Unconfined or Confined
Pretreatment Requirements	Low Technology	Removal of Solids	High Technology
Estimated Major Capital Costs (US$)	Land and Distribution System	$25,000-75,000 per well	$500,000-1,500,000 per well
Capacity	100-20,000 m^3/hectare-day	1,000-3,000 m^3/d per well	2,000-6,000 m^3/d per well
Maintenance Requirements	Drying and Scraping	Drying and Disinfection	Disinfection and Flow Reversal
Estimated Life Cycle	>100 Years	5-20 Years	25-50 Years
Soil AquiferTreatment	Vadose Zone and Saturated Zone	Vadose Zone and Saturated Zone	Saturated Zone

bypass the soil during the initial stages of the flooding period

- Sufficient clay and/or organic-rich sediment contents to provide large capacities to adsorb trace elements and heavy metals, as well as provide surfaces on which microorganisms can decompose organic constituents. The cation exchange capacity of clays also provides the capacity to remove ammonium ions and allow for subsequent nitrogen transformations

- A supply of available carbon that would favor rapid denitrification during flooding periods, support an active microbial population to compete with pathogens, and favor rapid decomposition of introduced organics (Fox, 2002; Medema and Stuyfsand, 2002; Skjemstad *et al*., 2002). BOD and TOC in the reclaimed water will also be a carbon source

Unfortunately, some of these characteristics are mutually exclusive, and the importance of each soil characteristic is dependent on the purpose of the recharge. For example, adsorption properties may be unimportant if recharge is primarily for storage.

After the applied recharge water has passed through the soil zone, the geologic and subsurface hydrologic conditions control the sustained infiltration rates. The following geologic and hydrologic characteristics should be investigated to determine the total usable storage capacity and the rate of movement of water from the spreading grounds to the area of groundwater withdrawal:

- Physical character and permeability of subsurface deposits

- Depth to groundwater

- Specific yield, thickness of deposits, and position and allowable fluctuation of the water table

- Transmissivity, hydraulic gradients, and pattern of pumping

- Structural and lithologic barriers to both vertical and lateral movement of groundwater

- Oxidation state of groundwater throughout the receiving aquifer

Although reclaimed water typically receives secondary treatment including disinfection and filtration prior to surface spreading, other treatment processes are sometimes provided**.** Depending on the ultimate use of the water and other factors (dilution, thickness of the unsaturated zone, etc.), additional treatment may be required. Nitrogen is often removed prior to surface spreading to eliminate concerns over nitrate contamination of groundwater and to simplify the permitting of storage systems as part of an overall reuse scheme. When extract water is used for potable purposes, post-treatment by disinfection is commonly practiced. In soil-aquifer treatment systems where the extracted water is to be used for nonpotable purposes, satisfactory water quality has been obtained at some sites using primary effluent for spreading providing that the hydraulic loading rates are low to prevent the development of anaerobic conditions (Carlson *et al*., 1982 and Lance *et al.,* 1980).

For surface spreading of reclaimed water to be effective, the wetted surfaces of the soil must remain unclogged, the surface area should maximize infiltration, and the quality of the reclaimed water should not inhibit infiltration.

Operational procedures should maximize the amount of water being recharged while optimizing reclaimed water quality by maintaining long contact times with the soil matrix. If nitrogen removal is desired and the major form of applied nitrogen is total kjehldal nitrogen, then maintenance of the vadose zone is necessary to allow for partial nitrification of ammonium ions adsorbed in the vadose zone. The depth to the groundwater table should be deep enough to prevent breakthrough of adsorbed ammonium to the saturated zone to ensure continuous and effective removal of nitrogen (Fox, 2002).

Techniques for surface spreading include surface flooding, ridge and furrow systems, stream channel modifications, and infiltration basins. The system used is dependent on many factors such as soil type and porosity, depth to groundwater, topography, and the quality and quantity of the reclaimed water (Kopehynski *et al.*, 1996).

a. Surface Flooding

Reclaimed water is spread over a large, gently sloped area (1 to 3 percent grade). Ditches and berms may enclose the flooding area. Advantages are low capital and operations and maintenance (O&M) costs. Disadvantages are large area requirements, evaporation losses, and clogging.

b. Ridge and Furrow

Water is placed in narrow, flat-bottomed ditches. Ridge and furrow is especially adaptable to sloping land, but only a small percentage of the land surface is available for infiltration.

c. Stream Channel Modifications

Berms are constructed in stream channels to retard the downstream movement of the surface water and, thus, increase infiltration into the underground. This method is used mainly in ephemeral or shallow rivers and streams where machinery can enter the streambeds when there is little or no flow to construct the berms and prepare the ground surface for recharge. Disadvantages may include a frequent need for replacement due to wash outs and possible legal restrictions related to such construction practices.

d. Riverbank or Dune Filtration

Riverbank and dune filtration generally rely on the use of existing waterways that have natural connections to groundwater systems. Recharge via riverbank or sand dune filtration is practiced in Europe as a means of indirect potable reuse. It is incorporated as an element in water supply systems where the source is untreated surface water, usually a river. The surface water is infiltrated into the groundwater zone through the riverbank, percolation from spreading basins, canals, lakes, or percolation from drain fields of porous pipe. In the latter 2 cases, the river water is diverted by gravity or pumped to the recharge site. The water then travels through an aquifer to extraction wells at some distance from the riverbank. In some cases, the residence time underground is only 20 to 30 days, and there is almost no dilution by natural groundwater (Sontheimer, 1980). In Germany, systems that do not meet a minimum residence time of 50 days are required to have post-treatment of the recovered water and similar guidelines are applied in the Netherlands. In the Netherlands, dune infiltration of treated Rhine River water has been used to restore the equilibrium between fresh and saltwater in the dunes (Piet and Zoeteman, 1980; Olsthoorn and Mosch, 2002), while serving to improve water quality and provide storage for potable water systems. Dune infiltration also provides protection from accidental spills of toxic contaminants into the Rhine River. Some systems have been in place for over 100 years, and there is no evidence that the performance of the system has deteriorated or that contaminants have accumulated. The City of Berlin has greater than 25 percent reclaimed water in its drinking water supply, and no disinfection is practiced after bank filtration.

e. Infiltration Basins

Infiltration basins are the most widely used method of groundwater recharge. Basins afford high loading rates with relatively low maintenance and land requirements. Basins consist of bermed, flat-bottomed areas of varying sizes. Long, narrow basins built on land contours have been effectively used. Basins constructed on highly permeable soils to achieve high hydraulic rates are called rapid infiltration basins. Basin infiltration rates may sometimes be enhanced or maintained by creation of ridges within the basin (Peyton, 2002). The advantage of ridges within the basin is that materials that cause basin clogging accumulate in the bottom of the ridges while the remainder of the ridge maintains high infiltration rates.

Rapid infiltration basins require permeable soil for high hydraulic loading rates, yet the soil must be fine enough to provide sufficient soil surfaces for biochemical and microbiological reactions, which provide additional treatment to the reclaimed water. Some of the best soils are in the sandy loam, loamy sand, and fine sand range.

When the reclaimed water is applied to the spreading basin, the water percolates through the unsaturated zone to the saturated zone of the groundwater table. The hydraulic loading rate is preliminarily estimated by soil studies, but final evaluation is completed through operating *in situ* test pits or ponds. Hydraulic loading rates for rapid infiltration basins vary from 65 to 500 feet per year (20 to 150 meters per year), but are usually less than 300 feet per year (90 meters per year) (Bouwer, 1988).

Though management techniques are site-specific and vary accordingly, some common principles are practiced in most infiltration basins. A wetting and drying cycle with periodic cleaning of the bottom is used to prevent clogging. Drying cycles allow for desiccation of clogging layers and re-aeration of the soil. This practice helps to maintain high infiltration rates, and microbial populations to consume organic matter, and helps reduce levels of microbiological constituents. Re-aeration of the soil also promotes nitrification, which is a prerequisite for nitrogen removal by denitrification. Periodic maintenance by cleaning of the bottom may be done by deep ripping of the soils or by scraping the top layer of soil. Deep ripping sometimes causes fines to migrate to deeper levels where a deep clogging layer may develop. The Orange County Water District (California) has developed a device to continuously remove clogging materials during a flooding cycle.

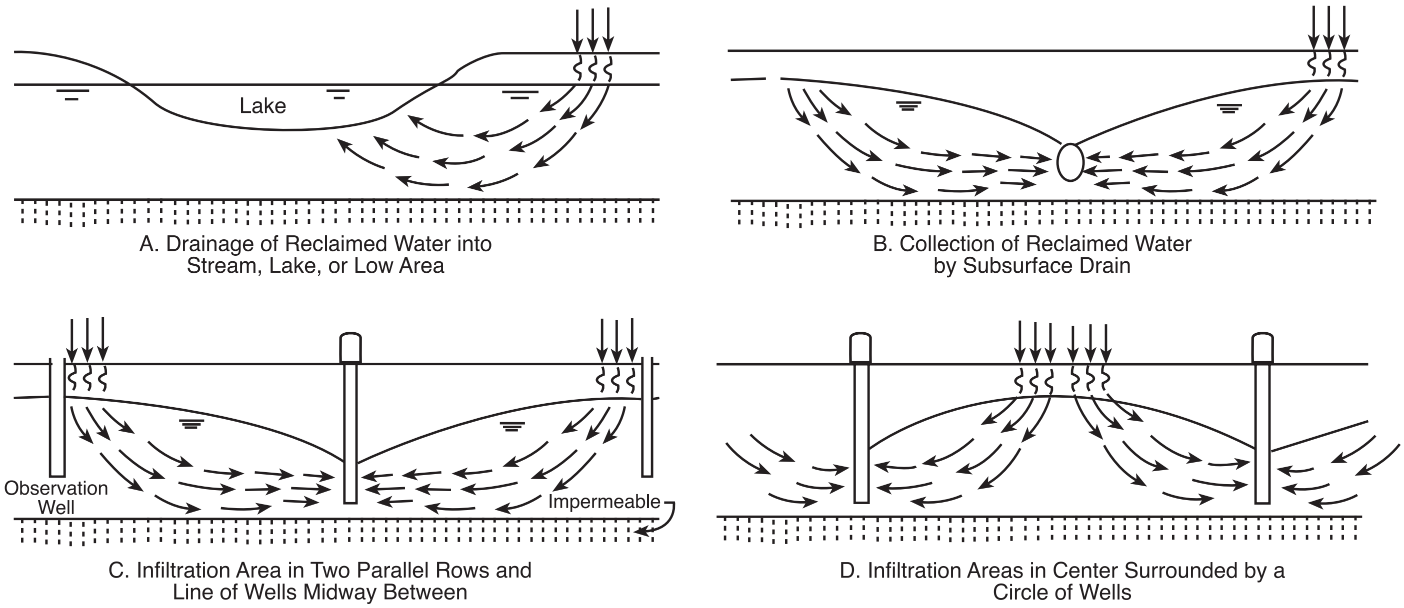
Spreading grounds can be managed to avoid nuisance conditions such as algae growth and insect breeding in the percolation ponds. Generally, a number of basins are rotated through filling, draining, and drying cycles. Cycle length is dependent on both soil conditions and the distance to the groundwater table. This is determined through field-testing on a case-by-case basis. Algae can clog the bottom of basins and reduce infiltration rates. Algae further aggravate soil clogging by removing carbon dioxide, which raises the pH, causing precipitation of calcium carbonate. Reducing the detention time of the reclaimed water within the basins minimizes algal growth, particularly during summer periods where solar intensity and temperature increase algal growth rates. The levels of nutrients necessary to stimulate algal growth are too low for practical consideration of nutrient removal as a method to control algae. Also, scarifying, rototilling, or discing the soil following the drying cycle can help alleviate clogging potential, although scraping or "shaving" the bottom to remove the clogging layer is more effective than discing it. Removing the hard precipitant using an underwater machine has also been accomplished (Mills, 2002).

2.5.1.2 Soil-Aquifer Treatment Systems

Soil-Aquifer Treatment (SAT) systems usually are designed and operated such that all of the infiltrated water is recovered via wells, drains, or seepage into surface water. Typical SAT recharge and recovery systems are shown in **Figure 2-7**. SAT systems with infiltration basins require unconfined aquifers, vadose zones free of restricting layers, and soils that are coarse enough to allow high infiltration rates, but fine enough to provide adequate filtration. Sandy loams and loamy or fine sands are the preferred surface soils in SAT systems. Recent work on SAT removal of dissolved organic carbon (DOC), trace organics, and organic halides has shown positive results (Fox *et al*., 2001; Drewes *et al*., 2001). The majority of trace organic compounds are removed by biodegradation and organic chlorine and organic bromine are removed to ambient levels. Short-term DOC removal is enhanced by maintaining aerobic conditions in the unsaturated zone (Fox, 2002).

In the U.S., municipal wastewater usually receives conventional primary and secondary treatment prior to SAT. However, since SAT systems are capable of removing more BOD than is in secondary effluent, efficient secondary treatment may not be necessary in cases where the wastewater is subjected to SAT and subsequently reused for nonpotable purposes. Higher organic content may enhance nitrogen removal by denitrification in the SAT system and may enhance removal of synthetic organic compounds by stimulating greater microbiological activity in the soil. However low hydraulic loading

Figure 2-7. Schematic of Soil-Aquifer Treatment Systems



rates must be used to prevent anaerobic conditions from developing which can prevent complete biodegradation in the sub-surface. More frequent cleaning of the basins would increase the cost of the SAT, but would not necessarily increase the total system cost.

Where hydrogeologic conditions permit groundwater recharge with surface infiltration facilities, considerable improvement in water quality may be achieved through the movement of wastewater through the soil, unsaturated zone, and saturated zone. **Table 2-9** provides an example of overall improvement in the quality of secondary effluent in a groundwater recharge SAT system. These water quality improvements are not limited to soil aquifer treatment systems and are applicable to most groundwater recharge systems where aerobic and/or anoxic conditions exist and there is sufficient storage time.

These data are the result of a demonstration project in the Salt River bed, west of Phoenix, Arizona (Bouwer and Rice, 1989). The cost of SAT has been shown to be less than 40 percent of the cost of equivalent aboveground treatment (Bouwer, 1991). It should also be noted that the SAT product water was recovered from a monitoring well located adjacent to the recharge basin. Most SAT systems allow for considerable travel time in the aquifer and provide the opportunity for improvement in water quality.

An intensive study, entitled, “An Investigation of Soil Aquifer Treatment for Sustainable Water Reuse,” was conducted to assess the sustainability of several different SAT systems with different site characteristics and effluent pretreatments (AWWARF, 2001). (See case study 2.7.16). In all of the systems studied, water quality improvements were similar to the results presented by Bouwer (1984). When significant travel times in the vadose or saturated zone existed, water quality improvements exceeded the improvements actually observed by Bouwer (1984).

The 3 main engineering factors that can affect the performance of soil aquifer treatment systems are: effluent pretreatment, site characteristics, and operating conditions (Fox, 2002).

Effluent Pretreatment – Effluent pretreatment directly impacts the concentrations of biodegradable matter that are applied to a percolation basin. Therefore, it is a key factor that can be controlled as part of a SAT system. One of the greatest impacts of effluent pretreatment during SAT is near the soil/water interface where high biological activity is observed. This condition occurs because both the highest concentrations of biodegradable matter and oxygen are present. Both organic carbon and ammonia may be biologically oxidized. They are the water quality parameters that control the amount of oxygen demand in applied effluents. One of the greatest impacts of effluent pretreatment is to the total oxygen demand of applied water. Near the soil/water surface, biological activity with an effluent that has high total oxygen demand will result in the use of all the dissolved oxygen. Aerobic

Table 2-9. Water Quality at Phoenix, Arizona, SAT System

	Secondary Effluent (mg/l)	Recovery Well Samples (mg/l)
Total dissolved solids	750	790
Suspended solids	11	1
Ammonium nitrogen	16	0.1
Nitrate nitrogen	0.5	5.3
Organic nitrogen	1.5	0.1
Phosphate phosphorus	5.5	0.4
Fluoride	1.2	0.7
Boron	0.6	0.6
Biochemical oxygen demand	12	<1
Total organic carbon	12	1.9
Zinc	0.19	0.03
Copper	0.12	0.016
Cadmium	0.008	0.007
Lead	0.082	0.066
Fecal coliforms/100 mL[a]	3500	0.3
Viruses, pfu/100 mL[b]	2118	<1

a Chlorinated effluent
b Undisinfected effluent
Source: Adapted from Bouwer and Rice, 1989.

conditions can be maintained with effluents that have low total oxygen demand. It should also be noted that the majority of oxygen demand exerted during wetting is from the oxidation of organic carbon while ammonia is removed by adsorption (Kopchynski *et al*., 1996).

Site Characteristics – Site characteristics are a function of local geology and hydrogeology. Site selection is often dependent on a number of practical factors including suitability for percolation, proximity to conveyance channels and/or water reclamation facilities, and the availability of land. The design of SAT systems must accommodate the site characteristics. The design options are primarily limited to the size and depth of percolation basins and the location of recovery wells. Increasing the depth of percolation basins can be done to access high permeability soils. The location of recovery wells affects the travel time for subsurface flow and mounding below the percolation basins.

Operating Conditions – The operation of SAT systems with wet/dry cycles is a common operating strategy. The primary purpose of wet/dry cycle operation is to control the development of clogging layers and maintain high infiltration rates, and in some cases, to disrupt insect life cycles. As a clogging layer develops during a wetting cycle, infiltration rates can decrease to unacceptable rates. The drying cycle allows for the desiccation of the clogging layer and the recovery of infiltration rates during the next wetting cycle. Operating conditions are dependent on a number of environmental factors including temperature, precipitation and solar incidence. Therefore, operating conditions must be adjusted to both local site characteristics and weather patterns.

2.5.1.3 Vadose Zone Injection

Vadose zone injection wells for groundwater recharge with reclaimed water were developed in the 1990s and have been used in several different cities in the Phoenix, Arizona, metropolitan area. Typical vadose zone injection wells are 6 feet (2 meters) in diameter and 100 to 150 feet (30 to 46 meters) deep. They are backfilled with porous media and a riser pipe is used to allow for water to enter at the bottom of the injection well to prevent air entrainment. An advantage of vadose zone injection wells is the significant cost savings as compared to direct injection wells. The infiltration rates per well are often similar to direct injection wells. A significant disadvantage is that they cannot be backwashed and a severely clogged well can be permanently destroyed. Therefore, reliable pretreatment is considered essential to maintaining the performance of a vadose zone injection well. Because of the considerable cost savings associated with vadose zone injection wells as compared to direct injection wells, a life cycle of 5 years for a vadose injection well can still make the vadose zone injection well the economical choice. Since vadose zone injection wells allow for percolation of water through the vadose zone and flow in the saturated zone, one would expect water quality improvements commonly associated with soil aquifer treatment to be possible.

2.5.1.4 Direct Injection

Direct injection involves pumping reclaimed water directly into the groundwater zone, which is usually a well-confined aquifer. Direct injection is used where groundwater is deep or where hydrogeological conditions are not conducive to surface spreading. Such conditions might include unsuitable soils of low permeability, unfavorable topography for construction of basins, the desire to recharge confined aquifers, or scarcity of land. Direct injection into a saline aquifer can create a freshwater "plume" from which water can be extracted for reuse, particularly in ASR systems (Pyne, 1995). Direct injection is also an effective method for creating barriers against saltwater intrusion in coastal areas.

Direct injection requires water of higher quality than for surface spreading because of the absence of vadose zone and/or shallow soil matrix treatment afforded by surface spreading and the need to maintain the hydraulic capacity of the injection wells, which are prone to physical, biological, and chemical clogging. Treatment processes beyond secondary treatment that are used prior to injection include disinfection, filtration, air stripping, ion exchange, granular activated carbon, and reverse osmosis or other membrane separation processes. By using these processes or various subsets in appropriate combinations, it is possible to satisfy present water quality requirements for reuse. In many cases, the wells used for injection and recovery are classified by the EPA as Class V injection wells. Some states require that the injected water must meet drinking water standards prior to injection into a Class V well.

For both surface spreading and direct injection, locating the extraction wells as great a distance as possible from the recharge site increases the flow path length and residence time in the underground, as well as the mixing of the recharged water with the natural groundwater. Treatment of organic parameters does occur in the groundwater system with time, especially in aerobic or anoxic conditions (Gordon *et al*., 2002; Toze and Hanna, 2002).

There have been several cases where direct injection systems with wells providing significant travel time have allowed for the passage of emerging pollutants of concern, such as NDMA and 1,4-dioxane into recovery wells. In these cases, the final pretreatment step was reverse osmosis. Since reverse osmosis effectively removes almost all nutrients, improvements in water quality by microbial activity might be limited in aquifers that receive reverse osmosis treated water. These emerging pollutants of concern have not been observed in soil aquifer treatment systems using spreading basins where microbial activity in the subsurface is stimulated.

Ideally, an injection well will recharge water at the same rate as it can yield water by pumping. However, conditions are rarely ideal. Injection/withdrawal rates tend to decrease over time. Although clogging can easily be remedied in a surface spreading system by scraping, discing, drying and other methods, remediation in a direct injection system can be costly and time consuming. The most frequent causes of clogging are accumulation of organic and inorganic solids, biological and chemical contaminants, and dissolved air and gases from turbulence. Very low concentrations of suspended solids, on the order of 1 mg/l, can clog an injection well. Even low concentrations of organic contaminants can cause clogging due to bacteriological growth near the point of injection.

Many criteria specific to the quality of the reclaimed water, groundwater, and aquifer material have to be taken into consideration prior to construction and operation. These include possible chemical reactions between the reclaimed water and groundwater, iron precipitation, ionic reactions, biochemical changes, temperature differences, and viscosity changes. Most clogging problems are avoided by proper pretreatment, well construction, and proper operation (Stuyzand, 2002). Injection well design and operations should consider the need to occasionally reverse the flow or backflush the well much like a conventional filter or membrane. In California and Arizona, injection wells are being constructed or retrofitted with dedicated pumping or backflushing equipment to maintain injection capacity and reduce the frequency of major well redevelopment events.

2.5.2 Fate of Contaminants in Recharge Systems

The fate of contaminants is an important consideration for groundwater recharge systems using reclaimed water. Contaminants in the subsurface environment are subject to processes such as biodegradation by microorganisms, adsorption and subsequent biodegradation, filtration, ion exchange, volatilization, dilution, chemical oxidation and reduction, chemical precipitation and complex formation, and photochemical reactions (in spreading basins) (Fox, 2002; Medema and Stuyzand, 2002). For surface spreading operations, chemical and microbiological constituents are removed in the top 6 feet (2 meters) of the vadose zone at the spreading site.

2.5.2.1 Particulate Matter

Particles larger than the soil pores are strained off at the soil-water interface. Particulate matter, including some bacteria, is removed by sedimentation in the pore spaces of the media during filtration. Viruses are mainly removed by adsorption and interaction with anaerobic bacteria (Gordon *et al*., 2002). The accumulated particles gradually form a layer restricting further infiltration. Suspended solids that are not retained at the soil/water interface may be effectively removed by infiltration and adsorption in the soil profile. As water flows through passages formed by the soil particles, suspended and colloidal solids far too small to be retained by straining are thrown off the streamline through hydrodynamic actions, diffusion, impingement, and sedimentation. The particles are then intercepted and adsorbed onto the surface of the stationary soil matrix. The degree of trapping and adsorption of suspended particles by soils is a function of the suspended solids concentration, soil characteristics, and hydraulic loading. Suspended solids removal is enhanced by longer travel distances underground.

For dissolved inorganic constituents to be removed or retained in the soil, physical, chemical, or microbiological reactions are required to precipitate and/or immobilize the dissolved constituents. Chemical reactions that are important to a soil's capability to react with dissolved inorganics include cation exchange reactions, precipitation, surface adsorption, chelation, complexation, and weathering (dissolution) of clay minerals.

While inorganic constituents such as chloride, sodium, and sulfate are unaffected by ground passage, many other inorganic constituents exhibit substantial removal. For example, iron and phosphorus removal in excess of 90 percent has been achieved by precipitation and adsorption in the underground, although the ability of the soil to remove these and other constituents may decrease over time. Heavy metal removal varies widely for different elements, ranging from 0 to more than 90 percent, depending on the speciation of the influent metals.

2.5.2.2 Dissolved Organic Constituents

Dissolved organic constituents are subject to biodegradation and adsorption during recharge. Biodegradation mainly occurs by microorganisms attached to the media surface (Skjemstad *et al*., 2002). The rate and extent of biodegradation is strongly influenced by the nature of the organic substances and by the presence of electron acceptors such as dissolved oxygen and nitrate. There are indications that biodegradation is enhanced if the aquifer material is finely divided and has a high specific surface area, such as fine sand or silt. However, such conditions can lead to clogging by bacterial growths. Coarser aquifer materials such as gravel and some sands have greater permeability and, thus, less clogging. However, biodegradation may be less rapid and perhaps less extensive. The biodegradation of easily degradable organics occurs a short distance (few meters) from the point of recharge. A large body of literature shows that biodegradable compounds do not survive long in anoxic or aerobic groundwater and only chemical compounds that have high solubility and extensive half-lives are of great concern (i.e. chlorinated solvents). Specific groups of compounds also require longer times due to their complex biodegradation pathways; however, the product water from SAT may be compared to membrane processed water since select groups of compounds may persist in both cases (Drewes *et al.*, 2003).

The end products of complete degradation under aerobic conditions include carbon dioxide, sulfate, nitrate, phosphate, and water. The end products under anaerobic conditions include carbon dioxide, nitrogen, sulfide, and methane. The mechanisms operating on refractory organic constituents over long time periods typical of groundwater environments are not well understood. However, sustainable removal has been observed over significant time periods demonstrating that biodegradation is the major removal mechanism since accumulation of organic carbon in the sub-surface is not observed (AWWARF, 2001). The degradation of organic contaminants may be partial and result in a residual organic product that cannot be further degraded at an appreciable rate (Khan and Rorije, 2002), and such metabolites are often difficult to identify and detect (Drewes *et al.,* 2001).

Results were presented in a 2001 AWWARF study entitled, "An Investigation of Soil Aquifer Treatment for Sustainable Water Reuse." This investigation demonstrated the potential removal ability of an entire SAT system where travel times are expected to be on the order of 6 months or greater before water is recovered. Since most trace organic compounds are present at concentrations that cannot directly support microbial growth, the sustainable removal mechanism for these compounds is co-metabolic. The microbes catalyze the mineralization of the organic compounds, but the microorganisms do not get enough energy from the trace organic compounds to support growth. In the study, the majority of compounds analyzed were below detection limits after 6 months of travel time in the sub-surface. Therefore, it appears that significant time in the sub-surface is required in a microbially active aquifer to efficiently remove trace organics that are potentially biodegradable by cometabolism. One would expect similar results for aerobic or anoxic (nitrate-reducing) aquifers. But results are not conclusive for anaerobic aquifers. Several pharmaceutical compounds do appear to be recalcitrant in a microbially active aquifer at concentrations in the part per trillion range. A bench scale study of an unconfined aquifer irrigated with reclaimed water found antipyrine moved rapidly through the soil, while caffeine was subject to adsorption and microbial degradation (Babcock *et al.,* 2002).

Endocrine-disrupting activity has also been evaluated during soil aquifer treatment and results consistently suggest that soil aquifer treatment rapidly reduces endocrine-disrupting activity to ambient levels (Turney *et al.,* In Press). Since the majority of compounds that are suspected to cause endocrine disruption are either strongly adsorbed or biodegradable, the results are consistent with microbial activity providing sustainable removal of organics during soil aquifer treatment.

2.5.2.3 Nitrogen

The 2 major forms of nitrogen in reclaimed water are typically ammonia and nitrate. As reported by AWWARF (2001), the concentrations and forms of nitrogen in applied effluents are a strong function of effluent pretreatment. Secondary effluents contained ammonia nitrogen at concentrations up to 20 mg-N/l while denitrified effluents contained primarily nitrate nitrogen at concentrations less than 10 mg-N/l. Ammonia nitrogen is the major form of oxygen demand in secondary effluents that are not nitrified.

Nitrogen can be efficiently removed during effluent pretreatment; however, appropriately operated SAT systems have the capacity to remove nitrogen in secondary effluents. The removal of nitrogen appears to be a sustainable, biologically mediated process. When ammonia is present in reclaimed water, the ammonia is removed by adsorption during wetting when insufficient oxygen is available to support nitrification. Nitrification of adsorbed ammonia occurs during subsequent drying cycles as re-aeration of vadose zone soils occurs. Nitrate is weakly adsorbed and is transported with bulk water flow during SAT. Removal of nitrate was consistently observed at all sites where anoxic or anaerobic conditions were present (AWWARF, 2001). The biological removal mechanism for denitrification was found to be site specific.

The 2001 AWWARF study entitled, "An Investigation of Soil Aquifer Treatment for Sustainable Water Reuse." investigated the mechanism of anaerobic ammonia oxidation (ANAMMOX) as a sustainable mechanism for nitrogen removal. During SAT, it is possible for adsorbed ammonia to serve as an electron donor to convert nitrate to nitrogen gas by ANAMMOX. Evidence for ANAMMOX activity was obtained in soils obtained from the Tucson site. Since adsorbed ammonia is available for nitrification when oxygen reaches soils containing adsorbed ammonia, ANAMMOX activity could occur as nitrate percolates through soils containing adsorbed ammonia under anoxic conditions. This implies that there is a sustainable mechanism for nitrogen removal during SAT when effluent pretreatment does not include nitrogen removal and the majority of applied nitrogen is ammonia. Appropriate wetting/drying cycles are necessary to promote nitrification in the upper vadose zone during drying cycles. The more mobile nitrate passes over soils with adsorbed ammonia under anoxic conditions deeper in the vadose zone. Extended wetting cycles with short dry cycles will result in ammonia adsorbed at increasing depths as adsorption sites become exhausted. Extended drying cycles will result in reaeration of soils at greater depths resulting in nitrification of adsorbed ammonia at greater depths. A mechanistic model was developed to provide guidelines for the operation of soil aquifer treatment systems to sustain nitrogen removal (Fox, 2003).

2.5.2.4 Microorganisms

The survival or retention of pathogenic microorganisms in the subsurface depends on several factors including climate, soil composition, antagonism by soil microflora, flow rate, and type of microorganism. At low temperatures (below 4 °C or 39 °F) some microorganisms can survive for months or years. The die-off rate is approximately doubled with each 10 °C (18 °F) rise in temperature between 5 and 30 °C (41 and 86 °F) (Gerba and Goyal, 1985). Rainfall may mobilize bacteria and viruses that had been filtered or adsorbed, and thus, enhance their transport.

The nature of the soil affects survival and retention. For example, rapid infiltration sites where viruses have been detected in groundwater were located on coarse sand and gravel types. Infiltration rates at these sites were high and the ability of the soil to adsorb the viruses was low. Generally, coarse soil does not inhibit virus migration. Other soil properties, such as pH, cation concentration, moisture holding capacity, and organic matter do have an affect on the survival of bacteria and viruses in the soil. Resistance of microorganisms to environmental factors depends on the species and strains present.

Drying the soil will kill both bacteria and viruses. Bacteria survive longer in alkaline soils than in acid soils (pH 3 to 5) and when large amounts of organic matter are present. In general, increasing cation concentration and decreasing pH and soluble organics tend to promote virus adsorption. Bacteria and larger organisms associated with wastewater are effectively removed after percolation through a short distance of the soil mantle. Lysimeter studies showed a greater than 99 percent removal of bacteria and 95 to 99 percent removal of viruses (Cuyk *et al.*, 1999). Factors that may influence virus movement in groundwater are given in **Table 2-10**. Proper treatment (including disinfection) prior to recharge, site selection, and management of the surface spreading recharge system can minimize or eliminate the presence of microorganisms in the groundwater. Once the microorganisms reach the groundwater system, the oxidation state of the water significantly affects the rate of removal (Medema and Stuyfzand, 2002; Gordon *et al*., 2002).

2.5.3 Health and Regulatory Considerations

Constraints on groundwater recharge are conditioned by the use of the extracted water and include health concerns, economic feasibility, physical limitations, legal restrictions, water quality constraints, and reclaimed water availability. Of these constraints, health concerns are the most important as they pervade almost all recharge projects (Tsuchihashi *et al*., 2002). Where reclaimed water will be ingested, health effects due to prolonged exposure to low levels of contaminants must be considered as well as the acute health effects from pathogens or toxic substances. [See Section 3.4.1 Health Assessment of Water Reuse and Section 2.6 Augmentation of Potable Supplies.]

One problem with recharge is that boundaries between potable and nonpotable aquifers are rarely well defined. Some risk of contaminating high quality potable groundwater supplies is often incurred by recharging "nonpotable" aquifers. The recognized lack of knowledge about the fate and long-term health effects of contaminants found in reclaimed water obliges a conservative approach in setting water quality standards and monitoring requirements for groundwater recharge. Because of these uncertainties, some states have set stringent water quality requirements and require high levels of treatment – in some cases, organic removal processes – where groundwater recharge impacts potable aquifers.

2.6 Augmentation of Potable Supplies

This section discusses indirect potable reuse via surface water augmentation, groundwater recharge, and direct potable reuse. For the purpose of this document, indirect potable reuse is defined as the augmentation of a community's raw water supply with treated wastewater followed by an environmental buffer (Crook, 2001). The treated wastewater is mixed with surface and/or groundwater, and the mix typically receives additional treatment before entering the water distribution system. Direct potable reuse is defined as the introduction of treated wastewater directly into a water distribution system without intervening storage (pipe-to-pipe) (Crook, 2001). Both such sources of potable water are, at face value, less desirable than using a higher quality source for drinking.

Table 2-10. Factors that May Influence Virus Movement to Groundwater

Factor	Comments
Soil Type	Fine-textured soils retain viruses more effectively than light-textured soils. Iron oxides increase the adsorptive capacity of soils. Muck soils are generally poor adsorbents.
pH	Generally, adsorption increases when pH decreases. However, the reported trends are not clear-cut due to complicating factors.
Cations	Adsorption increases in the presence of cations. Cations help reduce repulsive forces on both virus and soil particles. Rainwater may desorb viruses from soil due to its low conductivity.
Soluble Organics	Generally compete with viruses for adsorption sites. No significant competition at concentrations found in wastewater effluents. Humic and fulvic acids reduce virus adsorption to soils.
Virus Type	Adsorption to soils varies with virus type and strain. Viruses may have different isoelectric points.
Flow Rate	The higher the flow rate, the lower virus adsorption to soils.
Saturated vs. Unsaturated Flow	Virus movement is less under unsaturated flow conditions.

Source: Gerba and Goyal, 1985.

A guiding principle in the development of potable water supplies for almost 150 years was stated in the 1962 Public Health Service Drinking Water Standards: ". . . water supply should be taken from the most desirable source which is feasible, and efforts should be made to prevent or control pollution of the source." This was affirmed by the EPA (1976) in its Primary Drinking Water Regulations: " . . priority should be given to selection of the purest source. Polluted sources should not be used unless other sources are economically unavailable. . . "

2.6.1 Water Quality Objectives for Potable Reuse

Development of water quality requirements for either direct or indirect potable reuse is difficult. The task involves a risk management process that entails evaluating, enumerating, and defining the risks and potential adverse health impacts that are avoided by the practice of physically separating wastewater disposal and domestic water supply. By physically separating wastewater disposal and domestic water supply by environmental storage, the life cycle of waterborne diseases can be broken, thereby preventing or reducing disease in the human population. As the physical proximity and perceived distance between reclaimed water and domestic water supply decreases, human contact with and consumption of reclaimed water become more certain, and the potential impacts to human health become harder to define.

From a regulatory standpoint, there is a tendency to use the Safe Drinking Water Act (SDWA) National Primary Drinking Water Regulations (NPDWR) as a starting point for defining potable water quality objectives. For years, water reuse advocates have argued that reclaimed water from municipal wastewater meets the requirements of the NPDWR. However, the original purpose of the NPDWR was not intended to define potable water quality when the source is municipal wastewater.

There has been a dramatic increase in the ability to detect chemicals in recent years. Considering the hundreds of thousands of chemicals manufactured or used in the manufacturing of products, the number of chemicals regulated by the SDWA represent a small fraction of these compounds. The 1986 SDWA amendments required EPA to promulgate 25 new maximum contaminant levels (MCLs), or drinking water treatment requirements, for specific contaminants every 3 years (Calabrese *et al.* 1989). However, the 1996 SDWA amendments reduced that number by requiring the agency to "consider" regulating up to 5 contaminants every 5 years. **Figure 2-8** shows the potential impact to the number of regulated compounds under the NPDWR as outlined by the 1986 and 1996 SDWA amendments.

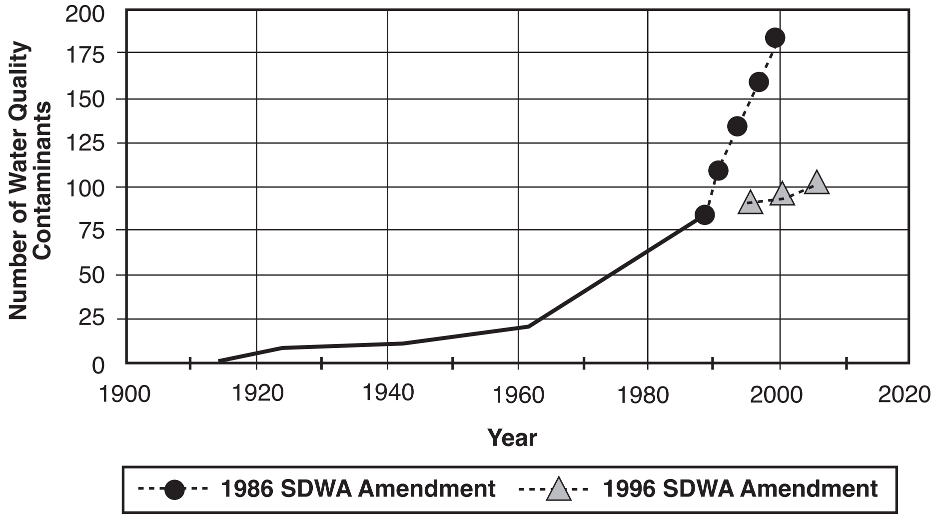
MCLs are thought of as standards for individual chemicals. However, contaminants can be regulated by specifying treatment processes and performance standards without directly measuring the contaminant. Because of the sheer numbers of potential chemicals, traditional wastewater treatment processes are not the panacea for all potable water quality concerns, particularly since current analytical methods are insufficient to identify all potential contaminants at concentrations of health significance. If the analytical method does not have sufficient sensitivity, then the presence of contaminants may go unobserved. Water reuse agencies in California observed problems with specific chemicals and trace organics being discharged to wastewater treatment plants. These elements were detected in the final effluents, only after analytical detection limits were lowered.

Additional concerns have been raised regarding the fate and transport of trace organic compounds (Daughton and Temes 1999 and Sedlak *et al.,* 2000). These include endocrine disruptors, pharmaceuticals, hormones, antibiotics, anti-inflammatories, and personal care products (antibacterial soaps, sunscreen, bath gels, etc.) that are present in municipal wastewaters. None of these individual compounds are regulated or monitored by maximum contaminant levels (MCLs) in the SDWA.

Some indirect water reuse projects (San Diego and Denver) have started using toxicological assays to compare the drinking water source to the reclaimed water. While these studies have generally shown that the assay results show no difference between the reclaimed water and the source water used for domestic supply, there are concerns that current toxicological methods are not sensitive enough to characterize the impact of reclaimed water on human health in the 10^{-4} and 10^{-6} risk range. As part of the 1996 SDWA amendments, EPA is charged with developing an evaluation that considers the health impact of an identified contaminant to sensitive subpopulations.

In 1996 and 1999, the Rand Corporation conducted epidemiological studies to monitor the health of those consuming reclaimed water in Los Angeles County (Sloss *et al.,* 1996 and Sloss *et al.,* 1999). The 1996 ecologic study design looked at selected infectious disease occurrence as well as cancer incidence and mortality. Investigators could find no link between the incidence of infectious disease or cancer rates and exposure to reclaimed water. The 1999 study focused on adverse birth outcomes (prenatal development, infant mortality, and birth defects). Similar results were reported for the 1999 study; there was no association between reclaimed water and adverse

Figure 2-8. Contaminants Regulated by the National Primary Drinking Water Regulations



birth outcomes. However, epidemiological studies are limited, and these studies are no exception. Researchers noted several weaknesses in their study design that contribute to the overall uncertainty associated with the findings. They found that it was difficult to get an accurate assessment of reclaimed water exposure in the different areas.

In addition to the uncertainties associated with toxicological and epidemiological studies, current analytical systems are insensitive to the contaminants of concern. Surrogates are often used as performance-based standards. Microbiological water quality objectives are defined by surrogates or treatment performance standards that do not measure the contaminant of concern, but nevertheless, provide some indication the treatment train is operating properly, and the product is of adequate quality. It is then assumed that under similar conditions of operation, the microbiological contaminant of concern is being removed concurrently. For example, coliforms are an indicator of microbiological water quality. While there are documents discussing the criteria for an ideal surrogate (AWWARF and KIWA, 1988), no surrogate meets every criterion. Hence, the shortcomings of the surrogate should also be remembered.

In 1998, the National Research Council (NRC) published, "Issues in Potable Reuse," an update of its 1980 report. In this update, the NRC did not consider addressing direct potable reuse for the reason that, without added protection (such as storage in the environment), the NRC did not view direct potable reuse as a viable option. Rather than face the risks associated with direct, pipe-to-pipe potable reuse, the NRC emphasized that there are far more manageable, nonpotable reclaimed water applications that do not involve human consumption. The focus of health impacts shifts from the acute microbiologically-induced diseases, for nonpotable reuse, to the diseases resulting from long-term chronic exposure, e.g., cancer or reproductive effects, for potable reuse.

While direct potable reuse may not be considered a viable option at this time, many states are moving forward with indirect potable reuse projects. For many cities or regions, the growing demand for water, lack of new water resources, and frequent calls for water conservation in low and consecutive low rainfall years have resulted in the need to augment potable supplies with reclaimed water. Indeed, in some situations, indirect potable reuse may be the next best alternative to make beneficial use of the resource. Further, the lack of infrastructure for direct nonpotable reuse may be too cumbersome to implement in a timely manner.

With a combination of treatment barriers and added protection provided by environmental storage, the problem of defining water quality objectives for indirect potable reuse is manageable. By employing treatment beyond typical disinfected tertiary treatment, indirect potable reuse projects will provide additional organics removal and environmental storage (retention time) for the reclaimed water, thereby furnishing added protection against the unknowns and uncertainty associated with trace organics. However, these processes will be operated using performance standards based on surrogates that do not address specific contaminants. Until better source control and protection programs are in place to deal with the myriad of chemicals discharged into the wastewater collection systems, or until analytical and toxicological testing becomes more sensitive, the concern over low-level contaminant concentrations will remain. If and when contaminants are found, treatment technologies can be applied to reduce the problem. EPA (2001) has identified several drinking water treatment processes capable of removing some endocrine disruptors. Examples are granular activated carbon and membrane treatment.

Potable reuse, whether direct or indirect, is not a risk-free practice. No human engineered endeavor is risk-free, but with appropriate treatment barriers (and process control) water quality objectives will be defined by an acceptable risk. Given the unknowns, limitations, and uncertainty with the current state of science and technology, it is not possible to establish the threshold at which no observed effect would occur, just as it is not reasonable to expect current scientific techniques to demonstrate the absence of an impact on human health.

2.6.2 Surface Water Augmentation for Indirect Potable Reuse

For many years, a number of cities have elected to take water from large rivers that receive substantial wastewater discharges. These cities based their decisions, in part, on the assurance that conventional filtration and disinfection eliminates the pathogens responsible for waterborne infectious disease. These water sources were generally less costly and more easily developed than upland supplies or underground sources. Such large cities as Philadelphia, Cincinnati, and New Orleans, drawing water from the Delaware, Ohio and Mississippi Rivers, respectively, are thus practicing indirect potable water reuse. The many cities upstream of their intakes can be characterized as providing water reclamation in their wastewater treatment facilities, although they were not designed, nor are they operated, as potable water sources. NPDES permits for these discharges are intended to make the rivers “fishable and swimmable,” and generally do not reflect potable water requirements downstream. These indirect potable reuse systems originated at a time when the principal concern for drinking water quality was the prevention of enteric infectious diseases and issues relating to chemical contaminants received lesser attention. Nevertheless, most cities do provide water of acceptable quality that meets current drinking water regulations. Unplanned or incidental indirect potable reuse via surface water augmentation has been, and will continue to be, practiced widely.

More recent indirect potable reuse projects that involve surface water augmentation are exemplified by the Upper Occoquan Sewage Authority (UOSA) treatment facilities in northern Virginia, which discharge reclaimed water into Bull Run, just above Occoquan Reservoir, a water supply source for Fairfax County, Virginia. The UOSA plant, in operation since 1978, provides AWT that is more extensive than required treatment for nonpotable reuse and accordingly provides water of much higher quality for indirect potable reuse than is required for nonpotable reuse (Joint Task Force, 1998). In Clayton County, Georgia, wastewater receives secondary treatment, and then undergoes land treatment, with the return subsurface flow reaching a stream used as a source of potable water. The Clayton County project, which has been in operation for 20 years, is being upgraded to include wetlands treatment and enhancements at the water treatment plant (Thomas *et al*., 2002).

While UOSA now provides a significant portion of the water in the system, varying from an average of about 7 percent of the average annual flow to as much as 80-90 percent during drought periods, most surface water augmentation indirect potable reuse projects have been driven by requirements for wastewater disposal and pollution control. Their contributions to increased public water supply were incidental. In a comprehensive, comparative study of the Occoquan and Clayton County projects, the water quality parameters assessed were primarily those germane to wastewater disposal and not to drinking water (Reed and Bastian, 1991). Most discharges that contribute to indirect potable water reuse, especially via rivers, are managed as wastewater disposal functions and are handled in conformity with practices common to all water pollution control efforts. The abstraction and use of reclaimed water is almost always the responsibility of a water supply agency that is not related politically, administratively, or even geographically to the wastewater disposal agency (except for being downstream). Increasing populations and a growing scarcity of new water sources have spurred a small but growing number of communities to consider the use of highly-treated municipal wastewater to augment raw water supplies. This trend toward planned, indirect potable reuse is motivated by need, but made possible through advances in treatment technology. These advances enable production of reclaimed water to almost any desired quality. Planned, indirect potable reuse via surface water augmentation and groundwater recharge is being practiced in the U.S. and elsewhere. Notwithstanding the fact that some proposed, high profile, indirect potable reuse projects have been defeated in recent years due to public or political opposition to perceived health concerns, indirect potable reuse will likely increase in the future.

2.6.3 Groundwater Recharge for Indirect Potable Reuse

As mentioned in Section 2.5.1, Methods of Groundwater Recharge, groundwater recharge via surface spreading or injection has long been used to augment potable aquifers. Although both planned and unplanned recharge into potable aquifers has occurred for many years, few health-related studies have been undertaken. The most comprehensive health effects study of an existing groundwater recharge project was carried out in Los Angeles County, California, in response to uncertainties about the health consequences of recharge for potable use raised by a California Consulting Panel in 1975-76.

In November 1978, the County Sanitation Districts of Los Angeles County (Districts) initiated the "Health Effects Study," a $1.4-million-project designed to evaluate the health effects of using treated wastewater for groundwater recharge based on the recommendations of the 1976 Consulting Panel. The focus of the study was the Montebello Forebay Groundwater Replenishment Project, located within the Central Groundwater Basin in Los Angeles County, California. Since 1962, the Districts' reclaimed water has been blended with imported river water (Colorado River and State Project water) and local stormwater runoff, and used for replenishment purposes. The project is managed by the Water Replenishment District of Southern California (WRD) and is operated by the Los Angeles County Department of Public Works. The Central Groundwater Basin is adjudicated; 85 groundwater agencies operate over 400 active wells. Water is percolated into the groundwater using 2 sets of spreading grounds: (1) the Rio Hondo Spreading Grounds consist of 570 acres (200 hectares) with 20 individual basins and (2) the San Gabriel River Spreading Grounds consist of 128 acres (52 hectares) with 3 individual basins and portions of the river. The spreading basins are operated under a wetting/drying cycle designed to optimize inflow and discourage the development of vectors.

From 1962 to 1977, the water used for replenishment was disinfected secondary effluent. Filtration (dual-media or mono-media) was added later to enhance virus inactivation during final disinfection. By 1978, the amount of reclaimed water spread averaged about 8.6 billion gallons per year (33×10^3 m^3 per year) or 16 percent of the total inflow to the groundwater basin with no more than about 10.7 billion gallons (40 million m^3) of reclaimed water spread in any year. The percentage of reclaimed water contained in the extracted potable water supply ranged from 0 to 11 percent on a long-term (1962-1977) basis (Crook *et al.,* 1990).

The primary goal of the Health Effects Study was to provide information for use by health and regulatory authorities to determine if the use of reclaimed water for the Montebello Forebay Project should be maintained at the present level, cut back, or expanded. Specific objectives were to determine if the historical level of reuse had adversely affected groundwater quality or human health, and to estimate the relative impact of the different replenishment sources on groundwater quality. Specific research tasks included:

- Water quality characterizations of the replenishment sources and groundwater in terms of their microbiological and chemical content.
- Toxicological and chemical studies of the replenishment sources and groundwater to isolate and identify organic constituents of possible health significance
- Field studies to evaluate the efficacy of soil for attenuating chemicals in reclaimed water
- Hydrogeologic studies to determine the movement of reclaimed water through groundwater and the relative contribution of reclaimed water to municipal water supplies
- Epidemiologic studies of populations ingesting reclaimed water to determine whether their health characteristics differed significantly from a demographically similar control population

During the course of the study, a technical advisory committee and a peer review committee reviewed findings and interpretations. The final project report was completed in March, 1984 as summarized by Nellor *et al.* in 1985. The results of the study did not demonstrate any measurable adverse effects on either the area groundwater or health of the people ingesting the water. Although the study was not designed to provide data for evaluating the impact of an increase in the proportion of reclaimed water used for replenishment, the results did suggest that a closely monitored expansion could be implemented.

In 1986, the State Water Resources Control Board, Department of Water Resources and Department of Health Services established a Scientific Advisory Panel on Groundwater Recharge to review the report and other pertinent information. The Panel concluded that it was comfortable with the safety of the product water and the continuation of the Montebello Forebay Project. The Panel felt that the risks, if any, were small and probably not dissimilar from those that could be hypothesized for commonly used surface waters.

Based on the results of the Health Effects Study and recommendations of the Scientific Advisory Panel, the Regional Water Quality Control Board in 1987 authorized an increase in the annual quantity of reclaimed water to be used for replenishment from 32,700 acre-feet per year to 50,000 acre-feet per year (20,270 gpm to 31,000 gpm or 1,280 to 1,955 l/s). In 1991, water reclamation requirements for the project were revised to allow for recharge up to 60,000 acre-feet per year (37,200 gpm or 2,350 l/s) and 50 percent reclaimed water in any one year as long as the running 3-year total did not exceed 150,000 acre-feet per year (93,000 gpm or 5,870 l/s) or 35 percent reclaimed water. The average amount of reclaimed water spread each year is about 50,000 acre-feet per year (31,000 gpm or 1,955 l/s). Continued evaluation of the project is being provided by an extensive sampling and monitoring program, and by supplemental research projects pertaining to percolation effects, epidemiology, and microbiology.

The Rand Corporation has conducted additional health studies for the project as part of an ongoing effort to monitor the health of those consuming reclaimed water in Los Angeles County (Sloss *et al.,* 1996 and Sloss *et. al.*, 1999). These studies looked at health outcomes for 900,000 people in the Central Groundwater Basin who are receiving some reclaimed water in their household water supplies. These people account for more than 10 percent of the population of Los Angeles County. To compare health characteristics, a control area of 700,000 people that had similar demographic and socioeconomic characteristics was selected, but did not receive reclaimed water. The results from these studies have found that, after almost 30 years of groundwater recharge, there is no association between reclaimed water and higher rates of cancer, mortality, infectious disease, or adverse birth outcomes.

The Districts, along with water and wastewater agencies and researchers in 3 western states, are currently conducting research to evaluate the biological, chemical, and physical treatment processes that occur naturally as the reclaimed water passes through the soil on the way to the groundwater. The SAT Project was developed to better understand the impact of SAT on water quality in terms of chemical and microbial pollutants (see Case Study 2.7.16). This work will continue to address emerging issues such as the occurrence and significance of pharmaceutically active compounds (including endocrine disruptors and new disinfection byproducts) and standardized monitoring techniques capable of determining pathogen viability. The Groundwater Replenishment (GWR) System is an innovative approach to keeping the Orange County, California, groundwater basin a reliable source for meeting the region's future potable water needs (Chalmers *et al.,* 2003). A joint program of the Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD), the GWR System will protect the groundwater from further degradation due to seawater intrusion and supplement existing water supplies by providing a new, reliable, high-quality source of water to recharge the Orange County Groundwater Basin (see Case Study 2.7.15).

2.6.4 Direct Potable Water Reuse

Direct potable reuse is currently practiced in only one city in the world, Windhoek, Namibia. This city uses direct potable reuse on an intermittent basis only. In the U.S., the most extensive research focusing on direct potable reuse has been conducted in Denver, Colorado; Tampa, Florida; and San Diego, California. A considerable investment in potable reuse research has been made in Denver, Colorado, over a period of more than 20 years. This research included operation of a 1-mgd (44-l/s) reclamation plant in many different process modes over a period of about 10 years (Lauer, 1991). The product water was reported to be of better quality than many potable water sources in the region. The San Diego Total Resource Recovery Project was executed to demonstrate the feasibility of using natural systems for secondary treatment with subsequent advanced wastewater treatment to provide a water supply equivalent or better than the quality of imported water supplied to the region (WEF/AWWA, 1988). **Tables 2-11** and **2-12** show the advanced wastewater treatment effluent concentrations of minerals, metals, and trace organics for the San Diego Project.

Microbial analysis performed over a 2.5-year period, showed that water quality of advanced wastewater treatment effluent was low in infectious agents. Specifically, research showed:

- Spiking studies were conducted to determine the removal level of viruses. Results of 4 runs showed an overall virus removal rate through the primary, secondary, and advanced wastewater treatment plants of between 99.999 9 percent and 99.999 99 percent. Levels of removal were influenced by the number of viruses introduced. Viruses were not detected in more than 20.2 x 10^4 l of sample.

- Enteric bacterial pathogens (that is, *Salmonella, Shigella,* and *Campylobacter*) were not detected in 51 samples of advanced wastewater treatment effluent.

- Protozoa and metazoa of various types were absent in the advanced wastewater treatment effluent. *Giardia lamblia* were not recovered, and based on recovery rates of cysts from raw wastewater, removal rates were estimated to be 99.9 percent (WEF/AWWA, 1998)

The treatment train operated in San Diego, after secondary treatment, includes the following processes:

- Coagulation with ferric chloride
- Multimedia filtration
- Ultraviolet disinfection
- pH adjustment with sulfuric acid
- Cartridge filter
- Reverse osmosis

Most of these unit processes are well understood. Their performance can be expected to be effective and reliable in large, well-managed plants. However, the heavy burden of sophisticated monitoring for trace contaminants that is required for potable reuse may be beyond the capacity of smaller enterprises.

The implementation of direct, pipe-to-pipe, potable reuse is not likely to be adopted in the foreseeable future in the U.S. for several reasons:

- Many attitude (opinion) surveys show that the public will accept and endorse many types of nonpotable reuse while being reluctant to accept potable reuse. In general, public reluctance to support reuse in-

Table 2-11. Physical and Chemical Sampling Results from the San Diego Potable Reuse Study

Constituents	Number of Samples	Units	Minimum Detection Limit	Number of Samples < MDL	Arithmetic Mean	Standard Deviation	90th Percentile
General							
COD	611	mg/L	15	6	<15.0	44.8[a]	2.7
pH	892	—	na	892	8.2	0.2	—
SS	116	mg/L	1	68	1.6	3.5	5.6
TOC	611	mg/L	1	85	<1.0	3.0[a]	1.1
Anions							
Chloride	97	mg/L	4	96	33.93	31.39	81.1
Fluoride	37	mg/L	0.13	13	<0.125	0.33[a]	0.241
Ammonia	71	mg/L	0.1	69	1.26	2.04	2.92
Nitrite	37	mg/L	0.01	13	<0.01	0.05[a]	0.03
Nitrate	91	mg/L	0.05	91	1.81	1.21	5.77
Phosphate	88	mg/L	1	28	<1.00	2.70[a]	2.2
Silicate	39	mg/L	0.2	39	1.2	0.42	1.83
Sulfate	96	mg/L	0.1	96	6.45	5.72	14.6
Cations							
Boron	24	mg/L	0.1	24	0.24	0.085	0.368
Calcium	21	mg/L	1	16	3.817	12.262	3.87
Iron	21	mg/L	0.01	20	0.054	0.077	0.135
Magnesium	21	mg/L	0.5	16	1.127	6.706	7.89
Manganese	21	mg/L	0.008	18	0.011	0.041	0.042
Potassium	21	mg/L	0.5	14	0.608	2.599	3.42
Sodium	21	mg/L	1	20	16.999	15.072	54.2
Zinc	20	mg/L	0.005	15	0.009	0.008	0.02

[a] Analysis gave negative result for mean.
Source: WEF/AWWA, 1998.

Table 2-12. San Diego Potable Reuse Study: Heavy Metals and Trace Organics Results

Constituents	Number of Samples	Units	Minimum Detection Limit[a]	Number of Samples > MDL	Arithmetic Mean	Standard Deviation
Metals						
Arsenic	11	μg/L	1	5	<1	8[b]
Cadmium	10	μg/L	1	1	1	0.3
Chromium	19	μg/L	1	10	2	3
Copper	20	μg/L	6	18	18	20
Lead	18	μg/L	1	15	3	7
Mercury	8	μg/L	1	0	1	0[c]
Nickel	20	μg/L	1.2	19	6	7
Selenium	12	μg/L	6	2	4	3[c]
Silver	16	μg/L	5	2	3	4
Organics						
Bis (2-ethyl hexyl phthalate)	33	μg/L	2.5	6	<2.50	3.27[b]
Benzyl/butyl phthalate	33	μg/L	2.5	1	2.5	0.02[c]
Bromodichloromethane	33	μg/L	3.1	0	3.1	0.00[c]
Chloroform	33	μg/L	1.6	0	1.6	0.00[c]
Dibutyl phthalate	33	μg/L	2.5	1	2.64	0.78[c]
Dimethylphenol	33	μg/L	2.7	0	2.7	0.00[c]
Methyl chloride	33	μg/L	2.8	6	<2.80	7.91[b]
Naphthalene	33	μg/L	1.6	0	1.6	0
1,1,1 – Trichloroethane	33	μg/L	3.8	0	3.8	0
1,2 – Dichlorobenzene	33	μg/L	4.4	0	4.4	0
4 - Nitrophenol	33	μg/L	2.4	0	2.4	0
Pentachlorophenol	33	μg/L	3.6	0	3.6	0
Phenol	33	μg/L	1.5	0	1.5	0

[a] <MDL was taken to be equal to MDL.
[b] Analysis gave negative result for mean.
[c] Statistics were calculated using conventional formulas.

Source: WEF/AWWA, 1998.

creases as the degree of human contact with reclaimed water increases. Further, public issues have been raised relevant to potential health impacts which may be present in reclaimed water.

- Indirect potable reuse is more acceptable to the public than direct potable reuse, because the water is perceived to be “laundered” as it moves through a river, lake, or aquifer (i.e. the Montebello Forebay and El Paso projects). Indirect reuse, by virtue of the residence time in the watercourse, reservoir or aquifer, often provides additional treatment. Indirect reuse offers an opportunity for monitoring the quality and taking appropriate measures before the water is abstracted for distribution. In some instances, however, water quality may actually be degraded as it passes through the environment.

- Direct potable reuse will seldom be necessary. Only a small portion of the water used in a community needs to be of potable quality. While high quality sources will often be inadequate to serve all urban needs in the future, the use of reclaimed water to replace potable quality water for nonpotable purposes will release more high quality potable water for future use.

2.7 Case Studies

The following case studies are organized by category of reuse applications:

Urban	Sections 2.7.1 through 2.7.6
Industrial	Sections 2.7.7 through 2.7.8
Agricultural	Sections 2.7.9 through 2.7.12
Environmental and Recreational	Section 2.7.13
Groundwater Recharge	Section 2.7.14 through 2.7.16
Augmentation of Potable Supplies	Section 2.7.17
Miscellaneous	Section 2.7.18 through 2.7.19

2.7.1 Water Reuse at Reedy Creek Improvement District

Reedy Creek Improvement District (RCID) provides municipal services to the Walt Disney World Resort Complex, located in Central Florida. In 1989, RCID faced a challenge of halting inconsistent water quality discharges from its wetland treatment system. The solution was a twofold approach: (1) land was purchased for the construction of rapid infiltration basins (RIBs) and (2) plans were drafted for the construction of a reuse distribution system. The RIBs were completed in 1990. Subsequently, all surface water discharges ceased. The RIBs recharge the groundwater via percolation of applied effluent to surficial sands and sandy clays. Eighty–five 1-acre basins were built and operate on a 6 to 8 week rotational cycle. Typically, 10 or 11 basins are in active service for a 1-week period; while the remaining basins are inactive and undergo maintenance by discing of the bottom sands. Initially, the RIBs served as the primary mechanism for reuse and effluent disposal, receiving 100 percent of the effluent. But the trend has completely reversed in recent years, and the RIBs serve primarily as a means of wet-weather recharge or disposal of sub-standard quality water. The majority of the effluent is used for public access reuse. In the past 3 years, over 60 percent of the effluent volume was used for public access reuse.

Initially, the reclaimed water distribution system served 5 golf courses and provided some landscape irrigation within RCID. In the past 10 years, the extent and diversity of uses has grown and now includes washdown of impervious surfaces, construction (such as concrete mixing and cleanup), cooling tower make up, fire fighting (suppression and protection), irrigation of all types of vegetation and landscaping, and all of the nonpotable needs for clean water within the treatment facility.

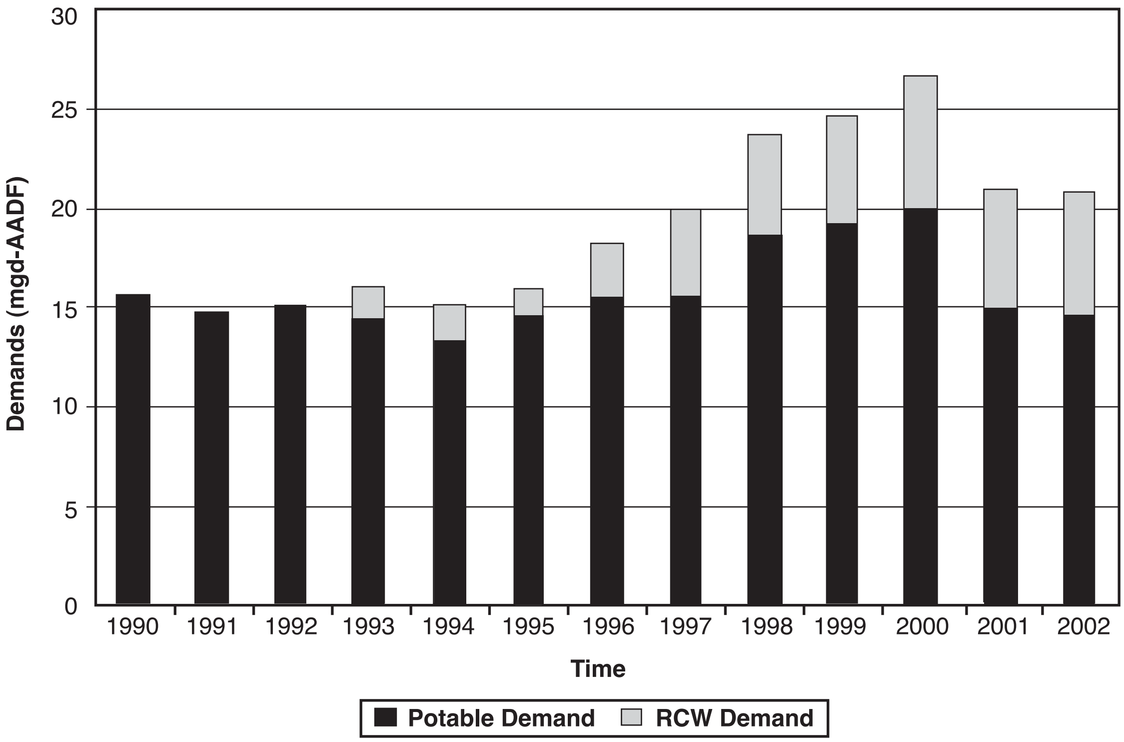
All product water bound for the reuse system is metered. There is a master meter at the master pumping station, and all customers are metered individually at the point of service. Rates are typically set at 75 to 80 percent of the potable water rate to encourage connection and use. Rates are based on volumetric consumption to discourage wasteful practices. New customers are required by tariff to connect to and use the reclaimed water system. If the system is not available, new customers are required to provide a single point of service to facilitate future connection. Existing customers using potable water for nonpotable purposes are included in a master plan for future conversion to reclaimed water.

Demands for reclaimed water have sometimes exceeded supply capabilities, especially during the months of April and May, when rainfall is lowest and demand for irrigation is at its highest. RCID has a number of means at its disposal to counteract this shortfall. The primary means uses 2, formerly idle, potable water wells to supplement the reclaimed water systems during high demand. These wells can provide up to 5,000 gpm (315 l/s) of additional supply. A secondary means requests that major, selected customers return to their prior source of water. Two of the golf courses can return to surface waters for their needs and some of the cooling towers can be quickly converted to potable water use (and back again).

Total water demand within RCID ranges from 18 to 25 mgd (180 to 1,100 l/s) for potable and nonpotable uses. Reclaimed water utilization accounts for 25 to 30 percent of this demand. Over 6 mgd (260 l/s) is typically consumed on an average day and peak day demands have exceeded 12 mgd (525 l/s). Providing reclaimed water for nonpotable uses has enabled RCID to remain within its consumptive use permit limitations for groundwater withdrawal, despite significant growth within its boundaries. Reclaimed water has been a major resource in enabling RCID to meet water use restrictions imposed by the water management districts in alleviating recent drought impacts. **Figure 2-9** is a stacked bar graph that shows the historical contribution reclaimed water has made to the total water resource picture at RCID.

The continued growth of the RCID reclaimed water system is expected to play an ever-increasing and critical role in meeting its water resource needs. Because alternative sources of water (e.g., surface water, brackish water, and stormwater) are not easily and reliably available and are prohibitively costly to obtain, it makes eco-

Figure 2-9. Water Resources at RCID



nomic sense for RCID to maximize its use of reclaimed water.

2.7.2 Estimating Potable Water Conserved in Altamonte Springs due to Reuse

It is taken for granted that implementing a reclaimed water system for urban irrigation will conserve potable water, but few efforts have been made to quantify the benefits. An analysis was performed to define the potential value of urban reuse for a moderately sized city, Altamonte Springs, Florida. Altamonte Springs began implementing its reclaimed water system in 1990.

First, annual potable water-use data were analyzed to ascertain if a significant difference could be seen between periods before and after reuse. **Figure 2-10** shows the historical potable water demands from 1977 to 2000, expressed as gallons of water used per capita per day.

Figure 2-10 indicates a much greater potable water demand before reuse was implemented than after. In 1990, the demand dropped by about 20 gallons per capita-day (76 liters per capita-day) in just one year.

Two differing methods were used to estimate the total potable water conserved through implementing a reclaimed water system. The first method, a linear extrapolation model (LEM), assumes that the rate of increasing water use per capita for 1990 to 2000 increases as it did from 1977 to 1989. Then, the amount conserved per year can be estimated by taking the difference in the potential value from the linear model and the actual potable water used. **Figure 2-11** predicts the amount of potable water saved by implementing the reuse system from 1990 to 2000.

The other method used a more conservative, constant model (CCM). This model averages the gallons of potable water per capita-day from the years before reuse and assumes that the average is constant for the years after reuse. **Figure 2-12** indicates this model's estimate of potable water conserved.

In the year 2000, the LEM model estimates that 102 gallons per capita-day (386 liters per capita-day) of potable water are saved. In the same year, the CCM method estimates a net savings of 69 gallons per capita-day. **Figure 2-13** shows the comparison of the amount conserved using the 2 different methods.

2.7.3 How Using Potable Supplies to Supplement Reclaimed Water Flows can Increase Conservation, Hillsborough County, Florida

Ensuring that an adequate source is available is one of the first steps in evaluating a potable water project. However, consideration of how many reclaimed water customers can be supplied by the flows from a water reclamation facility is seldom part of the reuse planning process. The problem with this approach has become apparent in recent years, as a number of large urban reuse systems have literally run out of water during peak reclaimed water demand times.

In order to understand why this happens, it is important to understand the nature of demands for reclaimed water. **Figure 2-14** illustrates expected seasonal reclaimed water demands for irrigation in southwest Florida. Every operator of a potable water system in this area expects demands to increase by 20 to 30 percent during April through June as customers use drinking water to meet peak season irrigation demands. For reclaimed water systems, which are dedicated to meeting urban irrigation demands, the peak season demands may increase by 50 to 100 percent of the average annual demand. It is, of course, the ability to meet these peak season demands that define the reliability of a utility system, including a reclaimed water system.

How Augmentation Can Help

While peak season demand is what limits the number of customers a utility can connect, it is also short lived, lasting between 60 to 90 days. Augmenting reclaimed water supplies during this time of peak demand can allow a municipality to increase the number of customers served with reclaimed water while preserving the reliability (level of service) of the system. To illustrate this point, consider the Hillsborough County South/Central reclaimed water system. Reclaimed water supplies from the Falkenburg, Valrico, and South County Water Reclamation Facilities (WRFs) are expected to be an annual average of 12.67 mgd (555 l/s) in 2002. However, to avoid shortfalls in the peak demand season, the County will need to limit connections to an average annual demand of 7.34 mgd (321 l/s) or less. The County presently has a waiting list of customers that would demand an annual average of approximately 10.69 mgd (468 l/s). What if augmentation water were used to allow the County to connect these customers instead of making these customers wait? Water balance calculations indicate that from July through March, there will be more than enough reclaimed water to meet expected demands. However, in April, May, and June, reclaimed water demands will exceed available supplies and customers will experience shortages. Using a temporary augmentation supply of water could offset these shortages during this 60 to 90 day period.

Figure 2-10. Altamonte Springs Annual Potable Water Demands per Capita

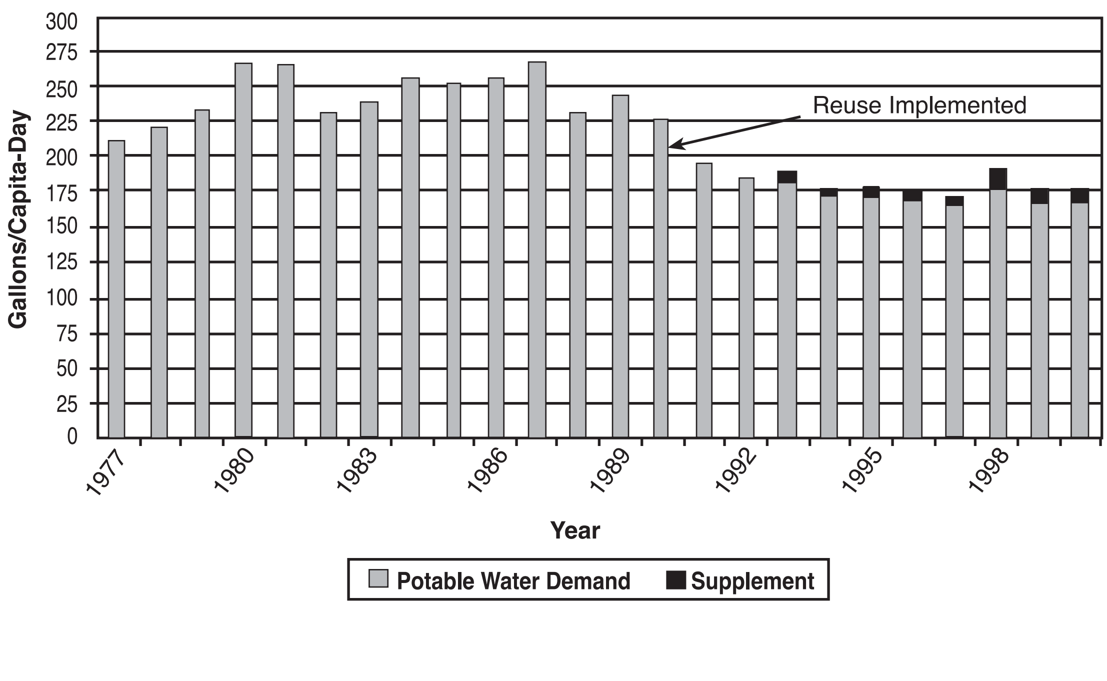


Figure 2-11. Estimated Potable Water Conserved Using Best LEM Method

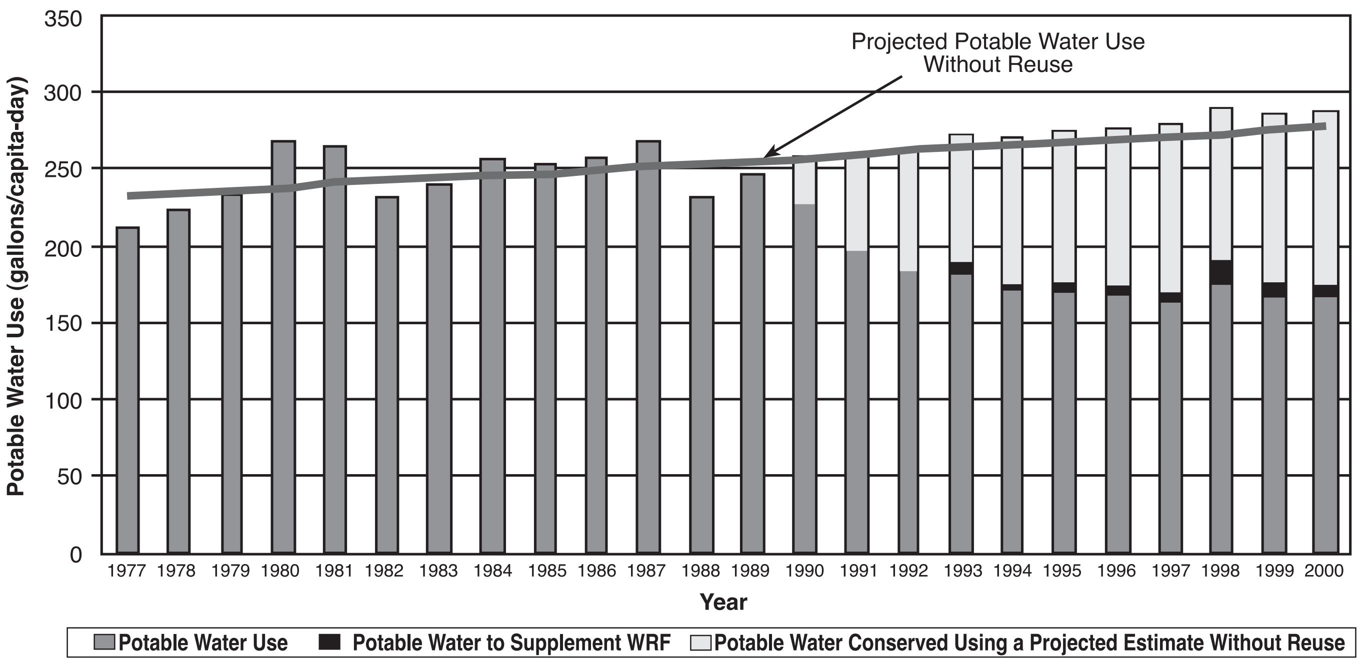


Figure 2-12. Estimated Potable Water Conserved Using the CCM Method

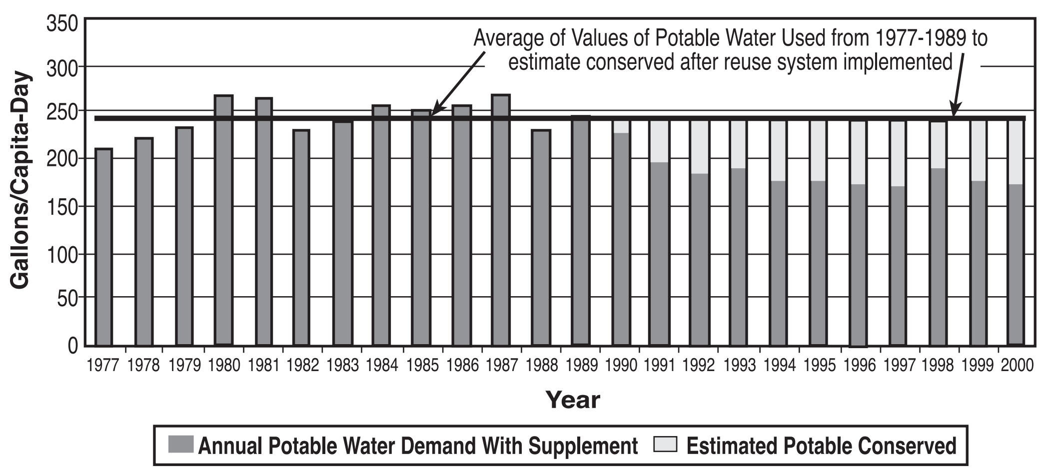


Figure 2-13. Estimated Potable Water Conserved Using Both Method

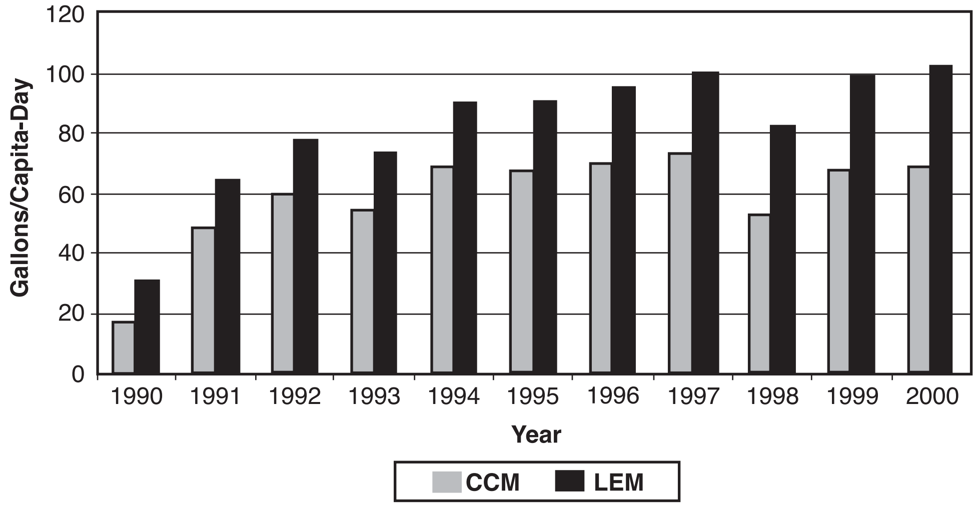


Figure 2-14. Estimated Raw Water Supply vs. Demand for the 2002 South/Central Service Area

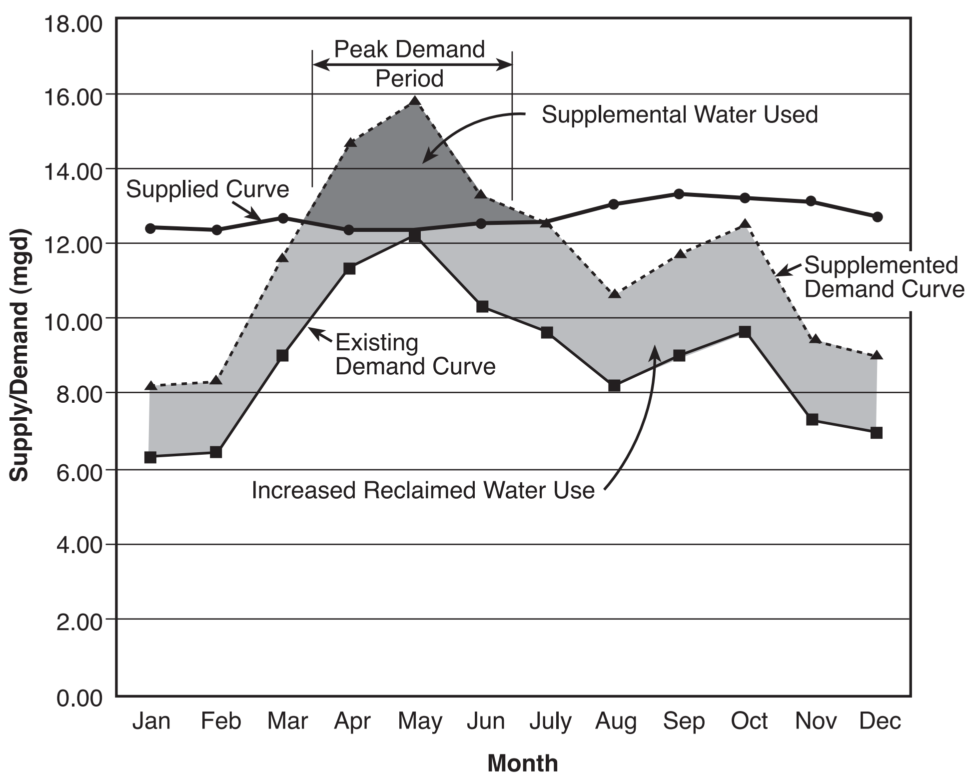


Figure 2-14 illustrates the expected seasonal supply curve for 2002. The bottom curve shows the expected demand for the limited case where the County does not augment its water supplies. The top curve indicates how the County can meet current demand by augmenting its reclaimed water supply during April through June. The limited reclaimed water system is constrained by peak seasonal demands (not exceeding supply) since customers expect year round service. For the system to meet all of the potential demands that have been identified, sufficient reclaimed water augmentation must be used to make up the differences in supply and demand.

The obvious question that must be answered is, "Can using supplemental water actually conserve water resources?" The answer is yes, to a point. The existing, limited reuse system serves an average annual demand of 7.34 mgd (321 l/s), conserving an annual average of 6.07 mgd (266 l/s) of potable water resources. This level of conservation is based on the County's experiences with reductions in potable water demand after reclaimed water becomes available. In order to provide service to the entire 10.69 mgd (468 l/s) reclaimed water demand, the County will need an average annual supply of supplemental water of 0.5 mgd (22 l/s). For the purposes of this analysis, it is assumed this supplemental water comes from the potable water system and so is subtracted from the "Annual Average Potable Water Conserved." This 0.5 mgd potable water supplemental supply increases the total volume of water conserved from 6.07 to 7.23 mgd (266 to 321 l/s). Therefore, 1.16 mgd (51 l/s) more potable water is conserved by using supplemental water. Therefore, an investment of 0.5 mgd (22 l/s) of supplemental water allows the County to save 1.16 mgd (51 l/s) of potable water resources or, put another way, for each gallon (3.8 liters) of supplemental water used we realize a 2.32-gallon (8.8-liter) increase in water resources conserved. There are, of course, limitations to this practice. As more supplemental water is used, the amount of reclaimed water used (as a percentage of the total demand) decreases. Eventually, the supplemental water used will be equal to the water resources conserved. That is the break-even point. In this case potable water was used as the supplemental water, but in reality, other nonpotable supplies, such as raw groundwater, would likely be used.

Short-term supplementation, such as that described above, is one of many tools that can be used by a reclaimed water provider to optimize its system. Utilities can also maximize their existing reclaimed water resources and increase efficiency by instituting Best Management Practices (BMPs). Examples of BMPs include individual metering, volume-based, water-conserving rate structures, planned interruption, peak season "interruptible service", and time-of-day and day-of-week restrictions. When a reclaimed water provider is already experiencing either a long-term supply/demand imbalance or temporary drought effects, that provider should first use BMPs, before considering reclaimed water supplementation. Utilities should also investigate opportunities for enhanced reclaimed water storage capacity including innovative technological solutions, such as aquifer storage and recovery, and wet-weather discharge points that produce a net environmental benefit. Instituting BMPs and the other options mentioned can enable a reclaimed water utility to delay, lessen, or potentially eliminate the need for augmentation of their reclaimed water system during peak reclaimed water demand periods.

2.7.4 Water Reclamation and Reuse Offer an Integrated Approach to Wastewater Treatment and Water Resources Issues in Phoenix, Arizona.

The rapidly developing area of North Phoenix is placing ever-increasing demands on the city's existing wastewater collection system, wastewater treatment plants, and potable water resources. As an integrated solution to these issues, water reclamation and reuse have become an important part of Phoenix Water Services Department's operational strategy.

Cave Creek Reclaimed Water Reclamation Plant (CCWRP), in northeast Phoenix, began operation in September 2001. The facility uses an activated sludge nitrification/denitrification process along with filtration and ultraviolet light disinfection to produce a tertiary-grade effluent that meets the Arizona Department of Environmental Quality's A+ standards. CCWRP is currently able to treat 8 mgd (350 l/s) and has an expansion capacity of 32 mgd (1,400 l/s).

The Phoenix reclamation plant delivers reclaimed water through a nonpotable distribution system to golf courses, parks, schools, and cemeteries for irrigation purposes. The reclaimed water is sold to customers at 80 percent of the potable water rate.

CCWRP's sister facility, North Gateway Water Reclamation Plant (NGWRP), will serve the northwest portion of Phoenix. The design phase has been completed. The NGWRP will have an initial treatment capacity of 4 mgd (175 l/s) with an ultimate capacity of 32 mgd (1,400 l/s). The plant is modeled after the Cave Creek facility using the "don't see it, don't hear it, don't smell it" design mantra. Construction will be preformed using the construction manager-at-risk delivery method.

Phoenix is using geographic information system (GIS) technology to develop master plans for the buildout of the reclaimed water distribution system for both the Cave Creek and North Gateway reclamation plants. Through GIS, potential reclaimed water customers are easily identified. GIS also provides information useful for determining pipe routing, reservoir, and pump station locations. The goal is to interconnect the 2 facilities, thus building more reliability and flexibility into the system. The GIS model is dynamically linked to the water system, planning, and other important databases so that geospacial information is constantly kept up to date. A hydraulic model is being used in conjunction with the GIS model to optimize system operation.

Irrigation demand in Phoenix varies dramatically with the seasons, so groundwater recharge and recovery is a key component of the water reuse program. Phoenix is currently exploring the use of vadose zone wells because they do not require much space and are relatively inexpensive to construct. This method also provides additional treatment to the water as it percolates into the aquifer. A pilot vadose zone well facility has been constructed at the NGWRP site to determine the efficacy of this technology. A vadose zone recharge facility along with a recovery well is being designed for the CCWRP site.

Nonpotable reuse and groundwater recharge with high quality effluent play an important role in the City's water resources and operating strategies. The North Phoenix Reclaimed Water System (**Figure 2-15**) integrates multiple objectives, such as minimizing the impact of development in the existing wastewater infrastructure by treating wastewater locally and providing a new water resource in a desert environment. By using state-of-the-art technology, such as GIS, Phoenix will be able to plan the buildout of the reclaimed water system to maximize its efficiency and minimize costs.

2.7.5 Small and Growing Community: Yelm, Washington

The City of Yelm, Washington, a community of 3,500 residents, is considered one of western Washington's fastest growing cities. In response to a determination from Thurston County that the continued use of septic systems in the Yelm area posed a risk to public health, the City developed a sewage plan. The original plan was to treat and discharge wastewater to the Nisqually River. However, the headwaters of the Nisqually River begin in Mount Rainier National Park and end in a National Wildlife Refuge before discharging into the Puget Sound Estuary. The river supports 5 species of Pacific salmon—chinook, coho, pink, chum, and steelhead—as well as sea-run cutthroat trout. Based on a settlement agreement with local environmental groups, the City agreed to pursue upland reuse of their Class A reclaimed water with the goal of eliminating the Nisqually River as a wastewater discharge location to augment surface water bodies only during times when reclaimed water could not be used 100 percent upland. Reclaimed water also plays a very important role in water conservation as Yelm has limited water resources.

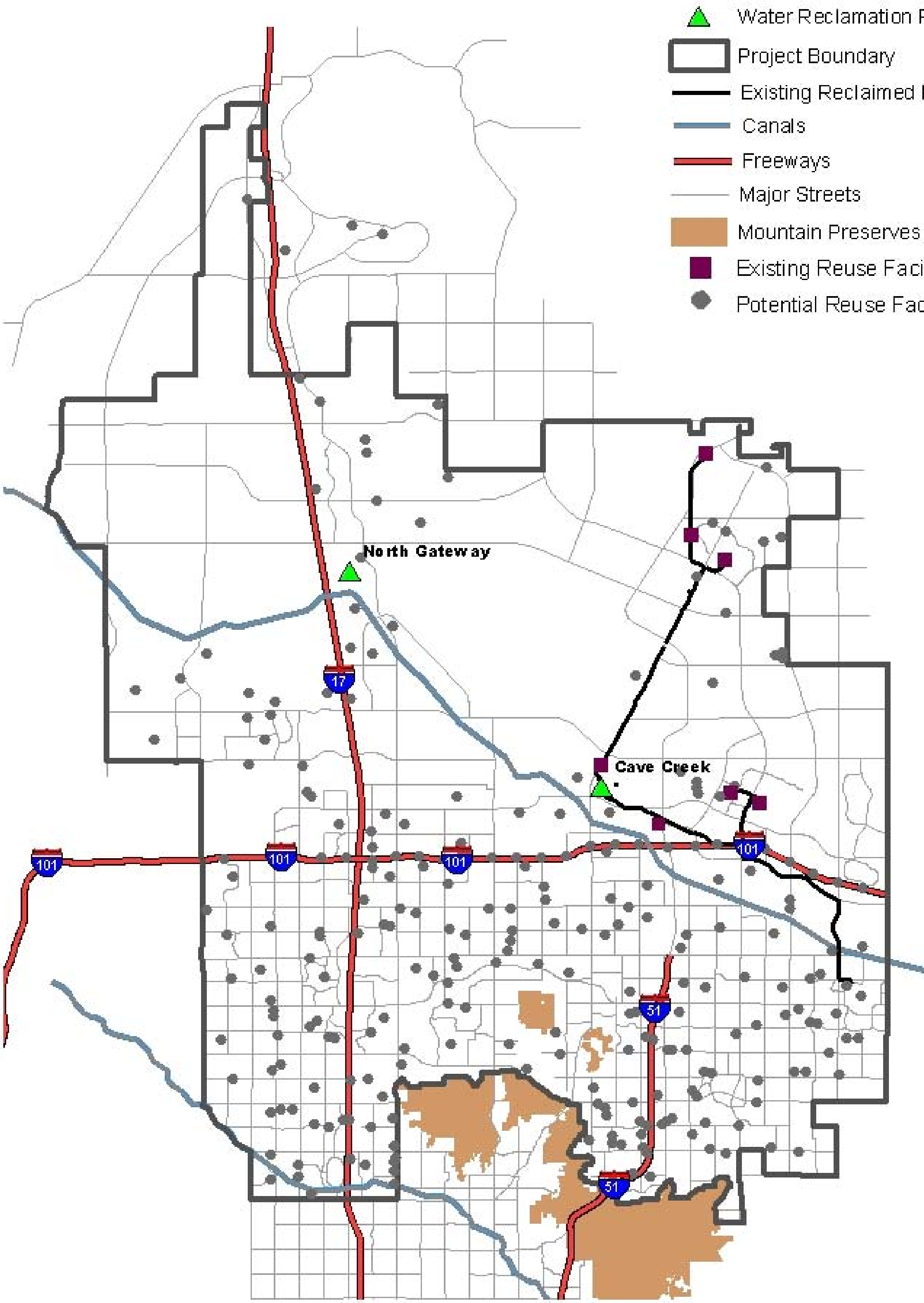
The reclamation plant went on line in August of 1999 and currently reclaims and reuses approximately 230,000 gpd (871 m^3/d). The facility has a design capacity to reclaim up to 1.0 mgd (44 l/s). State standards require the use of treatment techniques for source control, oxidation, coagulation, filtration, and disinfection. Final reclaimed water requirements include a daily average turbidity of less than 2.0 NTU with no values above 5.0 NTU, total coliform less than 2.2 per 100 ml as a 7-day median value and total nitrogen below 10 mg/l. Major facility components include a septic tank effluent pumping (STEP) collection system, activated sludge biological treatment with nitrogen removal using Sequencing Batch Reactor (SBR) technology, flow equalization, an automated chemical feed system with in-line static mixers to coagulate remaining solids prior to filtration, a continuous backwash, upflow sand media filtration system, and chlorine disinfection. The facility also includes an on-line computer monitoring system. Process monitors provide continuous monitoring of flow, turbidity, and chlorine residual. Alarms provide warning when turbidity reaches 2.0 NTU, the flow to the filters shuts off at 3.0 NTU, and the intermediate pumps shut down at 3.5 NTU. Chlorine concentrations are set for an auto-dialer alarm if the flash mixer falls below 1.5 mg/l or if the final residual is below 0.75 mg/l. Only reclaimed water that meets the required standard is sent to upland use areas.

Reclaimed water in Yelm is primarily used for seasonal urban landscape irrigation at local schools and churches, city parks, and a private residence along the distribution route. The true showcase of the Yelm project is Cochrane Memorial Park, an aesthetically pleasing 8-acre city park featuring constructed surface and submerged wetlands designed to polish the reclaimed water prior to recharging groundwater. In the center of the park, a fishpond uses reclaimed water to raise and maintain stocked rainbow trout for catch and release. The City also uses reclaimed water for treatment plant equipment washdown and process water, fire fighting, street cleaning, and dust control.

Although summers in western Washington are quite dry, during the winter rainy season there is not sufficient irrigation demand for reclaimed water. Excess water is sent to generate power in the Centralia Power Canal, a diversion from the Nisqually River. Based on state law, reclaimed water that meets both the reclamation standards and state and federal surface water quality requirements is "no longer considered a wastewater." However, per their settlement agreement, Yelm is continuing to pursue the goal of 100 percent upland reuse via a program to add reclaimed water customers and uses.

Yelm recently updated its Comprehensive Water Plan to emphasize an increased dependence on reclaimed water to replace potable water consumption to the greatest

Figure 2-15.   North Phoenix Reclaimed Water System



extent possible. The City is constructing storage capacity to provide collection of reclaimed water during non-peak periods for distribution during periods of peak demand. This will allow more efficient use of reclaimed water and eliminate the need for potable make-up water. Yelm is planning to use reclaimed water for bus washing, concrete manufacturing, and additional irrigation purposes.

Sources: Washington State Department of Ecology and City of Yelm, 2003.

2.7.6 Landscape Uses of Reclaimed Water with Elevated Salinity: El Paso, Texas

Because of declining reserves of fresh groundwater and an uncertain supply of surface water, the Public Service Board, the governing body of El Paso Water Utilities, has adopted a strategy to curtail irrigation use of potable water by substituting reclaimed municipal effluent. This strategy has been implemented in stages, starting with irrigation of a county-operated golf course using secondary effluent from the Haskell Plant, and a city-owned golf course with tertiary treated effluent from the Fred Hervey Plant. More recently, the reuse projects were expanded to use secondary effluent from the Northwest Plant to irrigate a private golf course, municipal parks, and school grounds (Ornelas and Brosman, 2002). Reclaimed water use from the Haskell Plant is also being expanded to include parks and school grounds.

Salinity of reclaimed water ranges from 680 to 1200 ppm as total dissolved salts (TDS) depending on the plant (Table 2-13). Reclaimed water from the Hervey Plant has the lowest salinity (680 ppm), and a large portion of it is now being injected into an aquifer for recovery as potable water. Reclaimed water from the Haskell Plant and the Northwest plant have elevated levels of salinity, and are likely to be the principal reclaimed sources for irrigation from now into the near future. The cause of elevated salinity at the Northwest Plant is currently being investigated, and it appears to be related to intrusion of shallow saline groundwater into sewer collection systems located in the valley where high water tables prevail.

Reuse of reclaimed water from the Hervey Plant on a golf course proceeded without any recognizable ill effects on turf or soil quality. This golf course is located on sandy soils developed to about 2 feet (60 cm) over a layer of caliche, which is mostly permeable. Broadleaf trees have experienced some foliar damage, but not to the extent of receiving frequent user complaints. This golf course uses low pressure, manual sprinklers, and plantings consist mostly of pines, which are spray resistant. Reuse of reclaimed water from the Northwest Plant, however, has caused severe foliar damage to a large number of broadleaf trees (Miyamoto and White, 2002). This damage has been more extensive than what was projected based on the total dissolved salts of 1200 ppm. However, this reclaimed water source has a Na concentration equal to or higher than saline reclaimed water sources in this part of the Southwest (**Table 2-13**). Foliar damage is caused primarily through direct salt adsorption through leaves. This damage can be minimized by reducing direct sprinkling onto the tree canopy. The use of low-trajectory nozzles or sprinklers was found to be

Table 2-13. Average Discharge Rates and Quality of Municipal Reclaimed Effluent in El Paso and Other Area Communities

Treatment Plants	Plant Capacity (mgd)	Reuse Area (acres)	Water Quality					Soil Type
			TDS (ppm)	EC (dS m[1])	SAR	Na (ppm)	Cl (ppm)	
El Paso								
Fred Hervey	10	150	680	0.9	3.7	150	180	Calciorthid, Aridisols
Haskell	27	329	980	1.6	7.3	250	280	Torrifluvent, Entisols
Northwest	17	194	1200	2.2	11.0	350	325	Paleorthid, Aridisols
Alamogordo[1]	--	--	1800	2.7	2	310	480	Camborthid, Aridisols
Odessa[2]	--	--	1650	2.4	1.9	330	520	Paleustal, Alfisols

[1]These water sources contain substantial quantities of Ca and SO_4.
[2]Reclaimed water quality of this source changes with season.

Sources: Ornela and Brosman, 2002; Miyamoto and White, 2002; Ornelas and Miyamoto, 2003; and Miyamoto, 2003.

effective through a test program funded by the Bureau of Reclamation (Ornelas and Miyamoto, 2003). This finding is now used to contain salt-induced foliar damage.

Another problem associated with the conversion to reclaimed water has been the sporadic occurrence of salt spots on the turf in areas where drainage is poor. This problem has been contained through trenching and subsoiling. Soil salinization problems were also noted in municipal parks and school grounds that were irrigated with potable water in the valley where clayey soils prevail. This problem is projected to increase upon conversion to reclaimed water from the Haskell Plant unless salt leaching is improved. The Texas A&M Research Center at El Paso has developed a guideline for soil selection (Miyamoto, 2003), and El Paso City Parks, in cooperation with Texas A&M Research Center, are initiating a test program to determine cost-effective methods of enhancing salt leaching. Current indications are that increased soil aerification activities, coupled with topdressing with sand, may prove to be an effective measure. If the current projection holds, reuse projects in El Paso are likely to achieve the primary goal, while demonstrating that reclaimed water with high Na and Cl concentrations (greater than 359 ppm) can be used effectively even in highly diverse soil conditions through site improvements and modified management practices.

2.7.7 Use of Reclaimed Water in a Fabric Dyeing Industry

The Central Basin Municipal Water District (CBMWD) reclaimed water system began operation in 1992 and currently serves approximately 3,700 acre-feet per year (2,300 gpm) for a variety of irrigation, commercial, and industrial uses. Industrial customers include the successful conversion of Tuftex Carpets in Santa Fe Springs, which was the first application in California of reclaimed water used for carpet dyeing. A significant benefit to using reclaimed water is the consistency of water quality. This reduces the adjustments required by the dye house that had previously been needed due to varying sources of water (e.g. Colorado River, State Water Project, or groundwater). Since completion of the initial system, CBMWD has continued to explore expansion possibilities, looking at innovative uses of reclaimed water.

The fabric dyeing industry represents a significant potential for increased reclaimed water use in CBMWD and in the neighboring West Basin Municipal Water District (WBMWD). More than 15 dye houses are located within the 2 Districts, with a potential demand estimated to be greater than 4,000 acre-feet per year (2,500 gpm). A national search of reclaimed water uses did not identify any existing use of tertiary treated wastewater in fabric dyeing.

General Dye and Finishing (General Dye) is a fabric dyeing facility located in Santa Fe Springs, California. This facility uses between 400 and 500 acre-feet per year (250 to 310 gpm) of water, primarily in their dye process and for boiler feed. CBMWD is working with the plant manager to convert the facility from domestic potable water to reclaimed water for these industrial purposes.

A 1-day pilot test was conducted on October 15, 2002 using reclaimed water in one of the 12 large dye machines used at the facility. A temporary connection was made directly to the dye machine fill line using a 1-inch hose from an air release valve on the CBMWD reclaimed water system. General Dye conducted 2 tests with the reclaimed water, using reactive dye with a polycotton blend and using dispersed dye with a 100-percent polyester fabric.

Both test loads used about 800 pounds of fabric with blue dyes. The identical means and methods of the dyeing process typically employed by General Dye with domestic water were also followed using reclaimed water. General Dye did not notice any difference in the dyeing process or quality of the end product using the reclaimed water versus domestic water.

A 1-week demonstration test was conducted between November 20 and November 27, 2002, based on the successful results of the 1-day pilot test. A large variety of colors were used during the demonstration test. No other parameters were changed. Everything was done exactly the same with the reclaimed water that would have been done with the domestic water. As with the pilot test, the results indicated that reclaimed water can successfully be used in the fabric dyeing process, resulting in plans for a full conversion of the General Dye facility to reclaimed water for all process water needs.

2.7.8 Survey of Power Plants Using Reclaimed Water for Cooling Water

A wide variety of power facilities throughout the U.S. were contacted and asked to report on their experience with the use of treated wastewater effluent as cooling water. **Table 2-14** presents a tabulation of data obtained from contacts with various power facilities and related wastewater treatment plants that supply them with effluent water. Table 2-14 also provides a general summary of the treatment process for each WWTP and identifies treatment performed at the power plant.

Table 2-14. Treatment Processes for Power Plant Cooling Water

Power Facility & Location	Average Cooling Water Supply & Return Flow (mgd)	Wastewater Treatment Plant Processes	Treatment for Cooling Water (by Power Plant)
1. Lancaster County Resource Recovery Facility Marietta, PA	Supply = 0.65 Return = 0 Zero discharge; all blow-down evaporated or leaves plant in sludge.	Secondary treatment with Alum, Floc & Polymer; Additions settle solids, remove phosphorus	Further treatment with clarification process, Flash Mix, Slow Mix. Also additions of ferric sulfate, polymer & sodium hypochlorite
2. PSE&G Ridgefield Park, NJ	Supply = 0.3 – 0.6 (make-up supply to cooling towers) Blow-down disposed of with plant wastewater to local sewer system.	Secondary Treatment, 85% minimum removal of solids	Water chemistry controlled with biocide, pH control, and surfactant
3. Hillsborough County Solid Waste to Energy Recovery Facility (operated by Ogden Martin Corp.) Tampa, FL	Supply = 0.7 (includes irrigation water) Blow-down of 0.093-mgd mixed with plant wastewater is returned to WWTP.	Advanced treatment with high level of disinfection. Partial tertiary treatment, removes phosphorus.	Chlorine addition, biocide, surfactant, tri-sodium phosphate, pH control with sulfuric acid.
4. Nevada Power – Clark and Sunrise Stations Las Vegas, NV	Supply = 2.72 (annual avg.) to Clark Sta. Return = 0 Blow-down is discharged to holding ponds for evaporation	Advanced Secondary treatment with nitrification, denitrification and biological phosphorus removal. Tertiary treatment through dual media filter & disinfection in chlorine contact tank.	None at present time. Previously treated with lime & softener; discontinued 2-3 years ago.
5. Panda Brandywine Facility Brandywine, MD	Supply = 0.65 Cooling tower blow-down is discharged to a local sewage system and eventually returned to the WWTP.	Primary & secondary settling. Biological nutrient removal, with post filtration via sand filters.	Addition of corrosion inhibitors, sodium hypochlorite, acid for pH control, and anti-foaming agents.
6. Chevron Refineries; El Segundo, CA Richmond, CA	Approx = 3-5 Return = 0	Tertiary treatment El Segundo: Ammonia Stripping plant across street. Richmond: Caustic Soda Treatment Plant Specifically for Chevron.	Richmond Plant uses Nalco Chemical for further treatment.
7. Curtis Stanton Energy Center Orange County, FL (near Orlando)	Supply = 10 Return = 0 Blow-down is evaporated in brine concentrator and crystallizer units at power plant for zero discharge.	Advanced Wastewater treatment including filtration, disinfection & biological nutrient removal to within 5:5:3:1*	PH adjustment with acid, addition of scale inhibitors and chlorine. Control of calcium level. All chemical adjustments done at cooling towers.
8. Palo Verde Nuclear Plant Phoenix, AZ	Total Supply to (3) units = 72 Return = 0 Zero discharge facility; all blow-down is evaporated in ponds.	WWTPs provide secondary treatment. Treated effluent not transmitted to Palo Verde is discharged to riverbeds (wetlands) under State of Arizona permits.	Tertiary treatment plant consisting of trickling filters for ammonia removal, 1st and 2nd stage clarifiers for removal of phosphorus, magnesium, and silica. Cooling tower water is further controlled by addition of dispersants, defoaming agents, and sodium

* 5:5:3:1 refers to constituent limits of 5 mg/l BOD, 5 mg/l TSS, 3 mg/l nitrogen and 1 mg/l phosphorus.

Source: DeStefano, 2000

It is important to note that, in all cases for the facilities contacted, the quality of wastewater treatment at each WWTP is governed by the receiving water body where the treated effluent is discharged, and its classification. For example, if the water body serves as a source of drinking water or is an important fishery, any treated effluent discharged into it would have to be of high quality. Effluent discharged to an urban river or to the ocean could be of lower quality.

2.7.9 Agricultural Reuse in Tallahassee, Florida

The Tallahassee agricultural reuse system is a cooperative operation where the city owns and maintains the irrigation system, while the farming service is under contract to commercial enterprise. During the evolution of the system since 1966, extensive evaluation and operational flexibility have been key factors in its success.

The City of Tallahassee was one of the first cities in Florida to use reclaimed water for agricultural purposes. In 1966, the City began to use reclaimed water from its secondary wastewater treatment plant for spray irrigation. In 1971, detailed studies showed that the system was successful in producing crops for agricultural use. The studies also concluded that the soil was effective at removing SS, BOD, bacteria, and phosphorus from the reclaimed water. Until 1980, the system was limited to irrigation of 120 acres (50 hectares) of land used for hay production. Based upon success of the early studies and experience, a new spray field was constructed in 1980, southeast of Tallahassee.

The southeast spray field has been expanded 3 times since 1980, increasing its total area to approximately 2100 acres (840 hectares). The permitted application rate of the site is 3.16 inches per week (8 cm per week), for a total capacity of 24.5 mgd (1073 l/s). Sandy soils account for the high application rate. The soil composition is about 95 percent sand, with an interspersed clay layer at a depth of approximately 33 feet (10 meters). The spray field has gently rolling topography with surface elevations ranging from 20 to 70 feet (6 to 21 meters) above sea level.

Secondary treatment is provided to the City's Thomas P. Smith wastewater reclamation plant and the Lake Bradford Road wastewater reclamation plant. The reclaimed water produced by these wastewater reclamation plants meet water quality requirements of 20 mg/l for BOD and TSS, and 200/100 ml for fecal coliform. Reclaimed water is pumped approximately 8.5 miles (13.7 km) from the treatment plant to the spray field and distributed via 16 center-pivot irrigation units.

Major crops produced include corn, soybeans, coastal Bermuda grass, and rye. Corn is stored as high-moisture grain prior to sale, and soybeans are sold upon harvest. Both the rye and Bermuda grass are grazed by cattle. Some of the Bermuda grass is harvested as hay and haylage. Cows are allows to graze in winter.

2.7.10 Spray Irrigation at Durbin Creek WWTP Western Carolina Regional Sewer Authority

The Durbin Creek Wastewater Treatment Facility, located near Fountain Inn, South Carolina, is operated by the Western Carolina Regional Sewer Authority (WCRSA). The plant discharges to Durbin Creek, a relatively small tributary of the Enoree River. Average flow from the Durbin Creek Plant is 1.37 mgd (5.2×10^3 m^3/day) with a peak flow of 6.0 mgd (22.7×10^3 m^3/day) during storm events. The plant is permitted for an average flow of 3.3 mgd (12.5×10^3 m^3/day).

The Durbin Creek plant is located on an 200-acre (81-hectare) site. Half of the site is wooded with the remaining half cleared for land application of biosolids. Hay is harvested in the application fields. Much of the land surrounding the plant site is used as a pasture and for hay production without the benefit of biosolids applications.

As a result of increasingly stringent NPDES permit limits and the limited assimilative capacity of the receiving stream, WCRSA began a program to eliminate surface water discharge at this facility. Commencing in 1995, WCRSA undertook a detailed evaluation of land application and reuse at Durbin Creek. The initial evaluation focused on controlling ammonia discharged to the receiving stream by combining agricultural irrigation with a hydrograph-controlled discharge strategy.

In order to appreciate the potential for reuse and land application to address current permit issues facing the Durbin Creek WWTP, a brief discussion of their origin is necessary. South Carolina develops waste load allocations calculated by a model that is based on EPA discharge criteria. Model inputs include stream flow, background concentrations of ammonia, discharge volume, water temperature, pH, and whether or not salmonids are present. Because water temperature is part of the model input, a summer (May through October) and a winter (November through April) season are recognized in the current NPDES permit. Ammonia concentrations associated with both acute and chronic toxicity are part of the model output. The stream flow used in the model is the estimated 7-day, 10-year low flow event (7Q10). For the receiving stream, the 7Q10 value is 2.9 cfs (0.08 m^3/s).

The permitted flow of 3.3 mgd (12.5 x 10^3 m^3/day) is used as the discharge volume in the model.

A detailed evaluation of the characteristics of the receiving water body flow was required to evaluate the potential of reuse to address the proposed NPDES limits. The probability of occurrence of a given 7-day low flow rate was then determined using an appropriate probability distribution. The annual summer and winter 7Q10 flows for the Durbin Creek site were then estimated with the following results:

Annual	7Q10 2.9 cfs (0.08 m^3/s)
Summer	7Q10 (May through October) 2.9 cfs (0.08 m^3/s)
Winter	7Q10 (November through April) 6.4 cfs (0.18 m^3/s)

The predicted annual 7Q10 of 2.9 cfs (0.08 m^3/s) matched the value used by the state regulatory agency and confirmed the validity of the analysis. The winter 7Q10 was found to be more than double that of the summer 7Q10. This information was then used in conjunction with the state's ammonia toxicity model to develop a conceptual summer and winter discharge permit for effluent discharge based on stream flow.

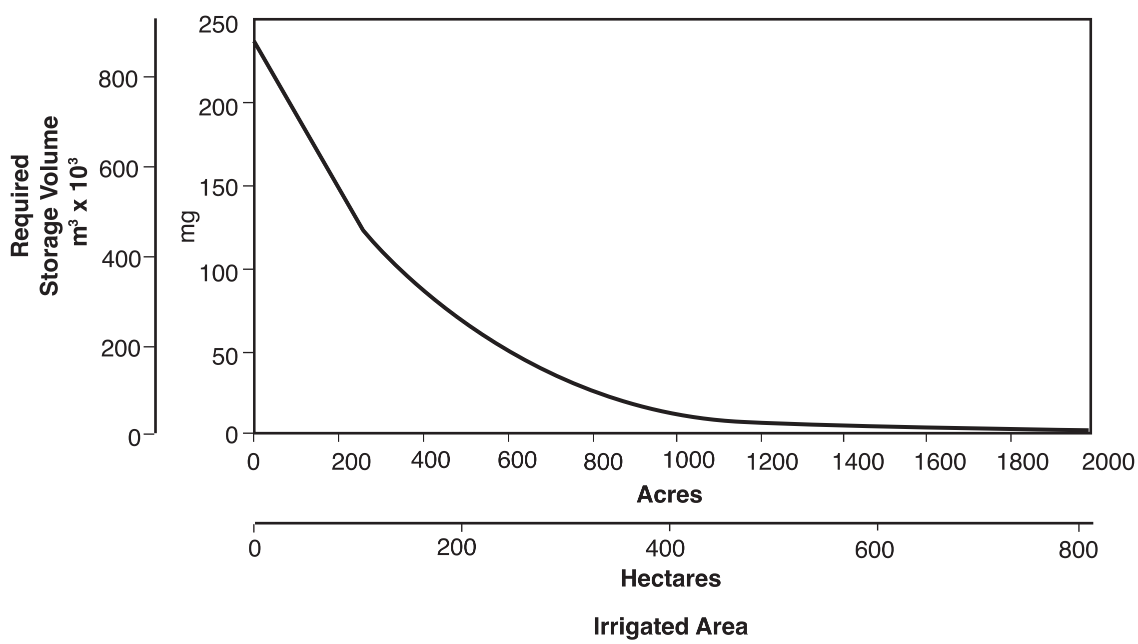
The next step was to evaluate various methods of diverting or withholding a portion of the design discharge flow under certain stream flow conditions.

The most prominent agricultural enterprise in the vicinity of the Durbin Creek WWTP is hay production. Thus, WCRSA decided to investigate agricultural reuse as its first alternative disposal method.

To evaluate how irrigation demands might vary over the summer season, a daily water balance was developed to calculate irrigation demands. The irrigation water balance was intended to calculate the consumptive need of an agricultural crop as opposed to hydraulic capacities of a given site. This provision was made because farmers who would potentially receive reclaimed water in the future would be interested in optimizing hay production and could tolerate excess irrigation as a means of disposal. Results of this irrigation water balance were then combined with the expected stream flow to evaluate the requirements of integrating agricultural irrigation with a hydrograph control strategy.

The results of this analysis are provided in **Figure 2-16,** which indicates the storage volume required as a function of the irrigated area given a design flow of 3.3 mgd (12.5 x 10^3 m^3/day). As shown in Figure 2-16, if no irrigated area is provided, a storage volume of approximately 240 million gallons (900 x 10^3 m^3) would be required to

Figure 2-16. Durbin Creek Storage Requirements as a Function of Irrigated Area



achieve compliance with a streamflow dependent permit. This storage volume decreases dramatically to approximately 50 million gallons (190 x 10^3 m^3) if 500 acres (200 hectares) of irrigated area are developed. As irrigated area increases from 500 to 1,200 acres (200 to 490 hectares), the corresponding ratio of increased irrigated area to reduction in storage is less. As indicated in Figure 2-16, storage could hypothetically be completely eliminated given an irrigated area of approximately 1,900 acres (770 hectares). The mathematical modeling of stream flows and potential demands has demonstrated that reuse is a feasible means of achieving compliance with increasingly stringent NPDES requirements in South Carolina.

2.7.11 Agricultural Irrigation of Vegetable Crops: Monterey, California

Agriculture in Monterey County, located in the central coastal area of California, is a $3 billion per year business. The northern part of the county produces a variety of vegetable crops, many of which may be consumed raw. As far back as the 1940s, residential, commercial, industrial, and agricultural users were overdrawing the County's northern groundwater supply. This overdraw lowered the water tables and created an increasing problem of saltwater intrusion. In the mid-1970s, the California Central Coast Regional Water Quality Control Board completed a water quality management plan for the area, recommending reclaimed water for crop irrigation.

At that time, agricultural irrigation of vegetable crops with reclaimed water was not widely accepted. To respond to questions and concerns from the agricultural community, the Monterey Regional Water Pollution Control Agency (MRWPCA) sponsored an 11-year, $7-million pilot and demonstration project known as the Monterey Wastewater Reclamation Study for Agriculture (MWRSA). Study objectives were to find answers to questions about such issues as virus and bacteria survival on crops, soil permeability, and yield and quality of crops, as well as to provide a demonstration of field operations for farmers who would use reclaimed water.

Five years of field operations were conducted, irrigating crops with 2 types of tertiary treated wastewater, with a well water control for comparison. Artichokes, broccoli, cauliflower, celery, and several varieties of lettuce were grown on test plots and a demonstration field. Crops produced with reclaimed water were healthy and vigorous, and the system operated without complications. The results of the study provided evidence that using reclaimed water can be as safe as irrigating with well water, and that large scale water reclamation can be accomplished. No virus was found in reclaimed water used for irrigation or on samples of crops grown with the reclaimed water. No tendency was found for metals to accumulate in soils or on plant tissues. Soil permeability was not impaired. By the time the study was completed in 1987, the project had gained widespread community support for water reclamation.

As a result of the MWRSA, a water reclamation plant and distribution system were completed in 1997. The project was designed to serve 12,000 acres (4,850 hectares) of artichokes, lettuce, cauliflower, broccoli, celery, and strawberries. Delivery of reclaimed water was delayed until spring of 1998 to address new concerns about emerging pathogens. The reclaimed water was tested for *E. Coli* 0157:H7, *Legionella*, *Salmonella*, *Giardia*, *Cryptosporidium*, and *Cyclospora*. No viable organisms were found and the results were published in the *Recycled Water Food Safety Study*. This study increased grower and buyer confidence. Currently, 95 percent of the project acreage is voluntarily using reclaimed water.

Growers felt strongly that health department regulations should be minimal regarding use of reclaimed water. The MRWPCA succeeded in getting the County Health Department to approve wording requirements for signs along public roads through the project to say, "No Trespassing," rather than previously proposed wording that was detrimental to public acceptance of reclaimed water. Similarly, field worker safety training requires only that workers not drink the water, and that they wash their hands before eating or smoking after working with reclaimed water.

Three concerns remain: safety, water quality, and long term soil health. To address safety, pathogen testing continues and results are routinely placed on the MRWPCA website at www.mrwpca.org. The water quality concern is partly due to chloride, but mostly due to sodium concentration levels. MRWPCA works with sewer users to voluntarily reduce salt levels by using more efficient water softeners, and by changing from sodium chloride to potassium chloride for softener regeneration. In 1999, the agency began a program of sampling soils from 3 different depth ranges 3 times each season from 4 control sites (using well water) and 9 test sites (using reclaimed water). Preliminary results indicate that using reclaimed water for vegetable production is not causing the soil to become saline.

2.7.12 Water Conserv II: City of Orlando and Orange County, Florida

As a result of a court decision in 1979, the City of Orlando and Orange County, Florida, were mandated to cease discharge of their effluent into Shingle Creek, which flows into Lake Tohopekaliga, by March 1988. The City and County immediately joined forces to find the best and most cost-effective solution. Following several rounds of extensive research, the decision was made to construct a reuse project in West Orange and Southeast Lake counties along a high, dry, and sandy area known as the Lake Wales Ridge. The project was named Water Conserv II. The primary use of the reclaimed water would be for agricultural irrigation. Daily flows not needed for irrigation would be distributed into rapid infiltration basins (RIBs) for recharge of the Floridan aquifer.

Water Conserv II is the largest reuse project of its type in the world, a combination of agricultural irrigation and RIBs. It is also the first reuse project in Florida permitted by the Florida Department of Environmental Protection to irrigate crops produced for human consumption with reclaimed water. The project is best described as "a cooperative reuse project by the City of Orlando, Orange County, and the agricultural community." The City and County jointly own Water Conserv II.

The project is designed for average flows of 50 mgd (2,190 l/s) and can handle peak flows of 75 mgd (3,285 l/s). Approximately 60 percent of the daily flows are used for irrigation, and the remaining ±40 percent is discharged to the RIBs for recharge of the Floridan aquifer. Water Conserv II began operation on December 1, 1986.

At first, citrus growers were reluctant to sign up for reclaimed water. They were afraid of potential damage to their crops and land from the use of the reclaimed water. The City and County hired Dr. Robert C.J. Koo, a citrus irrigation expert at the University of Florida's Citrus Research Center at Lake Alfred, to study the use of reclaimed water as an irrigation source for citrus. Dr. Koo concluded that reclaimed water would be an excellent source of irrigation water for citrus. The growers were satisfied and comfortable with Dr. Koo's findings, but wanted long-term research done to ensure that there would be no detrimental effects to the crop or land from the long-term use of reclaimed water. The City and County agreed, and the Mid Florida Citrus Foundation (MFCF) was created.

The MFCF is a non-profit organization conducting research on citrus and deciduous fruit and nut crops. All research is conducted by faculty from the University of Florida's Institute of Food and Agricultural Sciences (IFAS). The MFCF Board of Directors is comprised of citrus growers in north central Florida and representatives from the City of Orlando, Orange County, the University of Florida IFAS, and various support industries. Goals of the MFCF are to develop management practices that will allow growers in the northern citrus area to re-establish citrus and grow it profitably, provide a safe and clean environment, find solutions to challenges facing citrus growers, and promote urban and rural cooperation. All research conducted by the MFCF is located within the Water Conserv II service area. Reclaimed water is used on 163 of the 168 acres of research. MFCF research work began in 1987.

Research results to date have been positive. The benefits of irrigating with reclaimed water have been consistently demonstrated through research since 1987. Citrus on ridge (sandy, well drained) soils respond well to irrigation with reclaimed water. No significant problems have resulted from the use of reclaimed water. Tree condition and size, crop size, and soil and leaf mineral aspects of citrus trees irrigated with reclaimed water are typically as good as, if not better than, groves irrigated with well water. Fruit quality from groves irrigated with reclaimed water was similar to groves irrigated with well water. The levels of boron and phosphorous required in the soil for good citrus production are present in adequate amounts in reclaimed water. Thus, boron and phosphorous can be eliminated from the fertilizer program. Reclaimed water maintains soil pH within the recommended range; therefore, lime no longer needs to be applied.

Citrus growers participating in Water Conserv II benefit from using reclaimed water. Citrus produced for fresh fruit or processing can be irrigated by using a direct contact method. Growers are provided reclaimed water 24 hours per day, 7 days per week at pressures suitable for micro-sprinkler or impact sprinkler irrigation. At present, local water management districts have issued no restrictions for the use of reclaimed water for irrigation of citrus. By providing reclaimed water at pressures suitable for irrigation, costs for the installation, operation, and maintenance of a pumping system can be eliminated. This means a savings of $128.50 per acre per year ($317 per hectare per year). Citrus growers have also realized increased crop yields of 10 to 30 percent and increased tree growth of up to 400 percent. The increases are not due to the reclaimed water itself, but the availability of the water in the soil for the tree to absorb. Growers are maintaining higher soil moisture levels.

Citrus growers also benefit from enhanced freeze protection capabilities. The project is able to supply enough water to each grower to protect his or her entire production area. Freeze flows are more than 8 times higher than normal daily flows. It is very costly to the City and County to provide these flows (operating costs average $15,000 to $20,000 per night of operation), but they feel it is well worth the cost. If growers were to be frozen out, the project would lose its customer base. Sources of water to meet freeze flow demands include normal daily flows of 30 to 35 mgd (1,310 to 1,530 l/s), 38 million gallons of stored water (143,850 m^3), 80 mgd (3,500 l/s) from twenty-five 16-inch diameter wells, and, if needed, 20 mgd (880 l/s) of potable water from the Orlando Utilities Commission.

Water Conserv II is a success story. University of Florida researchers and extension personnel are delighted with research results to date. Citrus growers sing the praises of reclaimed water irrigation. The Floridan aquifer is being protected and recharged. Area residents view the project as a friendly neighbor and protector of the rural country atmosphere.

2.7.13 The Creation of a Wetlands Park: Petaluma, California

The City of Petaluma, California, has embarked on a project to construct a new water reclamation facility. The existing wastewater plant was originally built in 1938, and then upgraded over the years to include oxidation ponds for storage during non-discharge periods. The city currently uses pond effluent to irrigate 800 acres (320 hectares) of agricultural lands and a golf course. As part of the new facility, wetlands are being constructed for multiple purposes including treatment (to reduce suspended solids, metals, and organics), reuse, wildlife habitat, and public education and recreation. The citizens of Petaluma have expressed a strong interest in creating a facility that not only provides wastewater treatment and reuse, but also serves as a community asset. In an effort to further this endeavor, the citizens formed an organization called the Petaluma Wetlands Park Alliance.

Currently, the project is being designed to include 30 acres (12 hectares) of vegetated wetlands to remove algae. The wetlands will be located downstream from the City's oxidation ponds. The vegetated treatment wetlands will not be accessible to the general public for security reasons. However, an additional 30 acres (12 hectares) of polishing wetlands with both open water and dense vegetation zones will be constructed on an adjacent parcel of land. These polishing wetlands will be fed by disinfected water from the treatment wetlands, so public access will be allowed. Berms around all 3 wetland cells will provide access trails.

The parcel of land where the polishing wetlands will be constructed has many interesting and unique features. An existing creek and riparian zone extend through the upland portion of the parcel down to the Petaluma River. The parcel was historically farmed all the way to the river, but in an El Nino event, the river levees breached and 132 acres (53 hectares) of land has been returned to tidal mudflat/marsh. The parcel is directly adjacent to a city park, with trails surrounding ponds for dredge spoils. A plan has been developed to connect the 2 parcels via trails for viewing the tidal marsh, the polishing wetlands, and the riparian/creek area. The plan also calls for restoration and expansion of the riparian zone, planting of native vegetation, and restoration/enhancement of the tidal marsh. The polishing wetlands will be constructed on a portion of the 133 acres (54 hectares) of uplands. The remainder of the upland areas will either be restored for habitat or cultivated as a standing crop for butterfly and bird foraging. Landscaping on the wetlands site will be irrigated with reclaimed water. A renowned environmental artist developed the conceptual plan with an image of the dog-faced butterfly formed by the wetland cells and trails.

Funding for acquisition of the land and construction of the trails and restoration projects has been secured from the local (Sonoma County) open space district and the California Coastal Conservancy in the amount of $4 million. The citizen's alliance has continued to promote the concept. The alliance recently hosted a tour of the site with the National Audubon Society, asking that the site be considered for the location of an Audubon Interpretive Center.

2.7.14 Geysers Recharge Project: Santa Rosa, California

The cities of central Sonoma County, California, have been growing rapidly, while at the same time regulations governing water reuse and discharge have become more stringent. This has taxed traditional means of reusing water generated at the Laguna Wastewater Plant and Reclamation Facility. Since the early 1960s, the Santa Rosa Subregional Water Reclamation System has provided reclaimed water for agricultural irrigation in the Santa Rosa Plain, primarily to forage crops for dairy farms. In the early 1990s, urban irrigation uses were added at Sonoma State University, golf courses, and local parks. The remaining reclaimed water not used for irrigation was discharged to the Laguna de Santa Rosa from October through May. But limited storage capacity, conversion of dairy farms to vineyards (decreasing reclaimed water use by over two-thirds), and growing concerns over water quality impacts in the Laguna de Santa Rosa, pressured the system to search for a new and reliable means of reuse.

In the northwest quadrant of Sonoma County lies the Geysers Geothermal Steamfield, a super-heated steam resource used to generate electricity since the mid 1960s. At its peak in 1987, the field produced almost 2,000 megawatts (MW), enough electricity to supply an estimated 2 million homes and businesses with power. Geysers operators have mined the underground steam to such a degree over the years that electricity production has declined to about 1,200 MW. As a result, the operators are seeking a source of water to recharge the deep aquifers that yield steam. Geothermal energy is priced competitively with fossil fuel and hydroelectric sources, and is an important "green" source of electricity. In 1997, a neighboring sewage treatment district in Lake County successfully implemented a project to send 8 mgd (350 l/s) of secondary-treated water augmented with Clear Lake water to the southeast Geysers steamfields for recharge. In 1998, the Santa Rosa Subregional Reclamation System decided to build a conveyance system to send 11 mgd (480 l/s) of tertiary-treated water to the northwest Geysers steamfield for recharge. The Santa Rosa contribution to the steamfield is expected to yield an additional 85 MW or more of electricity production.

The conveyance system to deliver water to the steamfield includes 40 miles (64 km) of pipeline, 4 large pump stations, and a storage tank. The system requires a lift of 3,300 feet (1,005 meters). Distribution facilities within the steamfield include another 18 miles (29 km) of pipeline, a pump station, and tank, plus conversion of geothermal wells from production wells to injection wells.

The contract with the primary steamfield operator, Calpine Corporation, states that Calpine is responsible for the construction and operation of the steamfield distribution system and must provide the power to pump the water to the steamfield. The Subregional Reclamation System, in turn, is responsible for the construction and operation of the conveyance system to the steamfield and provides the reclaimed water at no charge. The term of the contract is for 20 years with an option for either party to extend for another 10 years.

One of the major benefits of the Geysers Recharge Project is the flexibility afforded by year-round reuse of water. The system has been severely limited because of seasonal discharge constraints and the fact that agricultural reuse is not feasible during the wet winter months. The Geysers steamfield will use reclaimed water in the winter, when no other reuse options are available. However, during summer months, demand for reuse water for irrigation is high. The system will continue to serve agricultural and urban users while maintaining a steady but reduced flow of reclaimed water to the Geysers. A detailed daily water balance model was constructed to assist in the design of the initial system and to manage the optimum blend of agricultural, urban, and Geysers recharge uses.

In addition to the benefits of power generation, the Geysers Recharge Project will bring an opportunity for agricultural reuse along the Geysers pipeline alignment, which traverses much of Sonoma County's grape-growing regions. Recent listings of coho salmon and steelhead trout as threatened species may mean that existing agricultural diversions of surface waters will have to be curtailed. The Geysers pipeline could provide another source of water to replace surface water sources, thereby preserving the habitat of the threatened species.

2.7.15 Advanced Wastewater Reclamation in California

The Groundwater Replenishment (GWR) System is a regional water supply project sponsored jointly by the Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD) in southern California. Planning between OCWD and OCSD eventually led to the decision to replace Water Factory 21 (WF21) with the GWR System. OCSD, an early partner with OCWD in WF21, will continue to supply secondary wastewater to the GWR System. As one of the largest advanced reclaimed water facilities in the world, the GWR System will protect the groundwater from further degradation due to seawater intrusion and supplement existing water supplies by providing a new, reliable, high-quality source of water to recharge the Orange County groundwater basin. For OCSD, reusing the water will also provide peak wastewater flow disposal relief and postpone the need to construct a new ocean outfall by diverting treated wastewater flows that would otherwise be discharged to the Pacific Ocean.

The GWR System addresses both water supply and wastewater management needs through beneficial reuse of highly treated wastewater. OCWD is the local agency responsible for managing and protecting the lower Santa Ana River groundwater basin. Water supply needs include both the quantity and quality of water. The GWR System offers a new source of water to meet future increasing demands from the region's groundwater producers, provides a reliable water supply in times of drought, and reduces the area's dependence on imported water. The GWR System will take treated secondary wastewater from OCSD (activated sludge and trickling filter effluent) and purify it using microfiltration (MF), reverse osmosis (RO) and ultraviolet (UV) disinfection. Lime is added to stabilize the water. This low-salinity water (less than 100 mg/l TDS) will be injected into the seawater barrier or percolated through the ground into Orange County's aquifers, where it will blend with groundwater from other sources, including imported and Santa Ana River stormwater, to improve the water quality. The GWR System will produce a peak daily production capacity of 78,400 acre-feet per year (70 mgd or 26,500 m^3/yr) in the initial phase and will ultimately produce nearly 145,600 acre-feet per year (130 mgd or 492,100 m^3/yr) of a new, reliable, safe drinking water supply, enough to serve over 200,000 families. Over time, the water produced by the GWR System will lower the salinity of groundwater by replacing the high-TDS water currently percolated into the groundwater basin with low-TDS reclaimed water from the GWR System. The project conforms to the California State Constitution by acknowledging the value of reclaimed water. Less energy is used to produce the GWR System water than would be required to import an equivalent volume of water, reducing overall electrical power demand in the region.

The GWR System will also expand the existing seawater intrusion barrier to protect the Orange County groundwater basin from further degradation. The groundwater levels have been lowered significantly in some areas of the groundwater basin due to the substantial coastal pumping required to meet peak summer potable water demands. The objective of the barrier is to create a continuous mound of freshwater that is higher than sea level, so that the seawater cannot migrate into the aquifer. As groundwater pumping activities increase, so do the amounts of freshwater required to maintain the protective mound. OCWD currently operates 26 injection wells to supply water to the barrier first created in the mid 1970s. Additional water is required to maintain a suitable barrier. To determine optimal injection well capacities and locations, a Talbert Gap groundwater computer model was constructed and calibrated for use as a predictive tool. Based on the modeling analysis, 4 new barrier wells will be constructed in an alignment along the Santa Ana River to cut off saltwater intrusion at the east end of the Talbert Gap. The modeling results also indicate that a western extension of the existing barrier is required. Twelve new barrier wells will be constructed at the western end of the Talbert Gap to inhibit saltwater intrusion under the Huntington Beach mesa.

The project benefits OCSD's wastewater management effort as well as helping to meet Orange County's water supply requirements. The GWR System conforms to the OCSD Charter, which supports water reuse as a scarce natural resource. By diverting peak wastewater effluent discharges, the need to construct a new ocean outfall is deferred, saving OCSD over $175 million in potential construction costs. These savings will be used to help off-set the cost of the GWR system where OCSD will pay for half of the Phase 1 construction. The GWR System also reduces the frequency of emergency discharges near the shore, which are a significant environmental issue with the local beach communities.

2.7.16 An Investigation of Soil Aquifer Treatment for Sustainable Water

An intensive study, entitled, "An Investigation of Soil Aquifer Treatment for Sustainable Water Reuse," was conducted to assess the sustainability of several different SAT systems with different site characteristics and effluent pretreatments (AWWARF, 2001). The sites selected for study and key characteristics of the sites are presented in **Table 2-15**.

Main objectives of the study were to: (1) examine the sustainability of SAT systems leading to indirect potable reuse of reclaimed water; (2) characterize the processes that contribute to removal of organics, nitrogen, and viruses during transport through the infiltration interface, soil percolation zone, and underlying groundwater aquifer; and (3) develop relationships among above-ground treatment and SAT for use by regulators and utilities.

The study reported the following results:

- Dissolved organic carbon (DOC) present in SAT product water was composed of natural organic matter (NOM), soluble microbial products that resemble NOM, and trace organics.
- Characterization of the DOC in SAT product water determined that the majority of organics present were not of anthropenic origin.
- The frequency of pathogen detection in SAT products waters could not be distinguished from the frequency of pathogen detection in other groundwaters.
- Nitrogen removal during SAT was sustained by anaerobic ammonia oxidation.

The study reported the following impacts:

- Effluent pretreatment did not affect final SAT product water with respect to organic carbon concentrations. A watershed approach may be used to predict SAT product water quality.
- Removal of organics occurred under saturated anoxic conditions and a vadose zone was not necessary for an SAT system. If nitrogen removal is desired during SAT, nitrogen must be applied in a reduced form, and a vadose zone combined with soils that can exchange ammonium ions is required.

Table 2-15. Field Sites for Wetlands/SAT Research

Facility	Key Site Characteristics
Sweetwater Wetlands/Recharge Facility, AZ	Deep vadose zone (>100 feet) with extensive vadose zone monitoring capabilities and several shallow groundwater wells located downgradient.
Mesa Northwest, AZ	Shallow vadose zone (5-20 feet). Multi-depth sampling capabilities below basins. Array of shallow groundwater wells located from 500 feet to greater than 10,000 feet from recharge site.
Phoenix Tres Rios Cobble Site, AZ	Horizontal flow and shallow (<21 feet) saturated zone sampling capabilities. Majority of flow infiltrates into groundwater.
Rio Hondo/Montebello Forebay, CA	Vadose zone (20-50 feet). Water supply is a mixture of reclaimed water and other available water sources. Multi-depth sampling capabilities.
San Gabriel/Montebello Forebay, CA	Shallow vadose zone (10-20 feet). Water supply is a mixture of reclaimed water and other available water sources. Multi-depth sampling capabilities.
Riverside Water Quality Control Plant Hidden Valley Wetlands, CA	Horizontal flow and shallow (<3 feet) vadose zone sampling capabilities. Approximately 25% of flow infiltrates into groundwater.
East Valley (Hansen Spreading Grounds), CA	Deep vadose zone (>100 feet). Multi-depth and downgradient sampling capabilities exist.
Avra Valley Wastewater Treatment Facility, AZ	Wastewater treatment applied is similar to facilities in Mesa and Phoenix, Arizona. However, drinking water supply is based only on local groundwater.

- The distribution of disinfection by-products produced during chlorination of SAT product water was affected by elevated bromide concentrations in reclaimed water.

2.7.17 The City of West Palm Beach, Florida Wetlands-Based Water Reclamation Project

The City of West Palm Beach water supply system consists of a 20-square-mile (52-km^2) water catchment area and surface water allocation from Lake Okeechobee, which flows to a canal network that eventually terminates at Clear Lake, where the City's water treatment plant is located. As part of the Everglades restoration program, the timing, location, and quantity of water releases to the South Florida Water Management District (SFWMD) canals from Lake Okechobee will be modified. More water will be directed towards the Everglades for hydropattern restoration and less water will be sent to the SFWMD canals. This translates into less water available for water supplies in the lower east coast area. Therefore, indirect potable reuse, reuse for aquifer recharge purposes, and aquifer storage and recovery are some of the alternative water supply strategies planned by the City of West Palm Beach.

The City of West Palm Beach has developed a program to use highly treated wastewater from their East Central Regional Wastewater Treatment Plant (ECRWWTP) for beneficial reuse including augmentation of their drinking water supply. Presently, all of the wastewater effluent from the ECRWWTP (approximately 35 mgd [1,530 l/s] average daily flow) is injected over 3,000 feet (914 meters) into the groundwater (boulder zone) using 6 deep wells. Rather than continuing to dispose of the wastewater effluent, the City of West Palm Beach developed the Wetlands-Based Water Reclamation Project (WBWRP). The project flow path is shown in **Figure 2-17**.

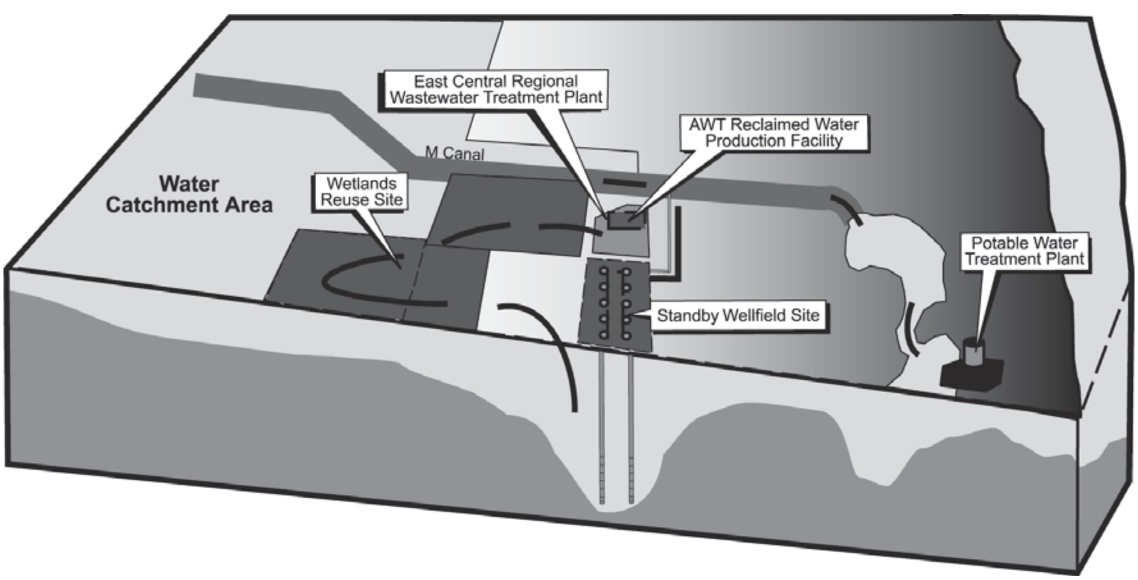
To protect and preserve its surface water supply system and to develop this reuse system to augment the water supply, the City purchased a 1,500-acre (607-hectare) wetland reuse site. This site consists of a combination of wetlands and uplands. A portion of this property was used for the construction of a standby wellfield. The standby wellfield site covers an area of 323 acres (131 hectares) and consists of wetlands and uplands dominated by Melaleuca trees. Two important goals of the project were to: (1) develop an advanced wastewater treatment facility at the ECRWWTP that could produce reclaimed water that, when discharged, would be compatible with the hydrology and water quality at the wetland reuse site, and (2) produce a reliable water supply to augment the City's surface water supply. Treatment was to be provided by the reclaimed water production facility, wetlands, and through aquifer recharge. Groundwater withdrawal would meet drinking water and public health standards. Monitoring was performed at the wetland reuse site from July 1996 to August 1997. The purpose of this monitoring was to establish baseline conditions in the wetlands prior to reclaimed water application and to determine the appropriate quality of the reclaimed water that will be applied to the wetland reuse site. In addition to the monitoring of background hydrology, groundwater quality, and surface water quality, the baseline-monitoring program investigated sediment quality, vegetation, fish, and the presence of listed threatened and endangered plant and animal species. Groundwater samples from the wetland reuse site and the standby wellfield met the requirements for drinking water except for iron. Iron was detected in excess of the secondary drinking water standards of 0.3 mg/l at all of the wells, but not in excess of the Class III surface water quality criteria of 1.0 mg/l. Total nitrogen (TN) concentrations in the wetlands ranged from 0.67 mg/l to 3.85 mg/l with an average value of 1.36 mg/l. The concentration of total phosphorus (TP) was low throughout the wetlands, ranging from less than 0.01 to 0.13 mg/l, with an average value of 0.027 mg/l.

In 1995, the City of West Palm Beach constructed a 150,000-gpd (6.6-l/s) AWT constructed wetlands demonstration project. The goals of this project were to demonstrate that an AWT facility could produce an effluent quality of total suspended solids (TSS), 5-day carbonaceous biochemical oxygen demand ($CBOD_5$), TN, and TP goals of 5, 5, 3, and 1 mg/l, respectively, and that wetlands could provide some additional treatment prior to discharge. The demonstration facility met the AWT goals as well as all of the surface water quality standards, state and federal drinking water standards (except for iron), and all public health standards (absence of *Cryptosporidium*, *Giardia*, enteric viruses, and coliforms).

A hydrologic model capable of simulating both groundwater flow and overland flow was constructed and calibrated to assess the hydrology, hydrogeology, and potential hydraulic conveyance characteristics within the project area. The model indicated that maintenance of viable wetlands (i.e., no extended wet or dry periods) can be achieved at the wetland reuse site, the standby wellfield, and with aquifer recharge to augment the water supply.

Reclaimed water will initially be applied to the wetland reuse site at a rate of 2 inches (5 cm) per week, which corresponds to a reclaimed water flow of approximately 6 mgd (263 l/s) over 770 acres (312 hectares) of the 1,415-acre (573-hectare) site. The results of the modeling indicate that up to 6 mgd (263 l/s) of reclaimed water can be applied to the wetland reuse site without producing more than an 8-inch (20-cm) average rise in surface water levels in the wetlands. A particle tracking analysis was conducted to evaluate the fate of discharge at the wetland reuse site and the associated time of travel in the surficial aquifer. The particle tracking analysis indicated that the travel time from the point of reclaimed

Figure 2-17. Project Flow Path



water application to the point of groundwater discharge (from the standby wellfield to the M Canal) ranged from 2 to 34 years. The M Canal flows into the City's surface water reservoir.

Based on the results of the demonstration project, a 10-mgd (438-l/s) reclaimed water facility was designed with operational goals for TN and TP of less than 2.0 mg/l and 0.05 mg/l (on an annual average basis) respectively, in order to minimize change in the wetland vegetation. A commitment to construction and operation of a high-quality reclaimed water facility has been provided to meet these stringent discharge requirements.

Public participation for this project consisted of holding several tours and meetings with regulatory agencies, public health officials, environmental groups, media, and local residents from the early planning phases through project design. Brochures describing the project drivers, proposed processes, safety measures, and benefits to the community were identified. A public relations firm was also hired to help promote the project to elected officials and state and federal policy makers.

2.7.18 Types of Reuse Applications in Florida

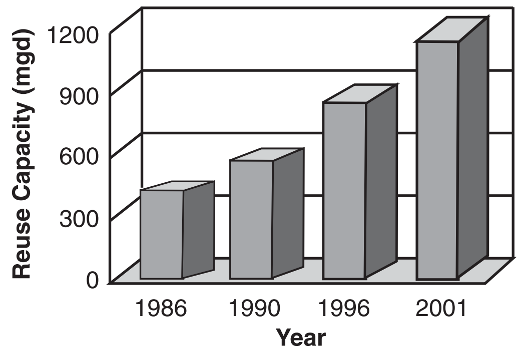
Florida receives an average of more than 50 inches (127 cm) of rainfall each year. While the state may appear to have an abundance of water, continuing population growth, primarily in the coastal areas, contributes to increased concerns about water availability. The result is increased emphasis on water conservation and reuse as a means to more effectively manage state water resources (FDEP, 2002a).

By state statute, Florida established the encouragement and promotion of water reuse as formal state objectives (York *et al*., 2002). In response, the Florida Department of Environmental Protection (FDEP), along with the state's water management districts and other state agencies, have implemented comprehensive programs designed to achieve these objectives.

As shown in **Figure 2-18**, the growth of reuse in Florida during 1986 to 2001 has been remarkable (FDEP, 2002b). In 2001, reuse capacity totaled 1,151 mgd (50,400 l/s), which represented about 52 percent of the total permitted capacity of all domestic wastewater treatment facilities in the state. About 584 mgd (25,580 l/s) of reclaimed water were used for beneficial purposes in 2001.

The centerpiece of Florida's Water Reuse Program is a detailed set of rules governing water reuse. Chapter 62-610, Florida Administrative Code (Florida DEP, 1999), includes discussion of landscape irrigation, agricultural irrigation, industrial uses, groundwater recharge, indirect potable reuse, and a wide range of urban reuse activities. This rule also addresses reclaimed water ASR, blending of demineralization concentrate with reclaimed water, and the use of supplemental water supplies.

Figure 2-18. Growth of Reuse in Florida



Source: Florida DEP, 2002b

Given the complexity of the program and the number of entities involved, program coordination is critical. The Reuse Coordinating Committee, which consists of representatives of the Florida DEP, Florida's 5 water management districts, Florida Department of Health, the Public Service Commission, Florida Department of Agriculture and Consumer Services and Florida Department of Community Affairs, meets regularly to discuss reuse activities and issues. In addition, permitting staffs from the water management districts and the Florida DEP meet regularly to discuss local reuse issues and to bring potential reclaimed water users and suppliers together. Indeed, statutory and rule provisions mandate the use of reclaimed water and implementation of reuse programs (York *et al*., 2002).

Florida's Water Reuse Program incorporates a number of innovations and advancements. Of note is the "*Statement of Support for Water Reuse*", which was signed by the heads of the agencies comprising the Reuse Coordinating Committee. EPA Region 4 also participated as a signatory party. The participating agencies committed to encouraging, promoting, and facilitating water reuse in Florida.

In addition, working as a partner with the Water Reuse Committee of the Florida Water Environment Association, Florida DEP developed the "*Code of Good Practices for Water Reuse*." This is a summary of key management, operation, and public involvement concepts that define quality reuse programs.

As outlined in the Water Conservation Initiative (FDEP, 2002a), the future of Florida's Water Reuse Program will be guided by the need to ensure that reclaimed water is used efficiently and effectively in Florida (York *et al*., 2002). The Water Conservation Initiative report contains 15 strategies for encouraging efficiency and effectiveness in the Water Reuse Program.

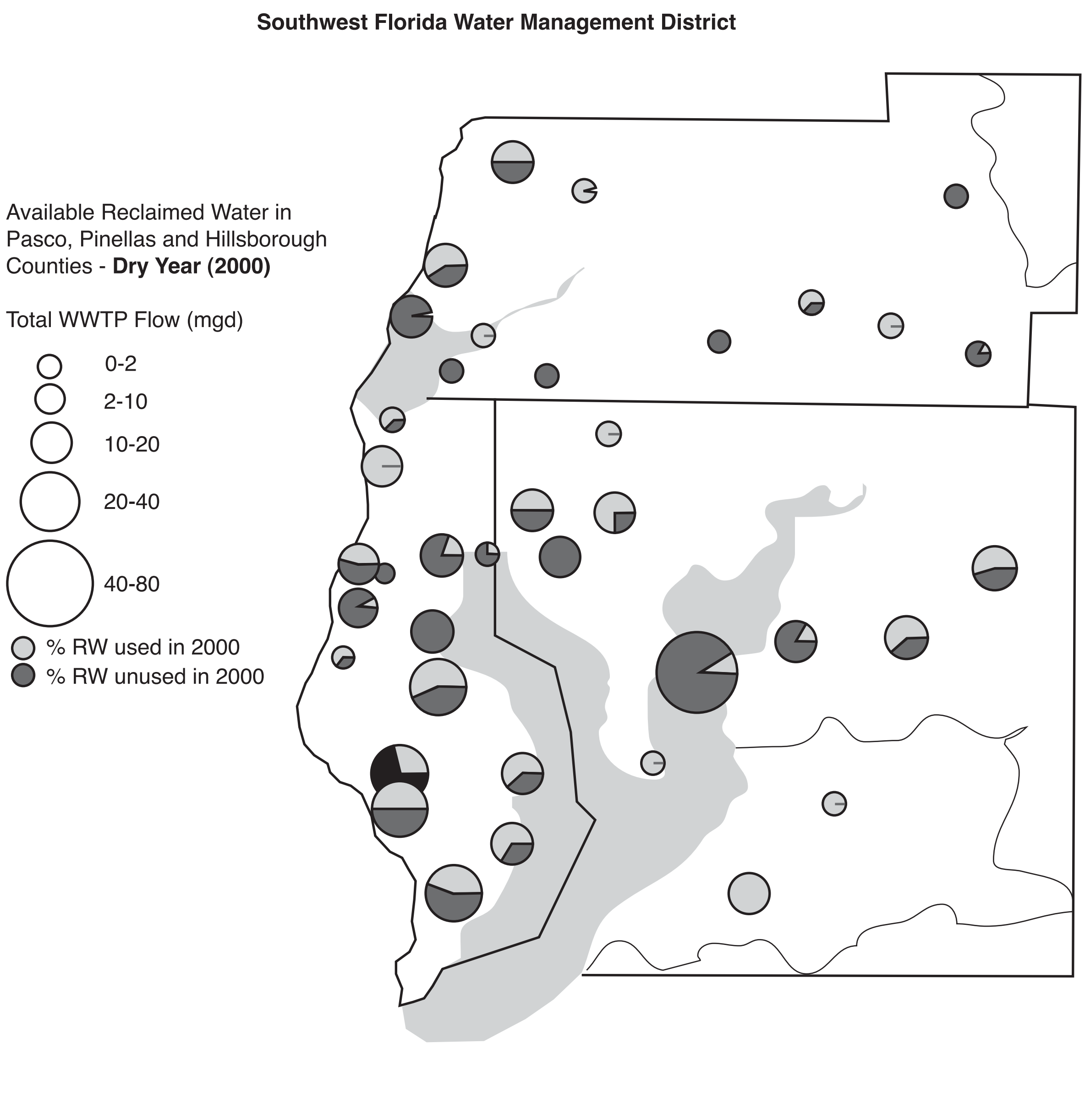
2.7.19 Regionalizing Reclaimed Water in the Tampa Bay Area

The Southwest Florida Water Management District (SWFMWD) is one of 5 water management districts in the state responsible for permitting groundwater and surface water withdrawals. The Tampa Bay area is within the SWFWMD and has experienced prolonged growth that has strained potable water supplies. A profile of the Tampa Bay area is given below:

- Home to nearly 2.5 million people who live in the 3 counties (Pasco, Hillsborough, and Pinellas) referred to as the Tampa Bay area.

- The largest water user group in the Tampa Bay area is the public, using 306.2 million mgd (13,410 l/s), representing 64 percent of the water total use in the area in the year 2000. There are 38 wastewater treatment facilities in the Tampa Bay area operated by 19 public and private utilities. In 2000 these facilities:

Figure 2-19. Available Reclaimed Water in Pasco, Pinellas, and Hillsborough Counties



- Produced an annual average of 201 mgd (8,800 l/s) of treated wastewater.

- 73 mgd (3,200 l/s) of reclaimed water was used for beneficial purposes, representing 36 percent use of available flows.

- Of the 73 mgd (3,200 l/s), 44 mgd (1,930 l/s) (60 percent) of reclaimed water replaced the use of traditional, high-quality (potable) water resources.

As the regulatory authority responsible for managing water supplies in the region, SWFWMD views the offset achieved through use of reclaimed water as an important contribution to the regional water supply. The District's "*Regional Water Supply Plan"* includes a goal to effectively use 75 percent of available reclaimed water resources in order to offset existing or new uses of high quality water sources. The objectives to meet the goal by 2020 or earlier are collectively designed to enhance the use and efficiency of reclaimed water by:

- Maximizing reclaimed water locally to meet water demands in service areas

- Increasing the efficiency of use through technology for dealing with wet-weather flows and demand management (i.e., meters, education, etc.)

- Interconnecting systems to move excess flows to areas where the water is needed, when it is needed, for a regional water resource benefit

There is not enough reclaimed water in the Tampa Bay area to meet all of the irrigation and other needs in the region. However, there are opportunities to transport excess reclaimed water flows that cannot be used locally to achieve benefits to areas of high demand or other beneficial uses, such as natural system restoration. As a first step in evaluating how reclaimed water may be used in the Tampa Bay Area, the SWFWMD developed an inventory of existing water reclamation facilities, their locations, total flow and flows already committed to beneficial reuse, and flows that might be available for an expanded reuse program (**Figure 2-19**). Subsequent planning efforts will build on this information to evaluate interconnections between reuse systems for optimal use.

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National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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