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Manual

Guidelines for Water Reuse

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CHAPTER 1

Introduction

With many communities throughout the world approaching or reaching the limits of their available water supplies, water reclamation and reuse has become an attractive option for conserving and extending available water supplies. Water reuse may also present communities an opportunity for pollution abatement when it replaces effluent discharge to sensitive surface waters.

Water reclamation and nonpotable reuse only require conventional water and wastewater treatment technology that is widely practiced and readily available in countries throughout the world. Furthermore, because properly implemented nonpotable reuse does not entail significant health risks, it has generally been accepted and endorsed by the public in the urban and agricultural areas where it has been introduced.

1.1 Objectives of the *Guidelines*

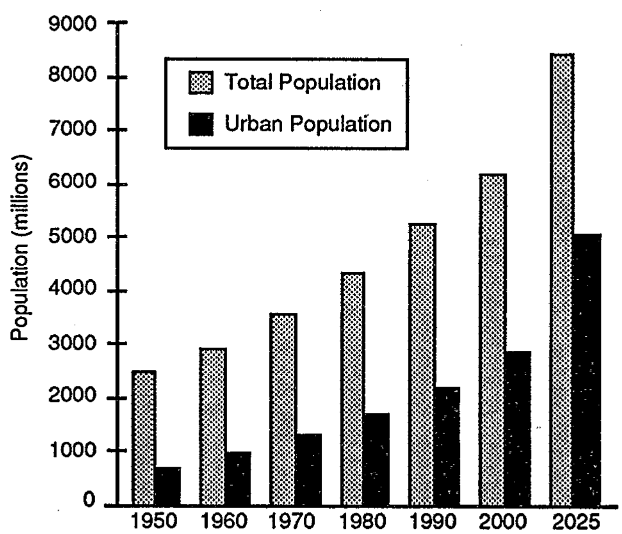
Water reclamation for nonpotable reuse has been adopted in the United States and elsewhere without the benefit of national or international guidelines or standards. However, in recent years, many states in the U.S. have adopted standards or guidelines, and the World Health Organization (WHO) has published guidelines for reuse for agricultural irrigation. The primary purpose of this document is to present guidelines, with supporting information, for utilities and regulatory agencies in the U.S. In states where standards do not exist or are being revised or expanded, the *Guidelines* can assist in developing reuse programs or appropriate regulations. The *Guidelines* will also be useful to consulting engineers and others involved in the evaluation, planning, design, operation, or management of water reclamation and reuse facilities. In addition, a section on reuse internationally is offered to provide background and discuss relevant issues for authorities in other countries where reuse is being considered. The document does not propose standards by either the U.S. Environmental Protection Agency (EPA) or the U.S. Agency for International Development (AID). In the U.S., water reclamation and reuse standards are the responsibility of state agencies.

These guidelines primarily address water reclamation for nonpotable urban, industrial, and agricultural reuse, about which little controversy exists. Also, attention is given to augmentation of potable water supplies by indirect reuse. Because direct potable reuse is not currently practiced in the U.S., only a brief overview is provided.

1.2 Water Demands

Demands on water resources for household, commercial, industrial, and agricultural purposes are increasing greatly, and the situation is exacerbated by growing urbanization. According to a United Nations report (United Nations, 1989), while world population will have grown 150 percent over the second half of the 20th century, the urban population will have grown 300 percent, with almost half the total population living in cities by the year 2000 (Figure 1).

Figure 1. Actual and Projected World Population

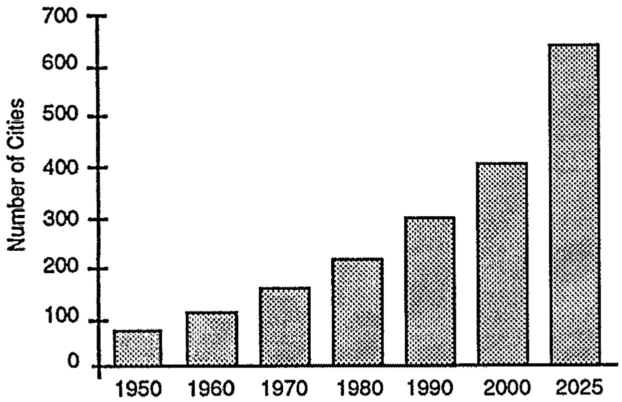


Source: UN, 1989.

Also, the number of large cities is growing rapidly (Figure 2). While fewer than 80 cities exceeded 1 million in population in 1950, by 1990 the number had grown to almost 300 and was projected to exceed 400 by the end of the century (United Nations, 1985).

Although rural populations can usually find the water they need locally, urban populations need to draw water from large drainage areas or extensive aquifers. Most cities have already fully exploited the readily available water resources and are now obliged to develop and treat sources of lower quality or go long distances to develop new supplies, both costly options.

Figure 2. **Growth of Cities of >1 Million Population**



Source: UN, 1985.

Furthermore, while people in rural communities can often dispose of their wastewaters satisfactorily on site, cities must generally discharge their wastewaters into nearby water courses, which requires adequate wastewater treatment prior to disposal to prevent water quality degradation and protect public health.

1.3 Source Substitution

The use of reclaimed water for nonpotable purposes offers the potential for exploiting a "new" resource that can be substituted for existing sources. By "source substitution" — replacing the potable water used for nonpotable purposes — an increased population can be served from an existing source.

Source substitution is not a new idea. In 1958, the United Nations Economic and Social Council enunciated a policy that "No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade" (United Nations, 1958). With the growth and increased density of populations, few cities now enjoy a surplus of high quality water; if they do, this surplus can be expected soon to be exhausted.

Many urban residential, commercial, and industrial uses can be satisfied with water of less than potable water quality: irrigation of lawns, parks, roadway borders and medians; air conditioning and industrial cooling towers; stack gas scrubbing; industrial processing; toilet and urinal flushing; construction; cleansing and maintenance, including vehicle washing; scenic waters and fountains; and environmental and recreational purposes. Customarily, public water supplies are designed to provide water of potable quality to serve all these purposes.

EPA policy states that "Because of human frailties associated with protection, priority should be given to selection of the purest source" (EPA, 1976). When the demand exceeds the capacity of the purest source, and additional sources are unavailable or available only at a high cost, a lower quality water can be substituted to serve the nonpotable purposes. In some coastal cities, such as Hong Kong, seawater has been substituted for high quality fresh water for toilet flushing. In the British midlands, highly polluted Trent River water has been used for industrial purposes in place of high quality sources. In many instances, however, treated wastewater from the city to be served, or a nearby city, may provide the most economical and/or available substitute source.

Understandably, the construction of reclaimed water transmission and distribution lines to existing users in large cities is likely to be expensive and disruptive. When retrofitting an urban area for water reuse, supplying large users can reduce system development costs. In Baltimore, Maryland, for example, a water reuse system was built in 1936 to serve a single large user, the Sparrows Point steel plant of the Bethlehem Steel Company. In 1942, 4.5 mi (7.3 km) of 96-inch (244 cm) pipeline was built from the Baltimore Back River activated sludge plant to the steel plant to provide 100 mgd (4,380 L/s) of water that would otherwise have come from a fresh water supply source (Okun, 1990).

Once established, reuse programs initially developed for large users may be extended to serve a more diverse customer base. Such was the case in St. Petersburg, Florida, where the reclaimed water lines were initially installed in 1977 to serve the irrigation needs of large commercial customers. By 1990, however, the reclaimed water system had grown to serve more than 6,000 single-family residential customers. The conservation benefits of source substitution are clearly underscored by the St. Petersburg system; the city has experienced about

10 percent population growth since 1976 without substantial increase in potable water demand (Eingold and Johnson, 1984).

The economics of source substitution with reclaimed water are site specific, depending on the marginal costs of new sources of high quality water and the costs of treatment and disposal of wastewaters. The reclamation and reuse of wastewaters will likely be most attractive in serving new residential, commercial, and industrial areas of a city, where the installation of dual distribution mains and dual building services would be far more economical than in already developed areas.

Reuse of reclaimed water for agricultural purposes near urban areas can also be economically attractive. Agricultural users are usually willing to make long-term commitments, often for as many as 20 years, to use large quantities of reclaimed water instead of fresh water sources.

One potential scenario is to provide a new reclaimed water system to serve agricultural needs outside the city with the expectation that when urban development replaces agricultural lands in time, reclaimed water use can be shifted from agricultural to urban needs. For example, in Orange County, California, the Irvine Ranch Water District currently provides reclaimed water to irrigate urban landscape and mixed agricultural lands. As agricultural land use is displaced by residential development in this growing urban area, the district has the flexibility to convert its reclaimed water service from agricultural to urban irrigation (Parsons, 1990).

Under the Safe Drinking Water Act, EPA has established maximum contaminant limits (MCLs) to control organic, inorganic, microbiological and radioactive contaminants in public drinking water supplies and is obliged to add about 25 more every three years. Also, most MCLs are becoming even more stringent over time. The costs to supply water for drinking and other potable uses will increase in the future to the point that economic analyses for specific locales may dictate changes in the way that nonpotable uses are satisfied, (i.e., by reclaimed water in dual distribution systems).

1.4 Pollution Abatement

While the need for additional water supply has indeed been the impetus for numerous water reclamation and reuse programs in arid and semi-arid areas, many programs in the U.S. were initiated in response to rigorous and costly requirements for effluent discharge to surface waters, particularly the removal of nitrogen and phosphorus. By eliminating effluent discharges for all or even a portion of the year through water reuse, a municipality may be able to avoid or reduce the need for the costly advanced wastewater treatment processes. For most nonpotable reuse applications, nutrient removal is unnecessary and actually contraindicated for irrigation.

The purposes and practices may differ between water reuse programs developed strictly for pollution abatement and those developed for water resources or conservation benefits. When systems are developed chiefly for the purpose of land application for wastewater treatment and/or disposal, the objective is to dispose of as much effluent on as little land as possible; thus, application rates are often greater than irrigation demands. On the other hand, when the reclaimed water is considered a valuable resource, the objective is to apply the water according to irrigation needs.

Differences are also apparent in the distribution of reclaimed water for these different purposes. Where disposal is the objective, meters are difficult to justify, and reclaimed water is often distributed at a flat rate or at minimal cost to the users. Where reclaimed water is intended to be used as a water resource, however, metering is appropriate to provide an equitable method for distributing the resource, limiting its waste, and recovering the costs. In St. Petersburg, Florida, where disposal was the original objective, the reclaimed water became an important resource and meters, which were not provided initially, are now being installed to prevent waste of the reclaimed water.

Naturally, a water reuse program can easily serve both water conservation and pollution abatement purposes. However, the scope of the *Guidelines* has focused on water reuse programs for resource management. Ample other sources exist for designing land treatment systems; most notably, EPA's *Process Design Manual on Land Treatment of Municipal Wastewater* (EPA, 1981 and 1984) provides a complete discussion of the design requirements for such systems.

1.5 Treatment and Water Quality Considerations

The overriding consideration in developing a reuse system is that the quality of the reclaimed water be appropriate for its intended use. Higher level uses, such as irrigation of public-access lands or vegetables to be consumed without processing require a higher level of wastewater treatment prior to reuse than will lower level uses, such as pasture irrigation.

In urban settings, where there is a high potential for human exposure to reclaimed water used for landscape irrigation, industrial purposes, toilet flushing, and many other purposes, there must be minimum hazard. According to Okun (1990), the most important water quality objective for such uses is that the water be adequately disinfected and that a chlorine residual be maintained in the distribution system. The reclaimed water must be clear, colorless, and odorless to ensure that it is aesthetically acceptable to the users and the public at large. Research by the Sanitation Districts of Los Angeles County (1977) has demonstrated that a high-quality secondary effluent, treated with small doses of either coagulant, polymer, or both; direct conventional sand filtration; and chlorine disinfection can easily and continuously provide a satisfactory product.

Several states have published standards or guidelines for one or more types of water reuse (See Section 4.1). Some of these states require specific treatment processes, others impose effluent quality criteria, and some require both. All of the states that have water reclamation criteria require disinfection for high-level uses and limits for either total or fecal coliform organisms (See Tables A-1 to A-8 in Appendix A).

Many states also include requirements for treatment reliability to prevent the distribution of any reclaimed water that may not be adequately treated because of a process upset, power outage, or equipment failure. Reliability requirements typically include provisions for alarms, standby power supplies, multiple or standby unit treatment processes, emergency storage or disposal provisions, and standby replacement equipment. A strict industrial pretreatment program is also necessary to ensure the reliability of the biological treatment processes by excluding potentially toxic levels of pollutants from the sewer system. Wastewater treatment facilities receiving substantial amounts of high-strength industrial wastes may be limited in the number and type of suitable reuse applications.

Dual distribution systems (i.e., reclaimed water distribution systems that parallel a potable water system) must also incorporate safeguards to prevent cross connections of reclaimed water and potable water lines and misuse of reclaimed water. For example, piping, valves, and hydrants are marked or color-coded to differentiate reclaimed water from potable water, backflow prevention devices are installed, and hose bibbs on reclaimed water lines may be prohibited to preclude the likelihood of incidental human contact.

1.6 Overview of the Guidelines

This document, the *Guidelines for Water Reuse,* is an update of the *Guidelines for Water Reuse* developed for EPA by Camp Dresser & McKee Inc. (CDM) in 1980. Funded under the co-sponsorship of EPA and the U.S. Agency for International Development (AID) through its global Water and Sanitation for Health (WASH) program, the updated and expanded guidelines reflect the significant technical and institutional developments in water reuse over the last decade and include consideration of the special needs for water reuse applications in other countries.

The *Guidelines* provide information for evaluating the requirements and potential benefits of water reuse systems, covering the key issues needed to evaluate water reclamation and reuse opportunities, assess the costs and benefits for reuse alternatives, and plan and implement a water reuse system. Major technical and non-technical issues are identified and discussed, drawing upon the experiences of those with water reuse programs.

The document has been arranged by issues, devoting separate chapters to each of the key technical, financial, legal and institutional, and public involvement considerations that a reuse planner might face. A separate chapter has also been provided to discuss reuse applications in other countries. These chapters are:

- **Chapter 2, Technical Issues in Planning Water Reuse Systems -** An overview of the potential uses of reclaimed water, the sources of reclaimed water, treatment requirements, seasonal storage requirements, and supplemental system facilities, including conveyance and distribution, operational storage, and alternative disposal systems.

- **Chapter 3, Types of Reuse Applications -** Urban, industrial, agricultural, recreational and habitat restoration/enhancement, groundwater recharge and augmentation of potable supplies. Direct potable reuse is also briefly discussed.

- **Chapter 4, Water Reuse Regulations and Guidelines in the U.S. -** Existing U.S. regulations, state standards and guidelines, and recommended guidelines.

- **Chapter 5, Legal and Institutional Issues -** Reuse ordinances, user agreements, water rights, franchise law, and case law.

- **Chapter 6, Funding Alternatives** - Funding and cost recovery options for reuse system construction and operation. Management issues for utilities.

- **Chapter 7, Public Information Programs** - Strategies for educating and involving the public in water reuse system planning and reclaimed water use.

- **Chapter 8, Water Reuse Outside the U.S.** - Water reuse systems in other countries, with an assessment of the differences between practices in the U.S. and elsewhere. Examples from a wide variety of countries are presented.

1.7 References

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CHAPTER 2

Technical Issues In Planning Water Reuse Systems

The technical issues involved in planning a water reuse system include:

- The identification and characterization of potential demands for reclaimed water;
- The identification and characterization of existing sources of reclaimed water to determine their potential for reuse;
- The treatment requirements for producing a safe and reliable reclaimed water that is suitable for its intended applications;
- The storage facilities required to balance seasonal fluctuations in supply with fluctuations in demand;
- The supplemental facilities required to operate a water reuse system, such as conveyance and distribution networks, operational storage facilities, and alternative disposal facilities; and
- The potential environmental impacts of implementing water reclamation.

The technical issues in this section apply broadly to most reuse applications. Technical issues of concern in specific reuse applications are discussed in Chapter 3, "Types of Reuse Applications."

2.1 Planning Approach

One goal of the *Guidelines for Water Reuse* is to outline a systematic approach to planning for reuse, so that planners can make sound preliminary judgments about the local feasibility of reuse–taking into account the full range of important issues that have been addressed in implementing earlier programs or that might be encountered in future programs.

Figure 3 illustrates a ~~three-phased~~ approach to reuse planning that groups reuse planning activities into successive stages of preliminary investigations, screening of potential markets, and detailed evaluation of selected markets. Through all of these stages, public involvement efforts provide guidance to the planning process, and from the very outset steps will be taken that will support project implementation should reuse prove to be feasible. Each stage of activity builds on previous stages until enough information is available to develop a conceptual reuse plan and to begin negotiating the details of reuse with selected users.

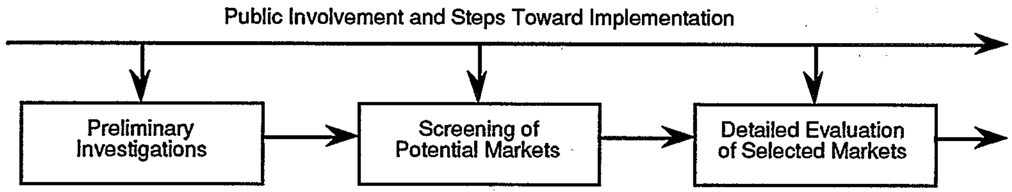
2.1.1 Preliminary Investigations

This is a fact-finding phase, meant to rough out physical, economic, and legal bounds to the water reuse plan. The primary task is to locate all potential sources of effluent for reclamation and reuse and all potential markets for this reclaimed water. It is also important to identify institutional constraints and enabling powers that might affect reuse. This phase should be approached with a broad view. Exploration of all possible options at this early stage in the planning program will both establish a practical context for the plan and help to avoid creating dead-ends in the planning process.

The questions to be addressed in this phase include:

- What local sources of effluent might be suitable for reuse?
- What are the potential local markets for reclaimed water?
- What public health considerations are associated with reuse, and how can these be addressed?
- What are the potential environmental impacts of water reuse?

Figure 3. Phases of Reuse Program Planning



- How would water reuse "fit in" with present uses of other water resources in the area?
- What are the present and projected user costs of fresh water in the area?
- What existing or proposed laws and regulations affect reuse possibilities in the area?
- What local, state or federal agencies must review and approve implementation of a reuse program?
- What are the legal liabilities of a purveyor or user of reclaimed water?
- What sources of funding might be available to support the reuse program?
- What reuse system would attract the public's interest and support?

The major task of this phase involves preliminary market assessment, as represented in the second question above. This involves defining the water market, probably through discussions with water wholesalers and retailers, and identifying major water users in the market. Initial contact by telephone and follow-up letter will probably be necessary to determine what portion of total water use might be satisfied by reclaimed water, what quality of water is required for each type of use, and how use of reclaimed water might affect the user's operations or discharge requirements.

Obviously, it will be important, even at this early stage, to develop good working relationships among wastewater managers, water supply agencies, and potential reclaimed water users. Potential users will be concerned with the quality of reclaimed water and reliability of its delivery; they will also want to know state and local regulations that apply to use of reclaimed water, and constraints such as hookup costs or additional wastewater treatment costs that might affect their ability to use the product.

2.1.2 Screening of Potential Markets

The essence of this phase is a comparison between the unit costs of fresh water to a given market and the unit costs of reclaimed water to that same market. On the basis of information gathered in preliminary investigations, one or more "intuitive projects," may be developed that are obvious possibilities or that just "seem to make sense." For example, if a large water-using industry is located next to a wastewater treatment plant, there exists a strong potential for reuse: the industry has a high demand for water, and costs of conveying reclaimed water would be low. But the value of reclaimed water — even to such an "obvious" potential user — will depend on:

- The quality of water to be provided, as compared to the user's requirements;
- The quantity of water available, and the ability to meet fluctuating demand;
- The effects of laws that regulate this reuse, and the attitudes of agencies responsible for enforcing applicable laws; and
- The present and projected future cost of fresh water to this user.

These questions all involve detailed study, and it lies beyond the capacities of most public entities to apply the required analyses to every reuse possibility in their areas. A useful first step is to identify a wide range of candidate reuse systems that might be suitable in the area and then to "screen" these alternatives down to a handful of promising project alternatives for detailed evaluation. In order to establish the most complete list of reuse possibilities, not only the different types of reuse that could improve use of water resources should be considered, but also such factors as:

- Different levels of treatment — if advanced wastewater treatment (AWT) is currently required prior to discharge of effluent, there might be cost savings available if a market exists for secondary effluent.

- Different project sizes — the scale of reuse can range from conveyance of reclaimed water to a single user to the general distribution of reclaimed water for a variety of nonpotable uses;

- Different conveyance networks — different distribution routes will have different advantages, taking better advantage of existing rights-of-way, for example, or serving a greater number of users.

In addition to a comparison of the overall costs estimated for each alternative, several other criteria can be factored into the screening process. The East Bay Dischargers Authority in Oakland, California, used demonstrated technical feasibility as one criterion, and the comparison of estimated unit costs of reclaimed water with unit costs of fresh water, as another (Murphy and Lee, 1979). East Bay Municipal Utility District, also of Oakland, used an even more complex screening process (East Bay Municipal Utility District, 1979) that included comparison of weighted values for a variety of objective and subjective factors, such as:

- How much flexibility would each system offer for future expansion or change?

- How much use of fresh water would be replaced by each system?

- How complicated would program implementation be, given the number of agencies that would be involved in each proposed system?

- To what degree would each system advance the "state-of-the-art" in reuse?

- What level of chemical or energy use would be associated with each system?

- How would each system affect land use in the area?

Review of user requirements could enable reduction of the list of potential markets to a few selected markets for which reclaimed water could be of significant value.

2.1.3 Detailed Evaluation of Selected Markets

The evaluation steps contained in this phase represent the heart of the analyses necessary to shape a reuse program. Following the screening steps above, a ranking of "most-likely" projects will be established, and the present fresh water consumption and costs for selected potential users will be known. In this phase, by looking in more detail at the conveyance routes and storage requirements of each selected system, the preliminary cost estimates for delivering reclaimed water to these users can be refined. Funding options can be compared, user costs developed, and a comparison made between the unit costs of fresh water and of reclaimed water for each selected system. It will be possible also to evaluate in more detail the environmental, institutional and social aspects of each project. Questions that may need to be addressed include the following:

- What are the specific water quality requirements of each user? What fluctuation can be tolerated?

- What is the daily and seasonal water use demand pattern for each potential user?

- Can fluctuations in demand best be met by pumping capacity or by storage? Where would storage facilities best be located?

- If additional treatment of the effluent is required, who should own and operate the additional treatment facilities?

- What costs will the users in each system incur in connecting to the reclaimed water delivery system?

- Will industrial users in each system face increased treatment costs for their waste streams as a result of using reclaimed water? If so, is increased internal recycling likely, and how will this affect their water use?

- Will water customers in the service area allow project costs to be spread over the entire service area?

- What interest do potential funding agencies have in supporting each type of reuse program being considered? What requirements would they impose on a project eligible for funding?

- Will use of reclaimed water force agricultural users to alter irrigation patterns or to provide better control of return flows?

- What payback period is acceptable to users who must invest in additional facilities for onsite treatment, storage or distribution of the reclaimed water?

- What are the prospects of industrial source control measures in your area, and would institution of such measures reduce the additional treatment steps necessary to permit reuse?

- How "stable" are the potential users in each selected candidate reuse system? Are they likely to remain in their present locations? Are process changes being considered that might affect their ability to use reclaimed water?

As is apparent, many of these questions can be answered only after further consultation with water supply agencies and prospective users. Both groups may seek more detailed information as well, including the preliminary findings made in the first two phases of effort.

The detailed evaluations should lead to a preliminary assessment of technical feasibility and costs. Comparison among alternative reuse programs will be possible, as well as preliminary comparison between these programs and alternative water supplies, both existing and proposed. In this phase, economic comparisons, technical optimization steps, and environmental assessment activities leading to a conceptual plan for reuse might be accomplished by working in conjunction with appropriate consulting organizations.

2.2 Potential Uses of Reclaimed Water

Urban public water supplies are treated to satisfy the requirements for potable use. However, potable use (drinking, cooking, bathing, laundry and dishwashing) represents only a fraction of the total daily residential use of treated potable water. The remainder may not require water of potable quality. In many cases, water used for nonpotable purposes, such as irrigation, may be drawn from the same ground or surface source as municipal supplies, creating an indirect demand on potable supplies. The *Guidelines* examine opportunities for substituting reclaimed water for potable water or potable supplies for uses where potable water quality is not required. Specific water use categories where reuse opportunities exist include:

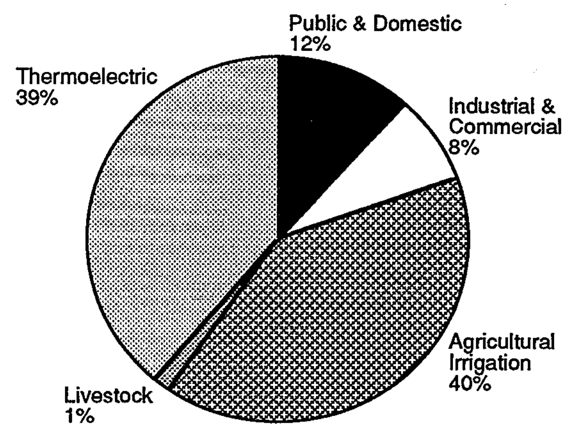
- Urban
- Industrial
- Agricultural
- Recreational
- Habitat restoration/enhancement, and
- Groundwater recharge.

The technical issues associated with the implementation of each of these reuse alternatives are discussed in detail in Chapter 3. The use of reclaimed water to provide both direct and indirect augmentation of potable supplies is also presented in Chapter 3.

2.2.1 National Water Use

Figure 4 presents the national pattern of water use according to the U.S. Geological Survey (Solley *et al.*, 1988). The largest water demands are associated with agricultural irrigation and thermoelectric generation, representing 40 percent and 39 percent respectively of the total water use in the United States. Public and domestic water users constitute 12 percent of the total demand. The remainder of the water use categories are industrial and commercial with 8 percent of the demand and livestock with 1 percent of the demand.

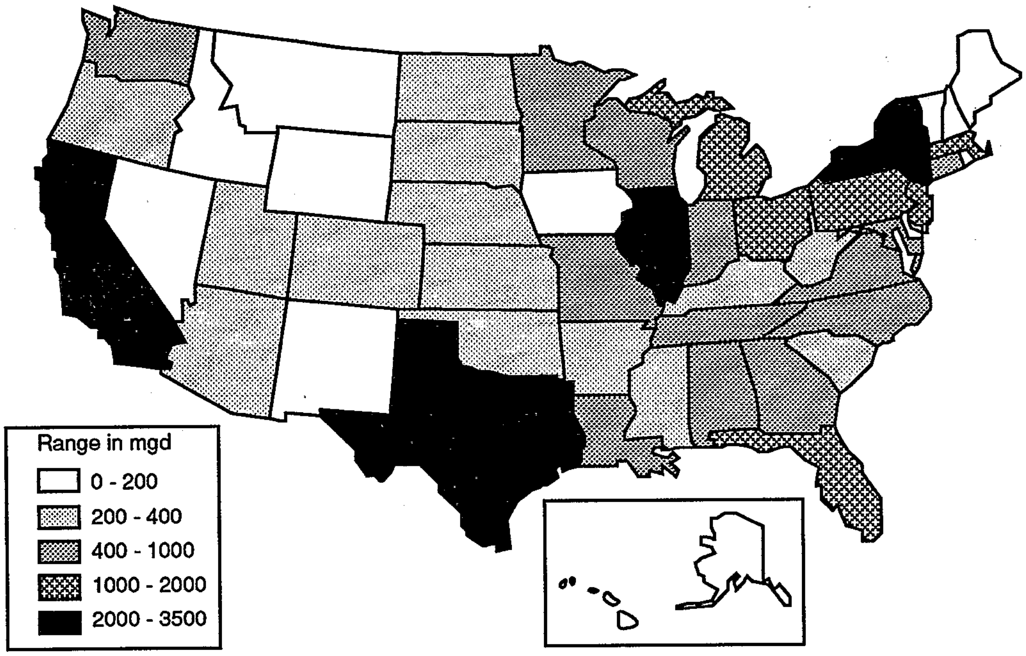
Figure 4. U.S. Fresh Water Demands by Major Uses, 1985



Source: Solley *et al.*, 1988.

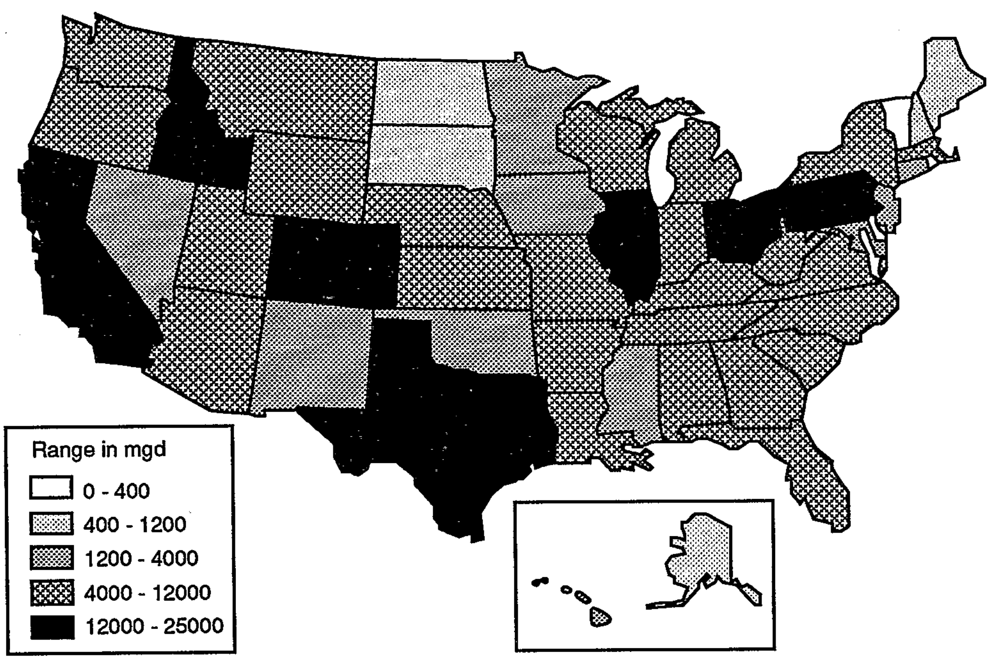
Figure 5 shows estimated wastewater effluent produced daily in each state, representing the total potential reclaimed water supply from existing wastewater treatment facilities. Figure 6 shows the estimated water demands by state in the United States. Areas of high water demands might benefit by augmenting their existing water supplies with reclaimed water. Municipalities in coastal and arid states, where water

Figure 5. **Total Treated Wastewater Design Flows by State**



Source: EPA, 1991.

Figure 6. **Total Fresh Water Demands by State, 1985**



Source: Adapted from Solley *et al.*, 1988 demands are high and fresh water supplies are limited, appear to have a reasonable supply of wastewater effluent that could, through proper treatment and reuse, greatly extend their water supplies.

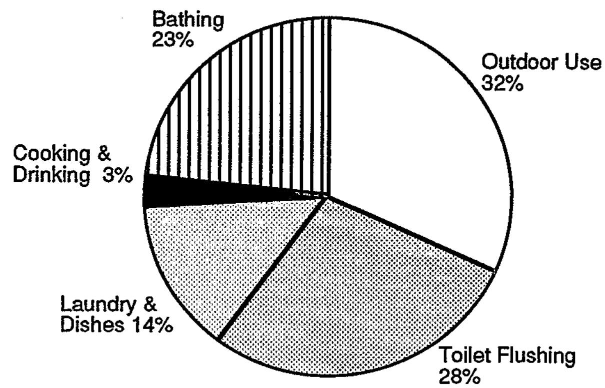
The arid states of the southwestern United States are obvious candidates for wastewater reclamation, and indeed significant reclamation projects are underway throughout this region. However, this macroscopic view can obscure local opportunities that may exist for a given municipality to benefit from reuse by: (1) extending local water supplies, and/or (2) reducing or eliminating surface water discharge. For example, the City of Atlanta, located in the relatively water-rich southeast, has experienced water restrictions as a result of recurrent droughts. In south Florida, subtropical conditions and almost 55 in/yr (140 cm/yr) of rainfall suggest an abundance of water; however, cultural practice and regional hydrogeology combine to result in frequent water shortages and restrictions on water use. Thus opportunities for water reclamation and reuse must be examined on a local level to judge their value and feasibility.

2.2.2 Potential Reclaimed Water Demands

The average total water usage in an urban potable water system is approximately 180 gal (680 L)/capita/d, of which 120 gal (450 L)/capita/d is for combined residential and public uses (Grisham and Fleming, 1989). This includes potable-quality water used extensively for purposes not requiring this high quality, such as toilet flushing, vehicle washing, industrial process and cooling water, general washdown, and landscape irrigation. Depending on the location of a community, the actual potable water requirement may range from 11 percent to 60 percent of the total water demand (American Water Works Association, 1983).

Residential water demand can further be categorized as indoor use, which includes toilet flushing, cooking, laundry, bathing, dishwashing and drinking, or outdoor use, which consists primarily of landscape irrigation. Outdoor use accounts for approximately 32 percent of this residential demand, while indoor use represents approximately 68 percent. (Sanders and Thurow, n.d.). Figure 7 presents the average residential water use by category. It should be noted that these are national averages and few residential households will actually match these figures. These estimates also show that the potable use (cooking, drinking, bathing, laundry and dishwashing) represents only about 40 percent of the total average residential demand. Reclaimed water could be used for the remaining 60 percent.

Figure 7. Average Residential Water Usage by Type of Use

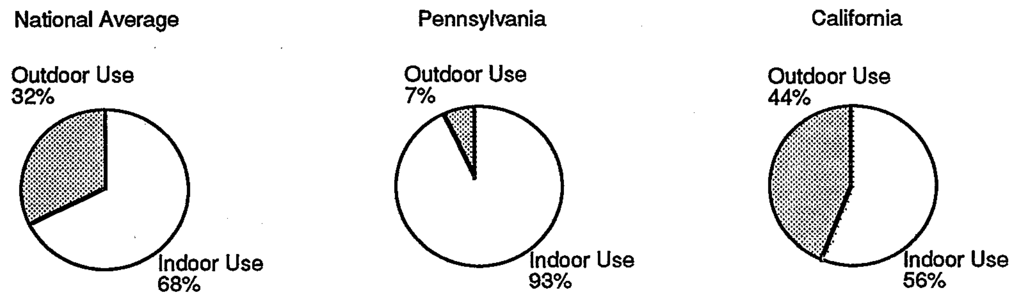


Source: Sanders and Thurow, n.d.

Outdoor residential water usage varies widely depending on the geographical area and season. On an annual average basis, outdoor use in the arid West and Southwest represents a much higher percentage of the total residential demand than in areas of the Midwest or East. Figure 8 compares the national average interior/exterior residential water usage to that for Pennsylvania and California. On an average daily basis, outdoor residential water use amounts to approximately 7 percent of the total residential demand in Pennsylvania and 44 percent in California (American Water Works Association, 1983). The largest portion of this use is for landscape irrigation. Since potable quality water is not required for outdoor use, reclaimed water can be used to meet this demand.

The need for irrigation is highly seasonal. In the North where turf goes dormant, irrigation needs will be zero in the winter months. However, irrigation demand may represent a significant portion of the total potable water demand in the summer months. In coastal South Carolina, winter irrigation use on the potable system is estimated to be less than 10 percent of the total demand. This increases to over 30 percent in the months of June and July. In Denver, during July and August when temperatures exceed 90°F (32°C), approximately 80 percent of all potable water is used for irrigation of bluegrass lawns. On these days, Denver residents consume 500 gal (1,900 L)/capita/d compared to their annual average of 150 gal (570 L)/capita/d (Sanders and Thurow, n.d.). Given the seasonal nature of urban irrigation, eliminating this demand from the potable system through reuse will result in a net annual reduction in potable demands and, more importantly, may also significantly reduce peak month potable water demands.

Figure 8. **Average Daily Residential Water Usage Comparison: National, Pennsylvania, & California**



Sources: Sanders and Thurow, n.d.
AWWA, 1983

It is not surprising then that landscape irrigation currently accounts for the largest urban use of reclaimed water in the United States. This is particularly true of urban areas with substantial residential areas and a complete mix of landscaped areas ranging from golf courses to office parks to shopping malls. In a "typical" American city, 70 percent of the landscaped areas surround residential properties, primarily single-family homes (University of California Division of Agricultural and Natural Resources, 1985). The urban areas also have schools, parks, and recreational facilities which require regular irrigation. Within Florida, for example, studies of potable water consumption have shown that 50 to 70 percent of all potable water produced is used for outside purposes, principally irrigation. These studies also show that more than half of the potable water demand in urban areas is used by single-family homes.

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

Agricultural irrigation, representing 40 percent of the total water demand nationwide, presents another significant opportunity for water reuse, particularly in areas where agricultural sites are near urban areas and can easily be integrated with urban reuse applications. Such is the case in Orange County, California, where the Irvine Ranch Water District currently provides reclaimed water to irrigate approximately 2,000 ac (800 ha) of urban landscape and 1,000 ac (400 ha) of mixed agricultural lands (orchards and vegetable row crops). As agricultural land use is displaced by residential development in this growing urban area, the district has the flexibility to convert its reclaimed water service to urban irrigation (Parsons, 1990).

In Manatee County, Florida, agricultural irrigation is a significant component of a county-wide water reuse program. During 1990, the county's three subregional water reclamation facilities, with a total treatment capacity of 28.8 mgd (1,260 L/s), provided about 21 mgd (920 L/s) of reclaimed water for a combination of uses that includes irrigation of golf courses, parks, a 1,500-ac (600-ha) gladioli farm, and about 6,000 ac (2,400 ha) of mixed agricultural lands (citrus, ridge and furrow crops, sod farms, and pasture). The reuse agreements with the agricultural users are for 20 years, ensuring a long-term commitment for reclaimed water with a significant water conservation benefit. The urban reuse system has the potential to grow as development grows; the county estimates that it can provide another 16 mgd (700 L/s) of reclaimed water to irrigate the lawns and landscaping of approximately 24,000 homes as wastewater flows increase with increased development (Ammerman and Heyl, 1991).

A detailed inspection of existing or proposed water use is essential for planning any water reuse system. This information is often available through municipal billing records or water use monitoring required through local or regional water management agencies. In other cases, predictive equations may be required to adequately describe water demands. Defining water needs for various reuse alternatives is explored further in Chapter 3.

2.2.3 Reuse and Water Conservation

The need to conserve the potable water supply is becoming an increasingly important part of urban and regional planning. For example, the Metropolitan Water District of Southern California has predicted that by the year 2010 water demands will exceed reliable supplies by approximately 326 billion gal (1,200 x 10^9 m^3) annually (Adams, 1990). To help conserve the potable water supplies, the Metropolitan Water District has developed a multi-faceted program that includes conservation incentives, groundwater storage, water exchange agreements, reservoir construction, and reclaimed water projects. Urban reuse of reclaimed water is an essential element of the program. In 1990, approximately 88 billion gal (330 x 10^6 m^3) of reclaimed water was used in Metropolitan's service area for groundwater recharge, landscape irrigation, and agricultural, commercial and industrial purposes. It is estimated that more than 195 billion gal (740 x 10^6 m^3) of reclaimed water will be reused by the Year 2010.

Perhaps the greatest benefit of urban reuse systems is their contribution in delaying or eliminating the need to expand potable water supply and treatment facilities. The City of St. Petersburg, Florida, has experienced about a 10 percent population growth since 1976 without any significant increase in potable water demand because of its urban reuse program. Prior to its reuse system, the average residential water demand in a study area in St. Petersburg was 435 gal (1,650 L)/d. After reclaimed water was made available, the potable demand was reduced to 220 gal (830 L)/d (Johnson and Parnell, 1987). The estimated potable water savings for the City of St. Petersburg since the implementation of its urban reuse program is shown in Figure 9.

Currently, 25 percent of all water supplied by the Irvine Ranch Water District in southern California is reclaimed water. Total water demand is expected to reach 51 mgd (2,235 L/s) in Irvine by the Year 2000 (Irvine Ranch Water District, 1991). By the Year 2000, Irvine expects to provide approximately 13 mgd (570 L/s of this demand with reclaimed water (Parsons, 1990). Altamonte Springs, a fast-growing city in central Florida, expects to stabilize potable water consumption by 1995 through implementation of its comprehensive urban water reuse system (Howard Needles Tammen & Bergendoff, 1986).

2.3 Sources of Reclaimed Water

Under the broad definition of water reclamation and reuse, sources of reclaimed water may range from industrial process waters to the tail waters of agricultural irrigation systems. For the purposes of these guidelines, however, the sources of reclaimed water are limited to the effluent generated by domestic wastewater treatment facilities (WWTFs).

Treated municipal wastewater represents a significant potential source of reclaimed water for beneficial reuse. As a result of the Federal Water Pollution Control Act Amendments of 1972, the Clean Water Act of 1977 and its subsequent amendments, centralized wastewater treatment has become commonplace in urban areas of the United States. In developed countries it is estimated that approximately 73 percent of the population is served by wastewater collection and treatment facilities. It is estimated that only 7 percent of the population of developing countries is served by wastewater collection and treatment facilities. (Van Leeuwen, 1988). Within the United States, the population generates an estimated 31 billion gal/d (1.4 x 10^6 L/s) of potential reclaimed water (Solley, *et al.*, 1988). As the world population continues to shift from rural to urban, the number of centralized wastewater collection and treatment facilities will also increase, creating significant opportunities to implement water reuse systems to augment water supplies and, in many cases, improve the quality of surface waters.

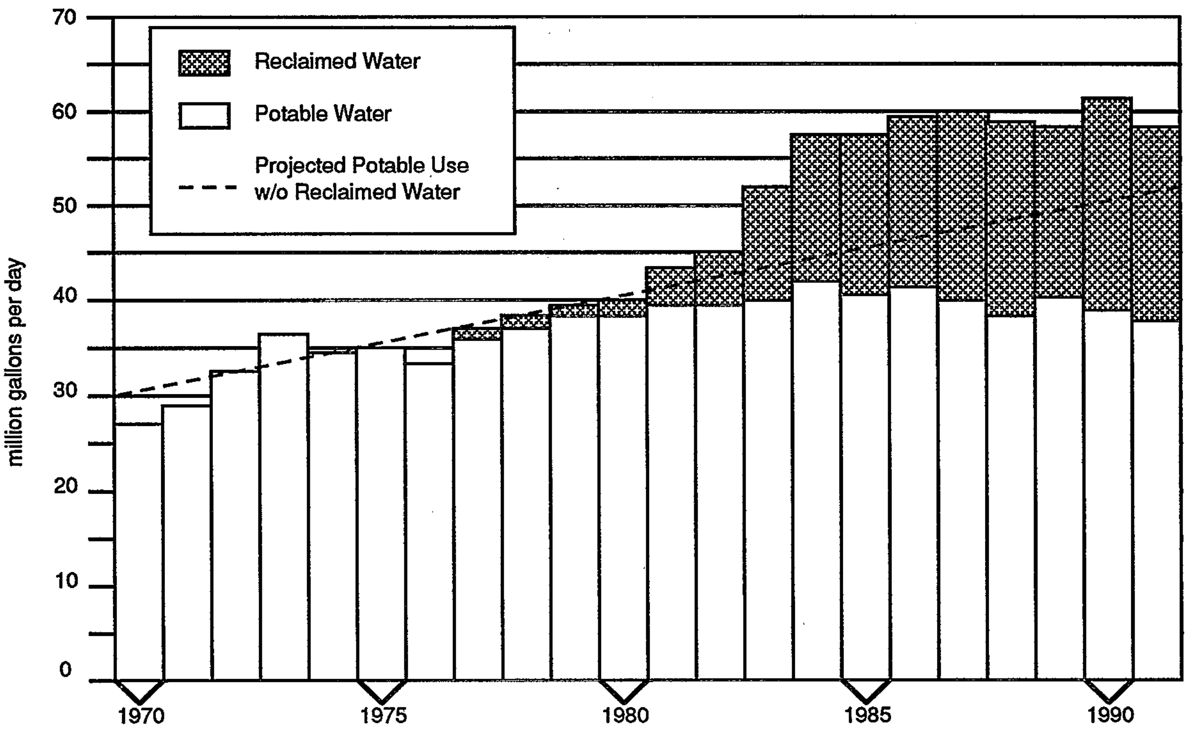
2.3.1 Locating the Sources

In areas of growth and new development, completely new collection, treatment, and distribution systems may be designed from the outset with water reclamation and reuse in mind. In most cases, however, existing facilities will be incorporated into the water reuse system. In areas where centralized treatment is already provided, the existing WWTFs are potential sources of reclaimed water.

In the preliminary planning of a water reuse system incorporating existing facilities, the following information is needed for the initial evaluation:

- ❑ Residential areas and their principal sewers,
- ❑ Industrial areas and their principal sewers,
- ❑ Wastewater treatment facilities,
- ❑ Areas with combined sewers,
- ❑ Existing effluent disposal facilities,
- ❑ Areas and types of projected development, and

Figure 9. **Estimated Potable Water Conservation Achieved Through Urban Reuse City of St. Petersburg, Florida**



Source: Johnson, 1992.

- ❑ Locations of potential reclaimed water users.

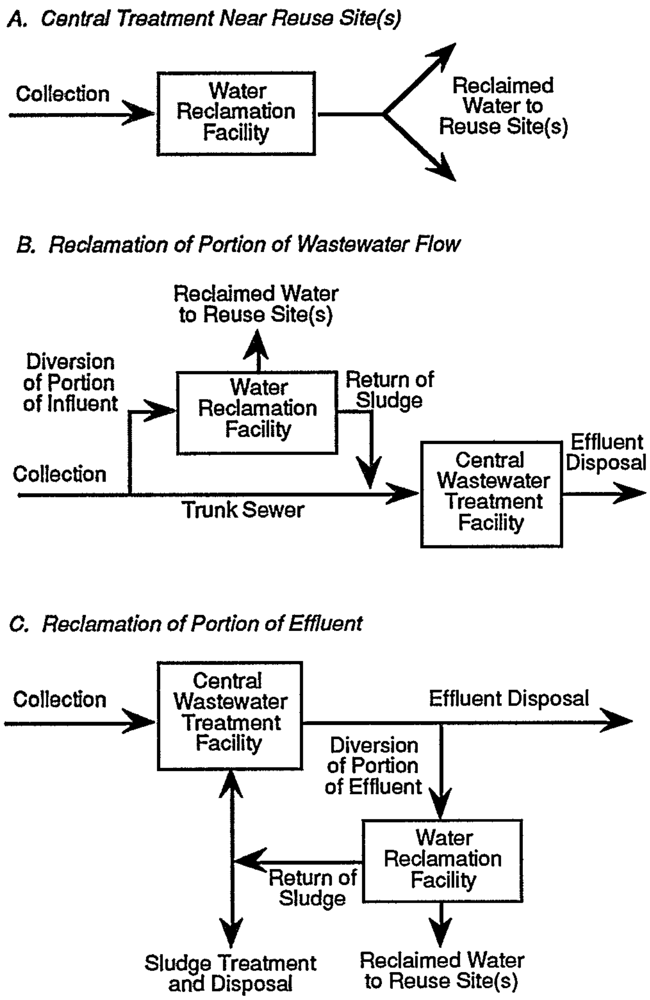
For economy, the wastewater treatment facilities ideally should be located near the major users of the reclaimed water. However, in adapting an existing system for water reuse, other options are available. For example, if a trunk sewer bearing flows to a WWTF passes through an area of significant potential reuse, a portion of the flows can be diverted to a new reclamation facility to serve that area. The sludge produced in the reclamation facility can be returned to the sewer for handling at the WWTF. By this method, odor problems may be reduced or eliminated at the reclamation facility. However, the effects of this practice can be deleterious to both sewers and downstream treatment facilities. Alternatively, an effluent outfall passing through a potential reuse area could be tapped for some or all of the effluent, and additional treatment could be provided, if necessary, to meet reclaimed water quality standards. These alternative configurations are illustrated in Figure 10.

2.3.2 Characterizing the Sources

Existing sources must be characterized to roughly establish the effluent's suitability for reclamation and reuse. To compare the quality and quantity of available reclaimed water with the requirements of potential users, information on the operation and performance of the existing WWTF and related facilities must be examined. Important factors to consider in this preliminary stage of reuse planning are:

- ❑ Level of treatment (e.g., primary, secondary, advanced) and specific treatment processes (e.g., ponds, activated sludge, filtration, disinfection, nutrient removal, disinfection);
- ❑ Effluent water quality;
- ❑ Effluent quantity (daily and season average, maximum, and minimum flows);
- ❑ Industrial wastewater contributions to flow;
- ❑ System reliability; and

Figure 10. Three Configuration Alternatives for Water Reuse Systems



- ❑ Supplemental facilities (e.g., storage, pumping, transmission).

2.3.2.1 Level of Treatment and Processes

Because meeting all applicable treatment requirements for the production of safe, reliable reclaimed water is one of the keys to operating any water reuse system, careful analysis of applicable requirements and provision of all necessary process elements are critical in designing a reuse system. At the early stage of planning, however, only a preliminary assessment of the compatibility of treatment facilities with potential reuse applications is needed. A detailed discussion of treatment requirements for water reuse applications is provided in Section 2.4.

Knowledge of the level of treatment and the treatment processes provided is important in evaluating the WWTF's suitability as a water reclamation facility and determining the possible reuse applications. An existing plant providing at least secondary treatment, while not originally designed for water reclamation and reuse, can be upgraded by modifying existing processes or adding new process units to the existing train to supply reclaimed water for most uses. For example, with the addition of chemicals, filters, and other facilities to ensure reliable disinfection, most secondary effluents can be enhanced to provide a source of reclaimed water suitable for unrestricted urban reuse. In Manatee County, Florida, filtration, additional disinfection and pumping facilities were constructed as part of a WWTF expansion. The design capacity of these units processes matched the identified reclaimed water irrigation demand of public access sites but was less than the total WWTF capacity. The unfiltered chlorinated reclaimed water was used for the irrigation of gladiolus on a restricted access site.

Some existing processes necessary for effluent disposal practices may no longer be required for water reuse. For example, an advanced wastewater treatment plant designed to remove nitrogen and/or phosphorus would need little or no nutrient removal for agricultural or urban irrigation, the nutrients in the reclaimed water being beneficial to plant growth.

2.3.2.2 Effluent Water Quality

Effluent water quality sampling and analysis are required as a condition of WWTF discharge permits. The specific parameters tested are those required for preserving the water quality of the receiving water body, [*e.g.*, biochemical oxygen demand (BOD), suspended solids (SS), coliforms (or other indicators), nutrients, and sometimes toxic organics and metals]. This information is useful in the preliminary evaluation of the potential utility of a source of reclaimed water. For example, as noted earlier, the nitrogen and phosphorus in reclaimed water represents an advantage for certain irrigation applications. For industrial reuse, however, nutrients may encourage biological growths that could cause fouling. Where the latter uses are a small fraction of the total use, the customer may be obliged to remove the nutrients or blend reclaimed water with other sources. The decision is based on case-by-case assessments.

In some cases, the water quality data needed to assess the suitability of a given source are not included in the WWTF's existing monitoring requirements and will have to be gathered specifically for the reuse evaluation. For example, coastal cities may experience saltwater infiltration of the sewer system, resulting in elevated chloride concentrations in the effluent. Chloride levels are of concern in irrigation because high levels are toxic to many plants. However, chloride levels at WWTFs are not typically monitored. Even in the absence of saltwater infiltration or industrial contributions, practices within the community being served may adversely impact reclaimed water quality. For example, the widespread use of water softeners may increase the concentration of salts to levels making the reclaimed water unusable for some applications.

The urban reuse system in the City of St. Petersburg, Florida, provides an example of the importance of reclaimed water quality. Between 1981 and 1991, the city substantially increased its residential irrigation customer base from approximately 20 percent of total connections to more than 95 percent of the 7,000 total reclaimed water service connections (Crook and Johnson, 1991). In 1985, the city received a significant number of complaints of damage to ornamental foliage from reclaimed water. The problem was traced to elevated chlorides in the reclaimed water. The chlorides had not been a problem when the customer base was dominated by golf course irrigation because turf grass has a high tolerance for chlorides. While efforts are being made to reduce saltwater infiltration to the sewerage system, residents are cautioned to plan their landscaping around salt-tolerant species (Johnson and Parnell, 1987). A case study of the St. Petersburg program is provided at the end of Chapter 3.

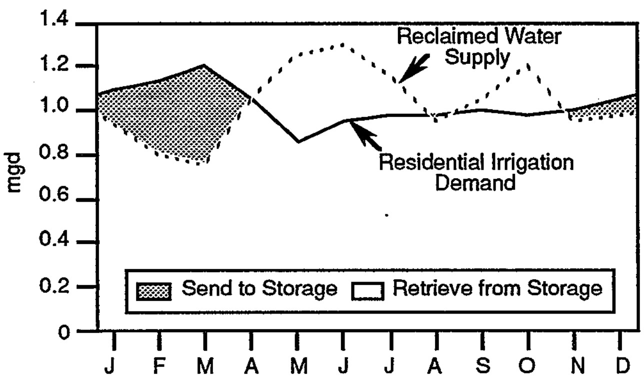
For the purpose of reuse planning, it is best to consider reclaimed water quality from the standpoint of a water supply, i.e., what quality is required for the intended use. Where a single large customer dominates the demand for reclaimed water, the treatment selected may suit the major customer. An example is Pomona, California, where activated carbon filters were used in place of conventional sand filters in the reclamation plant to serve paper mills that require low color in their water supply. Industrial reuse might be precluded if high levels of dissolved solids, dissolved organic material, chlorides, phosphates, and nutrients are present, unless additional treatment is provided by the industrial facility. Recreational reuse might be limited by nutrients, which might result in unsightly and odorous algae blooms. Trace metals in high concentrations might restrict the use of reclaimed water for agricultural and horticultural irrigation.

2.3.2.3 Effluent Quantity

Just as the water purveyor must meet the diurnal and seasonal variations in demand for potable water, so too must the purveyor meet such variations in demand for reclaimed water. Diurnal and seasonal fluctuations in supply and demand must be taken into account for both elements of a dual system. Diurnal variations in sources of reclaimed water are much more variable than in sources of potable water supplies.

For example, WWTF flows are low at night, when urban irrigation demand is high. Seasonal flow fluctuations may occur in resort areas subject to a periodic influx of tourists, and seasons of high flow do not necessarily correspond with seasons of high irrigation demand. Figure 11 illustrates the fluctuations in reclaimed water supply and irrigation demand in a southwest Florida community. Treatment facilities serving college campuses, resort areas, etc. also experience significant fluctuations in flow throughout the year.

Figure 11. Reclaimed Water Supply vs. Irrigation Demand



Where collection systems are prone to infiltration and inflow, significant fluctuations in flow may occur during the rainy season. A 1981 report on agricultural reuse systems in California cited a Lake County system where the dry season reclaimed water supply of 0.7 mgd (31 L/s) rose to 1.8 mgd (79 L/s) in the wet season due to groundwater infiltration (Boyle Engineering Corporation, 1981). In a 1990 study of rainfall induced infiltration, a review of ten systems documented a peak wet weather flow ranging from 3.5 to 20 times the average dry weather flow (EPA, 1990).

Information on flow quantities and fluctuations is critical in sizing the storage facilities necessary to balance supply and demand in water reuse systems. A complete discussion of seasonal storage requirements is provided in Section 2.5. Operational storage requirements to balance diurnal flow variations are detailed in Section 2.6.2.

2.3.2.4 Industrial Wastewater Contributions

Industrial waste streams differ from domestic wastewater in that they may contain relatively high levels of elements and compounds which may be toxic to plants and animals or may adversely impact treatment plant performance. Where industrial wastewater flow contributions to the WWTF are significant, reclaimed water quality may be affected. The degree of impact will, of course, depend on the nature of the industry. A rigorous pretreatment program is required for any water reclamation facility that receives industrial wastes to ensure the reliability of the biological treatment processes by excluding potentially toxic levels of pollutants from the sewer system. Planning a reuse system around a WWTF with substantial industrial flows will require identification of the constituents that may interfere with particular reuse applications, and appropriate monitoring for parameters of concern is prudent. Wastewater treatment facilities receiving substantial amounts of high-strength industrial wastes may be limited in the number and type of suitable reuse applications.

2.3.2.5 System Reliability

Reliability requirements for reclaimed water production go beyond EPA Class I reliability (EPA, 1974), which provides redundant facilities to prevent treatment upsets during power and equipment failures, flooding, peak loads, and maintenance shutdowns. Reliability for water reuse includes, in addition:

- Strict operator training and certification to ensure that qualified personnel are operating the WWTF;
- Instrumentation and control systems for on-line monitoring of treatment process performance and alarms for process malfunctions;
- A comprehensive quality assurance program to ensure accurate sampling and laboratory analysis protocol;
- Adequate emergency storage to retain reclaimed water of unacceptable quality for re-treatment or alternative disposal;
- Supplemental storage to ensure that the quantity of the supply is adequate to meet the user's demands; and
- A strict industrial pretreatment program and strong enforcement of sewer use ordinances to prevent illicit dumping of hazardous materials into the collection system.

Reliability and quality assurance are discussed in greater detail in Section 2.4.3.

2.3.2.6 Transmission and Distribution Facilities

Apart from facilities specifically associated with treatment, facilities for storage, transmission, and distribution must also be considered. Will the available pumping capacity of existing facilities be adequate to meet expected reclaimed water demands? Can existing lagoons be converted to operational storage facilities?

When the City of Venice, Florida, constructed a 2.1-mgd (92-L/s) water reclamation facility in the eastern portion of the city to reduce flows to an overloaded WWTF on the west side, the western WWTF remained in service to treat only about 0.3 mgd (13 L/s) to provide irrigation water for an adjacent golf course. At this reduced flow, however, significant volumes of storage and treatment capacity remained unused at the western site much of the year. To take advantage of these facilities, provisions were made in the wastewater collection system to divert flows from selected lift stations to either WWTF, allowing the city to balance supplies, demands, and storage needs as conditions warrant (Ammerman and Moore, 1991).

2.4 Treatment Requirements for Water Reuse

One of the most critical objectives in any reuse program is to assure that health protection is not compromised through the use of reclaimed water. Other objectives, such as preventing environmental degradation, avoiding public nuisance, and meeting user requirements, must also be satisfied in implementing a successful reuse program, but the starting point remains the safe delivery and use of properly treated reclaimed water.

Protection of public health is achieved by: (1) reducing concentrations of pathogenic bacteria, parasites, and enteric viruses in the reclaimed water; (2) controlling chemical constituents in reclaimed water; and/or (3) limiting public exposure (contact, inhalation, ingestion) to the reclaimed water. Where human exposure is likely in a reuse application, reclaimed water should be treated to a high degree prior to its use. Conversely, where public access to a reuse site can be restricted so that exposure is unlikely, a lower level of treatment may be satisfactory, provided worker safety is not compromised.

Providing the necessary treatment for the intended reuse application requires an understanding of the constituents of concern in wastewater and the levels of treatment and processes applicable for removing these constituents to achieve the desired reclaimed water quality.

2.4.1 *Health Assessment of Water Reuse*

The presence of toxic chemicals and pathogenic microorganisms in untreated wastewater creates the potential for adverse toxicological health effects and disease transmission where there is contact, inhalation, or ingestion of the chemical or microbiological constituents of health concern. Control measures include elimination or reduction in concentration of these constituents in reclaimed water and, where appropriate, practices to prevent or limit direct and indirect contact with the reclaimed water.

Health significant microorganisms and chemical constituents clearly are present in untreated wastewater and, thus, justifiably present a health concern. It is also clear that for most uses of reclaimed water, conventional, widely practiced water and wastewater treatment processes are capable of reducing these hazardous constituents to acceptable levels or virtually eliminating them from the water. For some uses, (e.g., indirect potable reuse), advanced treatment processes may be necessary to accomplish this task.

2.4.1.1 Pathogenic Microorganisms and Health Risks

The principal infectious agents that may be present in raw wastewater can be classified into three broad groups: bacteria, parasites (protozoa and helminths), and viruses. Table 1 lists many of the infectious agents potentially present in raw domestic wastewater.

a. Bacteria

One of the most common pathogens found in municipal wastewater is the genus Salmonella. This group contains a wide variety of species that can cause disease in man and animals. The three distinct forms of salmonellosis in humans are enteric fevers, septicemias, and acute gastroenteritis. The most severe form of salmonellosis is the typhoid fever caused by Salmonella typhi. The Salmonella septicemias are not particularly common in human populations. The third form of salmonellosis, acute gastroenteritis, is the form in which the Salmonella are most commonly encountered. In excess of 1,500 different serotypes have been identified.

A less common genus of bacteria that has been isolated from wastewater is *Shigella*, which produces an intestinal disease known as bacillary dysentery or shigellosis. Waterborne outbreaks of shigellosis have been reported where wastewater has contaminated wells used for drinking water (National Communicable Disease Center, 1969 and 1973). The survival time of *Shigella* in wastewater is relatively short, and shigellosis appears to be spread primarily by person-to-person contact. However, *Shigella* is the leading cause of recreational waterborne outbreaks in lakes and rivers.

There are a variety of other bacteria of lesser importance that have been isolated from raw wastewater. These include *Vibrio, Mycobacterium, Clostridium, Leptospira* and *Yersinia* species. While these pathogens may be present in wastewater, their concentrations are usually too low to initiate disease outbreaks. *Vibrio cholerae* is the disease agent for cholera, which is not common in the United States but is still prevalent in other parts of the world. Man is the only known host, and the most frequent mode of transmission is through the water route. *Mycobacterium tuberculosis* has been found in wastewater (Greenberg and Kupka, 1957), particularly where an institution treating tuberculosis patients is involved or where industries such as dairies and slaughterhouses handling tubercular animals discharge to a municipal sewerage system. Outbreaks among persons swimming in water contaminated with wastewater have been reported (California Department of Health and Cooper, 1975).

Waterborne gastroenteritis of unknown cause is frequently reported, with the suspected agent being bacterial. One potential source of this disease is certain gram-negative bacteria normally considered to be nonpathogenic. These include enteropathogenic *Escherichia coli* and certain strains of *pseudomonas* which may affect the newborn. Waterborne enterotoxigenic *E. coli* have been implicated in gastrointestinal disease outbreaks (National Communicable Disease Center, 1975).

Campylobacter coli has been identified as the cause of a form of bacterial diarrhea in man. While it has been well-established that this organism causes disease in animals, it has also been implicated as the etiological agent in human waterborne disease outbreaks (Craun, 1988).

In recognition of the many constraints associated with analyzing wastewater for all of the potential pathogens that may be present, it has been common practice to use a microbial indicator or surrogate to indicate fecal contamination of water. Bacteria of the coliform group have long been considered the prime indicators of fecal contamination and are the most frequently applied indicators of water quality by state regulatory agencies. The coliform group is made up of a number of bacteria, including the genera *Klebsellia, Citribacter, Escherichia, Serratia,* and *Enterobacteria*. The total coliform group are all gram-negative aspogenous rods and are found in feces of warm-blooded animals and in soil. Fecal coliform bacteria are restricted to the intestinal tract of

Table 1. Infectious Agents Potentially Present in Untreated Domestic Wastewater

Pathogen	Disease
Protozoa	
Entamoeba histolytica	Amebiasis (amebic dysentery)
Giardia lamblia	Giardiasis
Balantidium coli	Balantisiasis (dysentery)
Cryptosporidium	Cryptosporidiosis, diarrhea, fever
Helminths	
Ascaris lumbricoides (roundworm)	Ascariasis
Ancylostoma duodenale (hookworm)	Ancylostomiasis
Necator americanus (roundworm)	Necatoriasis
Ancylostoma (spp.) (hookworm)	Cutaneous larva migrams
Strongloides stercoralis (threadworm)	Strongyloidiasis
Trichuris trichiura (whipworm)	Trichuriasis
Taenia (spp.) (tapeworm)	Taeniasis
Enterobius vermicularis (pinworm)	Enterobiasis
Echinococcus granulosus (spp.) (tapeworm)	Hydatidosis
Bacteria	
Shigella (4 spp.)	Shigellosis (dysentery)
Salmonella typhi	Typhoid fever
Salmonella (1700 serotypes)	Salmonellosis
Vibro cholerae	Cholera
Escherichia coli (enteropathogenic)	Gastroenteritis
Yersinia enterocolitica	Yersiniosis
Leptospira (spp.)	Leptospirosis
Legionella	Legionnaire's disease
Campylobacter jejune	Gastroenteritis
Viruses	
Enteroviruses (72 types) (polio, echo, coxsackie, new enteroviruses)	Gastroenteritis, heart anomolies, meningitis, others
Hepatitis A virus	Infectious hepatitis
Adenovirus (47 types)	Respiratory disease, eye infections
Rotavirus (4 types)	Gastroenteritis
Parvovirus (3 types)	Gastroenteritis
Norwalk agent	Diarrhea, vomiting, fever
Reovirus (3 types)	Not clearly established
Astrovirus (5 types)	Gastroenteritis
Calicivirus (2 types)	Gastroenteritis
Coronavirus	Gastroenteritis

Source: Adapted from Sagik *et al.*, 1978; Hurst *et al.*, 1989.

warm-blooded animals and comprise a portion of the total coliform group. *Escherichia coli* and enterococci are sometimes used as indicators of bacteriological contamination in recreational waters. Coliform organisms are used as indicators because they occur naturally in the feces of warm-blooded animals in higher concentrations than pathogens and are easily and unambiguously detectable, exhibit a positive correlation with fecal contamination, and generally respond similarly to environmental conditions and treatment processes as many bacterial pathogens. However, coliform bacteria determinations, by themselves, do not adequately predict the presence or concentration of pathogenic viruses or protozoa.

b. Protozoa

There are a number of protozoan and metazoan agents that are pathogenic to humans and that occur in municipal wastewater. Probably the most important of the parasites is the protozoan *Entamoeba histolytica,* which is responsible for amoebic dysentery and amoebic hepatitis. The amoeba is found in sewage in the form of cysts, which are excreted by infected humans. The cysts, upon entering a susceptible host by contaminated food or water, germinate in the gut and can initiate infection. The diseases are worldwide, but in the U.S., *Entamoeba histolytica* has not been an important disease agent since the 1950s.

Waterborne disease outbreaks around the world have been linked to the protozoans *Giardia lamblia* and *Cryptosporidium*, although no *Giardia* or *Cryptosporidium* cases related to water reuse practices have been reported. The flagellate *Giardia lamblia* is the cause of giardiasis, which is responsible for gastrointestinal disturbances, diarrhea, and general discomfort, and is emerging as a major waterborne disease. Infection is caused by ingestion of *Giardia* cysts. *Cryptosporidium* cause diarrheal disease, with oocysts being the infectious stage (Rose, 1986).

c. Helminths

There are several helminthic parasites that occur in wastewater. The most important are intestinal worms, including the stomach worm *Ascaris lumbricoides,* the tapeworms *Taenia saginata* and *Taenia solium,* the whipworm *Trichuris trichirar,* the hookworms *Ancylostoma duodenia* and *Necator americanus,* and the threadworm *Strongyloides stercoralis.* Many of the helminths have complex life cycles, including a required stage in intermediate hosts. The infective stage of some helminths is either the adult organism or larvae, while the eggs or ova of other helminths constitute the infective stage of the organisms. The free living nematode larvae stages are not pathogenic to human beings. The eggs and larvae are resistant to environmental stresses and may survive usual wastewater disinfection procedures, although eggs are readily removed by commonly used wastewater treatment processes, such as sedimentation, filtration, or stabilization ponds.

d. Viruses

Over 100 different enteric viruses capable of producing infections or disease are excreted by humans. Enteric viruses are those which multiply in the intestinal tract and are released in the fecal matter of infected persons. Not all types of enteric viruses have been determined to cause waterborne disease.

The most important human enteric viruses are the enteroviruses (polio, echo, and coxsackie), rotaviruses, reoviruses, parvoviruses, adenoviruses, and hepatitis A virus (Hurst, *et al.*, 1989; WPCF, 1989). The reoviruses and adenoviruses, which are known to cause respiratory illness, gastroenteritis, and eye infections, have been isolated from wastewater. Of the viruses that cause diarrheal disease, only the Norwalk virus and rotavirus have been shown to be major waterborne pathogens (Rose, 1986). Hepatitis A, the virus causing infectious hepatitis, is a virus frequently reported to be transmitted by water.

There is no evidence that the human immunodeficiency virus (HIV), the pathogen that causes the acquired immunodeficiency syndrome (AIDS), can be transmitted via a waterborne route (Riggs, 1989). The results of one laboratory study (Casson *et al.*, 1992), where primary and undisinfected secondary effluent samples were inoculated with HIV (Strain IIIB) and held for up to 48 hours at 25°C (77°F), indicated that HIV survival was significantly less than poliovirus survival under similar conditions.

It has been reported that viruses and other pathogens that may be present in wastewater used for irrigation do not readily penetrate fruits or vegetables unless the skin is broken (Bryan, 1974). In one study where soil was inoculated with poliovirus, viruses were detected in the leaves of plants only when the plant roots were damaged or cut (Shuval, 1978). Although absorption of viruses by plant roots and subsequent acropetal translocation has been reported (Murphy and Syverton, 1958), it probably does not occur with sufficient regularity to be a mechanism for transmission for interepidermic survival of viruses. Therefore, the likelihood of translocation of pathogens through trees or vines to the edible portions of crops is extremely low, and the health risks are negligible.

The study of low level or endemic occurrence of waterborne virus diseases has been virtually ignored for several reasons:

- Current virus detection methods are not sufficiently sensitive to accurately detect low concentrations of viruses even in large volumes of water.
- Enteric virus infections are often not apparent, thus making it difficult to establish the endemicity of such infections.
- The apparently mild nature of most enteric virus infections preclude reporting by the patient or the physician.
- Current epidemiological techniques are not sufficiently sensitive to detect low level transmission of viral diseases through water.
- Illness due to enteroviral infections may not become obvious for several months or years.
- Once introduced into a population, person-to-person contact becomes a major mode of transmission of an enteric virus, thereby obscuring the role of water in its transmission.

2.4.1.2 Mechanism of Disease Transmission

Diseases can be transmitted to humans either directly by skin contact, ingestion, or inhalation of infectious agents in water, or indirectly by contact with objects previously contaminated. The following circumstances must occur for an individual to become infected from exposure to reclaimed water: (a) the infectious agent must be present in the community and, hence, in the wastewater from that community; (b) the agents must survive all the wastewater treatment processes to which they are exposed; (c) the individual must either directly or indirectly come in contact with the reclaimed water; and (d) the agents must be present in sufficient numbers to cause infection at the time of contact.

Whether illness occurs depends on a series of complex interrelationships between the host and the infectious agent. Specific variables include: the numbers of the invading microorganism (dose); the numbers of organisms necessary to initiate infection (infective dose); the organism's ability to cause disease (pathogenicity); and the relative susceptibility of the host. The infectious dose of some organisms may be lower than the dose required to cause overt symptoms of the disease. Infection may be defined as an immunological response to pathogenic agents by a host without necessarily showing signs of a disease.

Table 2. Infectious Doses of Selected Pathogens

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

Source: Adapted from Feachem *et al.*, 1981 and Feachem *et al.*, 1983.

Table 3. Microorganism Concentrations in Raw Wastewater

Organism	Concentration (number/100 mL)
Fecal Coliforms	$10^4 - 10^9$
Fecal streptococci	$10^4 - 10^6$
Shigella	1 - 1,000
Salmonella	400 - 8,000
Helminth ova	1 - 800
Enteric virus	100 - 50,000
Giardia lamblia cysts	$50 - 10^4$
Entamoeba histolytica cysts	0 - 10

Susceptibility is highly variable and dependent upon both the general health of the subject and the specific pathogen in question. Infants, elderly persons, malnourished persons, and persons with concomitant illness are more susceptible than healthy adults. The infectious doses of selected pathogens are presented in Table 2.

The large variety of pathogenic microorganisms that may be present in raw domestic wastewater is derived principally from the feces of infected human and animal hosts. There are occasions when host infections cause passage of pathogens in urine. The three principal infections leading to significant appearance of pathogens in urine are: urinary schistosomiasis, typhoid, and leptospirosis. Coliform and other bacteria may be numerous in urine during urinary tract infections, but they constitute little public health risk in wastewater. Microbial agents resulting from venereal infections can also be present in urine, but they are so vulnerable to conditions outside the body that wastewater is not an important vehicle of transmission (Feachem *et al.*, 1983).

2.4.1.3 Presence and Survival of Pathogens

The occurrence and concentration of pathogenic microorganisms in raw wastewater depends on a number of factors, and it is not possible to predict with any degree of assurance what the general characteristics of a particular wastewater will be with respect to infectious agents. Important variables include the sources contributing to the wastewater, the general health of the contributing population, the existence of "disease carriers" in the population, and the ability of infectious agents to survive outside their hosts under a variety of environmental conditions.

Table 4. Typical Pathogen Survival Times at 20-30 °C

Pathogen	Survival Time (days): Fresh Water & Sewage	Crops	Soil
Viruses[a]			
Enteroviruses[b]	<120 but usually <50	<60 but usually <15	<100 but usually <20
Bacteria			
Fecal coliforms[a]	<60 but usually <30	<30 but usually <15	<70 but usually <20
Salmonella spp.[a]	<60 but usually <30	<30 but usually <15	<70 but usually <20
Shigella spp.[a]	<30 but usually <10	<10 but usually <5	
Vibrio cholerae[c]	<30 but usually <10	<5 but usually <2	<20 but usually <10
Protozoa			
Entamoeba histolytica cysts	<30 but usually <15	<10 but usually <2	<20 but usually <10
Helminths			
Ascaris lumbricoides eggs	Many months	<60 but usually <30	Many months

a In seawater, viral survival is less, and bacterial survival is very much less, than in fresh water.
b Includes polio-, echo-, and coxsackieviruses.
c *V. cholerae* survival in aqueous environments is a subject of current uncertainty.

Source: Adapted from Feacham *et al.*, 1983.

Table 3 illustrates the variation and order of magnitude of the concentration of certain organisms that may be present in raw wastewater. Bradley and Hadidy (1981) reported that raw sewage in Aleppo, Syria, contained 1,000 to 8,000 *Ascaris* eggs/L, due to an estimated 42 percent of the population excreting an average of 800,000 eggs/person/day. *Salmonella* may be present in concentrations up to 10,000/L. The excretion of *Salmonella typhi* by asymptomatic carriers may vary from 5×10^3 to 45×10^6 bacteria/g of feces (Drexel University, 1978).

Enteroviruses are not normally excreted for prolonged periods by healthy individuals, and their occurrence in municipal wastewater fluctuates widely. Virus concentrations are generally highest during the summer and early autumn months. Viruses shed from an infected individual commonly range from 1,000 to 100,000 infective units/g of feces, but may be as high as 1,000,000/g of feces (Feachem *et al.*, 1983). Viruses as a group are generally more resistant to environmental stresses than many of the bacteria, although some viruses persist for only a short time in municipal wastewater. In water-short areas such as Israel where per capita water use is relatively low, virus concentrations have been reported to range from 600 to approximately 50,000 plaque-forming units per 100 milliliters (pfu/100 mL) (Buras, 1976). This is in contrast to virus levels in the U.S. which have been reported to be as high as 700 virus units/100 mL but are typically less than 100 pfu/100 mL (Melnick *et al.*, 1978; EPA, 1979).

Under favorable conditions, pathogens can survive for long periods of time on crops or in water or soil. Factors that affect survival include number and type of organism, soil organic matter content (presence of organic matter aids survival), temperature (longer survival at low temperatures), humidity (longer survival at high humidity), pH, amount of rainfall, amount of sunlight (solar radiation detrimental to survival), protection provided by foliage, and competitive microbial fauna and flora. Survival times for any particular microorganism exhibit wide fluctuations under differing conditions. Typical ranges of survival times for some common pathogens on crops and in water and soil are presented in Table 4.

2.4.1.4 Aerosols

Aerosols are particles less than 50 µm in diameter that are suspended in air. Viruses and most pathogenic bacteria are in the respirable size range; hence, a possible direct means of human infection by aerosols is by inhalation. Bacteria and viruses have been found in aerosols emitted by spray irrigation systems using untreated and poorly treated wastewater (Camann and

Guentzel, 1985; Camann and Moore, 1988; Teltsch *et al.*, 1980).

The concentration of pathogens in aerosols is a function of their concentration in the applied wastewater and the aerosolization efficiency of the spray process. During spray irrigation, the amount of water that is aerosolized can vary from less than 0.1 percent to almost 2 percent, with a mean aerosolization efficiency of 1 percent or less (Johnson *et al.*, 1980a, 1980b; Bausum *et al.*, 1983; Camann *et al.*, 1988). Infection or disease may be contracted indirectly by deposited aerosols on surfaces such as food, vegetation, and clothes. The infective dose of some pathogens is lower for respiratory tract infections than for infections via the gastrointestinal tract; thus, for some pathogens, inhalation may be a more likely route for disease transmission than either contact or ingestion (Hoadley and Goyal, 1976).

A comprehensive evaluation of viruses indicated that a number of waterborne viruses are capable, if aerosolized, of producing respiratory tract infections and disease (Sobsey, 1978). The infectivity of an inhaled aerosol depends on the depth of the respiratory penetration and the presence of pathogenic organisms capable of infecting the respiratory system. Aerosols in the 2 to 5 µm size range are primarily removed in the respiratory tract, some to be subsequently swallowed. Thus, if gastrointestinal pathogens are present, infection could result. A considerably greater potential for infection occurs when respiratory pathogens are inhaled in aerosols smaller than 2 µm in size, which pass directly to the alveoli of the lungs (Sorber and Guter, 1975).

In general, bacteria and viruses in aerosols remain viable and travel farther with increased wind velocity, increased relative humidity, lower temperature, and lower solar radiation. Other important factors include the initial concentration of pathogens in the wastewater and droplet size. Aerosols can be transmitted for several hundred meters under optimum conditions. Some types of pathogenic organisms, e.g., enteroviruses and *Salmonella*, appear to survive the wastewater aerosolization process much better than the indicator organisms (Teltsch *et al.*, 1980).

One study found that coliforms were carried 295 to 425 ft (90 to130 m) with a wind velocity of 3.4 mph (1.5 m/s), and it was estimated that fine mist could be carried 1000-1300 ft (300-400 m) with an 11 mph (5 m/s) wind (Sepp, 1971). Another study found that the mean net bacterial aerosol levels, i.e., the observed minus the simultaneous mean upwind value, were 485 colony-forming units (CFU)/m^3 at a distance of 70-100 ft (21-30 m) from the most downwind row of sprinkler heads in a spray field and 37 CFU/m^3 at 660 ft (200 m) downwind (Bausum *et al.*, 1983). The sprayed wastewater had received treatment in stabilization lagoons before disinfection with chlorine.

During a study in Israel, echovirus 7 was detected in air samples collected at 130 ft (40 m) downwind from sprinklers spraying undisinfected secondary effluent (Teltsch and Katzenelson, 1978). Aerosol measurements at Pleasanton, California, where undisinfected secondary effluent was sprayed, indicated that the geometric mean aerosol concentration of enteroviruses obtained 165 ft (50 m) downwind of the wetted spray area was 0.014 pfu/m^3 (Johnson *et al.*, 1980b). This concentration is equal to one virus particle in 2,500 cu f^t (71 m^3) of air.

One of the most comprehensive aerosol studies, the Lubbock Infection Surveillance Study (Camann *et al.*, 1986), monitored viral and bacterial infections in a mostly rural community surrounding a spray injection site near Wilson, Texas. The source of the irrigation water was undisinfected trickling filter effluent from the Lubbock Southeast water reclamation plant. Spray irrigation of the wastewater significantly elevated air densities of fecal coliforms, fecal streptococci, mycobacteria, and coliphage above the ambient background levels for at least 650 ft (200 m) downwind. The geometric mean concentration of enteroviruses recovered 150-200 ft (44 - 60 m) downwind was 0.05 pfu/m^3, a level higher than that observed at other wastewater aerosol sites in the U.S. and in Israel (Camann *et al.*, 1988). While disease surveillance found no obvious connection between the self-reporting of acute illness and the degree of aerosol exposure, serological testing of blood samples indicated that the rate of viral infections was slightly higher among members of the study population who had a high degree of aerosol exposure (Camann *et al.*, 1986).

For intermittent spraying of disinfected reclaimed water, occasional inadvertent contact should pose little health hazard from inhalation. Aerosols from cooling towers which issue continuously may present a greater concern if the water is not properly disinfected. For example, *Legionella pneumophila*, the bacterium that causes Legionnaire's Disease, is present in many types of water and proliferates in some cooling water systems, thus presenting a potential health hazard regardless of the source of the water. The concentration of pathogens in the recirculated waters of cooling towers using reclaimed water is reduced somewhat by the treatment to prevent biofouling, which is generally by the addition of chlorine. On the other hand, the evaporation in cooling towers concentrates contaminants in the water, and the water in the tower and in aerosols or windblown spray may contain pathogen concentrations little different from the reclaimed water. Although a great deal of effort has been expended to quantify the numbers of fecal coliforms and enteric pathogens in cooling tower waters, there is no evidence that they occur in large numbers, although the numbers of other bacteria may be quite large (Adams and Lewis, n.d.).

Because there is limited information available regarding the health risks associated with wastewater aerosols, health implications are difficult to assess. Several studies in the U.S. have been directed at residents in communities subjected to aerosols from sewage treatment plants (Camann *et al.*, 1979; Camann *et al.*, 1980; Fannin *et al.*, 1980; Johnson *et al.*, 1980a). These investigations have not detected any definitive correlation between exposure to aerosols and disease. Although some studies have indicated higher incidences of respiratory and gastrointestinal illnesses in areas receiving aerosols from sewage treatment plants than in control areas, the elevated illness rates were either suspected to be the result of other factors, such as economic disparities, or were not verified by antibody tests for human viruses and isolations of pathogenic bacteria, parasites, or viruses (Fannin *et al.*, 1980; Johnson *et al.*, 1980a).

There have not been any documented disease outbreaks resulting from the spray irrigation of disinfected reclaimed water, and studies indicate that the health risk associated with aerosols from spray irrigation sites using reclaimed water is low (EPA, 1980b). However, until more sensitive and definitive studies are conducted to fully evaluate the ability of pathogens contained in aerosols to cause disease, the general practice is to limit exposure to aerosols produced from reclaimed water that is not highly disinfected through design or operational controls. Emission of aerosols or windblown spray from cooling towers receiving reclaimed water also may warrant attention.

2.4.1.5 Infectious Disease Incidence Related to Wastewater Reuse

Epidemiological investigations directed at wastewater-contaminated drinking water supplies, use of raw or minimally-treated wastewater for food crop irrigation, health effects to farmworkers who routinely contact poorly treated wastewater used for irrigation, and the health effects of aerosols or windblown spray emanating from spray irrigation sites using undisinfected wastewater have all provided evidence of infectious disease transmission from such practices (Lund, 1980; Feachem *et al.*, 1983; Shuval *et al.*, 1986). However, epidemiological studies of the exposed population at water reuse sites receiving disinfected reclaimed water treated to relatively high levels are of limited value because of the mobility of the population, the small size of the study population, the difficulty in determining the actual level of exposure of each individual, the low illness rate—if any—resulting from the reuse practice, insufficient sensitivity of current epidemiological techniques to detect low-level disease transmission, and other confounding factors. It is particularly difficult to detect low-level transmission of viral disease because many enteric viruses cause such a broad spectrum of disease syndromes that scattered cases of acute illness would probably be too varied in symptomology to be attributed to a single etiological agent.

The limitations of epidemiological investigations notwithstanding, water reuse in the U.S. has not been implicated as the cause of any infectious disease outbreaks (WPCF, 1989).

Reasonable standards of personal hygiene, e.g., use of protective clothing, change of clothing at the end of the work period, avoiding exposure to reclaimed water where possible, and care in handwashing and bathing following exposure and prior to eating, appear to be effective in protecting the health of workers at water reuse sites, regardless of the level of treatment provided. Protective measures may be relaxed at sites where reclaimed water has received a high level of treatment and disinfection.

The use of pathogen risk assessment models to assess health risks associated with the use of reclaimed water is a relatively new concept. Risk analysis has been used as a tool in assessing relative health risks from microorganisms in drinking water (Gerba and Haas, 1988; Regli *et al.*, 1991; Rose *et al.*, 1991) and reclaimed water (Asano and Sakaji, 1990; Rose and Gerba, 1991). Risk analyses require several assumptions to be made, e.g., minimum infectious dose of selected pathogens, concentration of pathogens in reclaimed water, quantity of reclaimed water (or pathogens) ingested, inhaled, or otherwise contacted by humans, and probability of infection based on infectivity models. Operation and management practices, such as treatment reliability features and use area controls, play an important role in reducing estimated health risks. At the present time, no reclaimed water standards or guidelines in the U.S. are based on risk assessment using microorganism infectivity models.

2.4.1.6 Chemical Constituents

The chemical constituents potentially present in municipal wastewater are a major concern when reclaimed water is used for potable reuse and may also affect the acceptability of reclaimed water for other uses such as food crop irrigation. The mechanisms of food crop contamination include: physical contamination, where evaporation and repeated application may result in a buildup of contaminants on crops; uptake through the roots from the applied water or the soil; and foliar uptake. With the exception of possible inhalation of volatile organics from indoor exposure, chemical concerns are less important where reclaimed water is not to be consumed. Chemical constituents are also a consideration when reclaimed water percolates into groundwater as a result of irrigation, groundwater recharge, or other uses. These practices are covered in Chapter 3. Some of the inorganic and organic constituents of importance in water reclamation and reuse are listed in Table 5.

a. Inorganics

In general, the health hazards associated with the ingestion of inorganic constituents, either directly or through food, are well-established (EPA, 1976), and EPA has set maximum contaminant levels (MCLs) for drinking water. The concentrations of inorganic constituents in reclaimed water depend mainly on the source of wastewater and the degree of treatment. Residential use of water typically adds about 300 mg/L of dissolved inorganic solids, although the amount added can range from approximately 150 mg/L to more than 500 mg/L. As indicated in Table 5, the presence of total dissolved solids, nitrogen, phosphorus, heavy metals, and other inorganic constituents may affect the acceptability of reclaimed water for different reuse applications. Wastewater treatment generally can reduce many trace elements to below recommended maximum levels for irrigation and drinking water with existing technology (Culp, *et al.*, 1980).

b. Organics

The organic makeup of raw wastewater includes naturally occurring humic substances, fecal matter, kitchen wastes, liquid detergents, oils, grease, and other substances that one way or another become part of the sewage stream. Industrial and residential wastes can contribute significant quantities of synthetic organic compounds.

The need to remove organic constituents is related to the end use of reclaimed water. Some of the adverse effects associated with organic substances include:

- Aesthetically displeasing: they may be malodorous and impart color to the water.
- Nuisance: deposits of organic matter may present vector control and eventually health problems.
- Clogging: particulate matter may clog sprinkler heads or accumulate in soil and affect permeability.
- Oxygen consuming: organic substances upon decomposition deplete the dissolved oxygen content in streams and lakes, thus negatively impacting aquatic life which depends upon this supply of oxygen for survival.
- Use limiting: many industrial applications cannot tolerate water high in organic content.
- Disinfection effects: organic matter can interfere with chlorine, ozone, and ultraviolet disinfection, thereby making them less available for disinfection purposes.
- Health effects: ingestion of water containing certain organic compounds may result in acute or chronic health effects.

The health effects resulting from organic constituents are of primary concern for indirect or direct potable reuse but, as with certain inorganic constituents, may also be of concern where reclaimed water is utilized for food crop irrigation, where reclaimed water from irrigation or other beneficial uses reaches potable groundwater supplies, or where the organics may bioaccumulate in the food chain, e.g., in fish-rearing ponds. The effects may be manifested from short-term exposure or become apparent only after years of exposure. Although drinking water standards contain MCLs for some organic contaminants, compliance with existing standards alone would not assure that reclaimed water is safe for potable reuse.

Traditional measures of organic matter such as BOD, chemical oxygen demand (COD), and total organic carbon (TOC) are widely used as indicators of treatment efficiency and water quality for many nonpotable uses of reclaimed water, but they have only indirect relevance to toxicity and health effects evaluation. The identification and quantification of extremely low levels of organic constituents in water is possible using sophisticated analytical instrumentation such as gas chromatography/ mass spectrometry (GC/MS) interfaced with computers. GC/MS analyses are costly and may require extensive

Table 5. Inorganic and Organic Constituents of Concern in Water Reclamation and Reuse

Constituent	Measured Parameters	Reason for Concern
Suspended Solids	Suspended solids (SS), including volatile and fixed solids cause plugging in irrigation systems.	Organic contaminants, heavy metals, etc. are adsorbed on particulates. Suspended matter can shield microorganisms from disinfectants. Excessive amounts of SS
Biodegradable Organics	Biochemical oxygen demand, Chemical oxygen demand, Total organic carbon	Aesthetic and nuisance problems. Organics provide food for microorganisms, adversely affect disinfection processes, make water unsuitable for some industrial or other uses, consume oxygen, and may result in acute or chronic effects if reclaimed water is used for potable purposes.
Nutrients	Nitrogen, Phosphorus, Potassium	Nitrogen, phosphorus, and potassium are essential nutrients for plant growth, and their presence normally enhances the value of the water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesirable aquatic life. When applied at excessive levels on land, nitrogen can also lead to nitrate build-up in groundwater.
Stable Organics	Specific compounds (e.g., pesticides, chlorinated hydrocarbons)	Some of these organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of reclaimed water for irrigation or other uses.
Hydrogen Ion Concentration	pH	The pH of wastewater affects disinfection, coagulation, metal solubility, as well as alkalinity of soils. Normal range in municipal wastewater is pH = 6.5 - 8.5, but industrial waste can alter pH significantly.
Heavy Metals	Specific elements (e.g., Cd, Zn, Ni, and Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of the reclaimed water for irrigation or other uses.
Dissolved Inorganics	Total dissolved solids, electrical conductivity, specific elements (e.g., Na, Ca, Mg, Cl, B)	Excessive salinity may damage some crops. Specific ions such as chloride, sodium, boron are toxic to some crops. Sodium may pose soil permeability problems.
Residual Chlorine	Free and combined chlorine	Excessive amount of free available chlorine (>0.05 mg/L) may cause leaf-tip burn and damage some sensitive crops. However, most chlorine in reclaimed water is in a combined form, which does not cause crop damage. Some concerns are expressed as to the toxic effects of chlorinated organics in regard to groundwater ontamination.

Source: Adapted from Pettygrove and Asano, 1985.

and difficult sample preparation, particularly for nonvolatile organics.

In addition, organic compounds in wastewater can be transformed into chlorinated organic species where chlorine is used for disinfection purposes. To date, most attention has focused on the trihalomethane (THM) compounds, a family of organic compounds typically occurring as chlorine or bromine substituted forms of methane. Chloroform is the most prevalent THM compound and has been implicated in the development of cancer of the liver and kidney.

Although a large number of specific organic constituents have been identified in wastewater, about 90 percent of the residual organic fraction remains unidentified. Toxicological testing of reclaimed water organic residuals using the Ames Salmonella Microsome Mutagen Assay and the Mammalian Cell Transformation Assay have indicated mutagenicity, cytotoxicity, and

Table 6. Typical Composition of Untreated Municipal Wastewater[a]

Constituent	Concentration Range[b] Strong	Medium	Weak	U.S. Average[c]
Solids, total:	1,200	720	350	—
Dissolved, total[d]	850	500	250	—
Fixed	525	300	145	—
Volatile	325	200	105	—
Suspended	350	220	100	192
Fixed	75	55	20	—
Volatile	275	165	80	—
Settleable solids, mL/L	20	10	5	—
Biochemical oxygen demand, 5-day 20°C	400	220	110	181
Total organic carbon	290	160	80	102
Chemical oxygen demand	1,000	500	250	417
Nitrogen (total)	85	40	20	34
Org-N	35	15	8	13
NH_3-N	50	25	12	20
NO_2-N	0	0	0	—
NO_3-N	0	0	0	0.6
Phosphorus (total)	15	8	4	9.4
Organic	5	3	1	2.6
Inorganic	10	5	3	6.8
Chlorides[d]	100	50	30	—
Alkalinity (as $CaCO_3$)[d]	200	100	50	211
Grease	150	100	50	—
Total coliform bacteria[e] (#/100 mL)	—	—	—	$22x10^6$
Fecal coliform bacteria[e] (#/100 mL)	—	—	—	$8x10^6$
Viruses, PFU/100 mL[g]	—	—	—	500

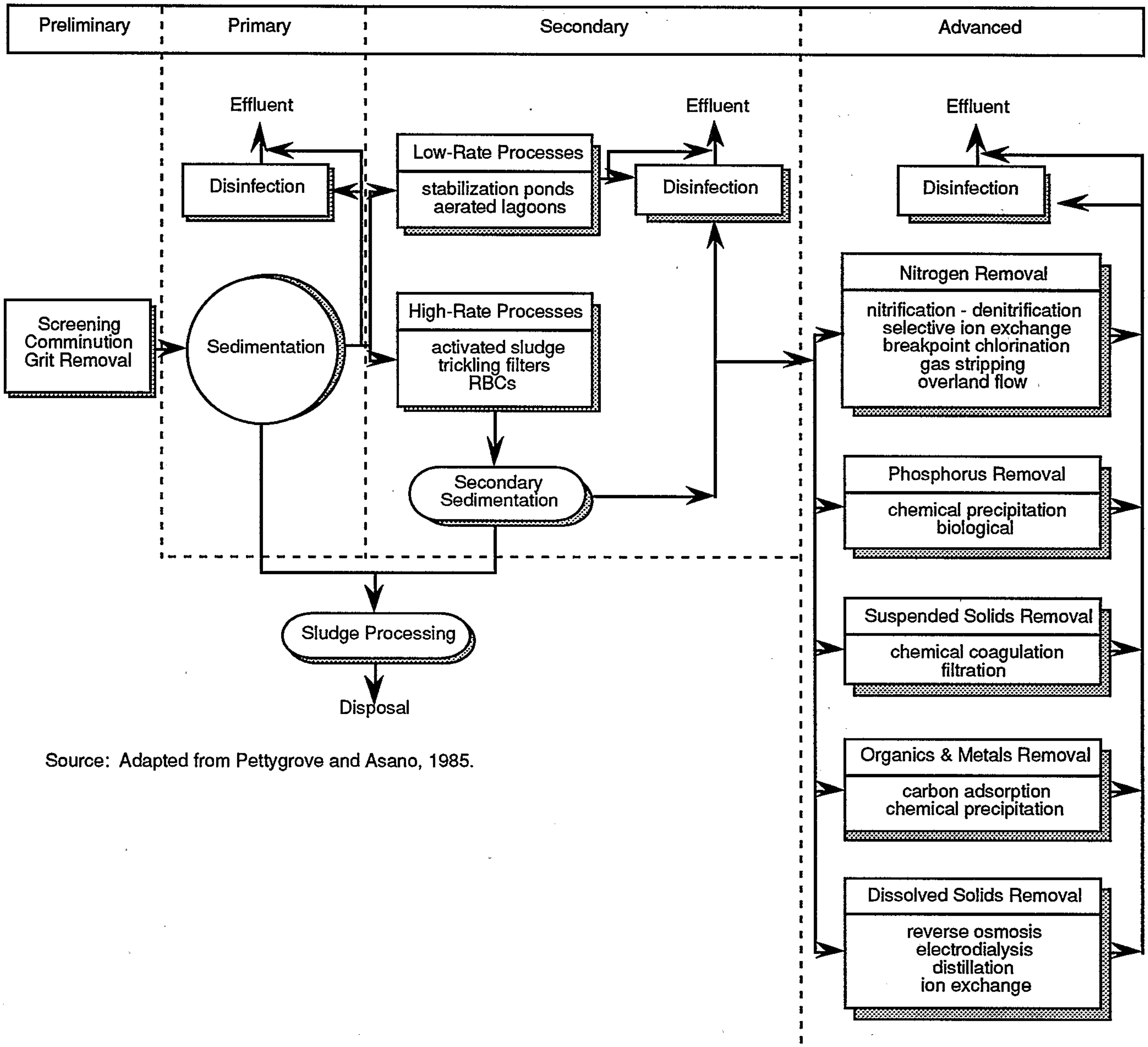
a All values are expressed in mg/L, except as noted.
b After Metcalf & Eddy, Inc., 1979.
c Culp *et al.*, 1979.
d Values should be increased by amount in domestic water supply.
e Geldreich, 1978.
f Most probable number/100 mL of water sample.
g Plaque-forming units.

carcinogenicity in *in vitro* cellular assays (Nellor, *et al.*, 1984). However, these *in vitro* toxicological evaluations cannot be relied on by themselves to provide proof of carcinogenic activity. The only way to address the question of whether the unknown aggregated trace organic substances in reclaimed water would cause any meaningful risk to populations consuming the water is by whole animal tests on mixture concentrates and by retrospective surveillance of the population. State-of-the-art toxicology studies on animals provide the only recognized method for evaluating risk prior to public exposure (State of California, 1987).

Results of epidemiological studies of populations receiving drinking water considered to contain significant quantities of organic compounds have been inconclusive, although positive correlations were found in several studies. Causal relationships could not be proven on the basis of the results of the studies. The National Academy of Sciences (1983) concluded that the associations were small and had a wide margin of error, which could be attributed to the methodological difficulties inherent in most epidemiological studies (National Academy of Sciences, 1983). NAS also concluded that, when viewed collectively, the epidemiological studies provided sufficient evidence for maintaining the hypothesis that there may be a potential health risk.

While technology regarding trace organics has advanced substantially in the last decade, uncertainties persist regarding the range of compounds, additive, synergistic or antagonistic effects, and the total health significance of trace organics in drinking water. The ability to identify and quantify low levels of contaminants in water has outstripped our capability to evaluate and interpret the significance of the levels measured in assessing potential health effects.

Figure 12. Generalized Flow Sheet for Wastewater Treatment



Source: Adapted from Pettygrove and Asano, 1985.

2.4.2 Treatment Requirements

Raw municipal wastewater may include contributions from domestic and industrial sources, infiltration and inflow from the collection system, and, in the case of combined sewer systems, urban stormwater runoff. The quantity and quality of wastewater derived from each source vary among communities depending upon the number of commercial and industrial establishments in the area and the condition of the sewer system. Table 6 presents the typical composition of untreated municipal wastewater.

Levels of wastewater treatment are generally classified as preliminary, primary, secondary, and advanced. A generalized flow sheet for municipal wastewater treatment is given in Figure 12.

2.4.2.1 Preliminary Treatment

Preliminary treatment of wastewater consists of the physical processes of screening or comminution and grit removal. Coarse screening is generally the first treatment step employed and is used for the removal of large solids and trash that may interfere with downstream treatment operations. Comminution devices have been

Table 7. Typical Constituent Removal Efficiencies for Primary and Secondary Treatment

	Average Percent Removal*		
Constituent	Primary Treatment	Activated Sludge	Trickling Filters
BOD	42	89	69
COD	38	72	58
TSS	53	81	63
NH3-N	18	63	—
Phosphorus	27	45	—
Oil and grease	65	86	—
Arsenic	34	83	—
Cadmium	38	28	—
Chromium	44	55	5
Copper	49	70	19
Iron	43	65	56
Lead	52	60	46
Manganese	20	58	40
Mercury	11	30	16
Selenium	0	13	0
Silver	55	7	—
Zinc	36	75	55
Color	15	55	56
Foaming agents	27	—	—
Turbidity	31	—	—
TOC	34	—	—

* Note: Actual percent removal will vary.

Source: Adapted from WPCF, 1989, and other sources.

Table 8. Typical Percent Removal of Microorganisms by Conventional Wastewater Treatment*

		Secondary Treatment	
Infectious Agent	Primary Treatment	Activated Sludge	Trickling Filter
Fecal coliform	<10	0-99	85-99
Salmonella	0-15	70-99+	85-99+
Mycobacterium tuberculosis	40-60	5-90	65-99
Shigella	15	80-90	85-99
Entamoeba histolytica	0-50	Limited	Limited
Helminth ova	50-98	Limited	60-75
Enteric viruses	Limited	75-99	0-85

*Not including disinfection.

Source: Crook, 1990.

used with limited success to cut up solids into a smaller uniform size to improve downstream operations. Grit chambers are designed to remove material such as sand, gravel, cinders, eggshells, bone chips, seeds, coffee grounds, and large organic particles, such as food wastes. Settling of most organic solids is prevented in the grit chamber due to the high flow velocity of wastewater through the chamber. Other preliminary treatment operations can include flocculation, odor control, chemical treatment, and pre-aeration.

2.4.2.2 Primary Treatment

Primary treatment is a physical treatment process to remove settleable organic and inorganic solids by sedimentation and floating materials by skimming. This process also is effective for the removal of some organic nitrogen, organic phosphorus and heavy metals, but does little for the removal of colloidal and dissolved constituents. Additional phosphorus and heavy metal removal can be achieved through the addition of chemical coagulants and polymers. Average constituent removal efficiencies for primary treatment processes are given in Table 7.

Primary treatment has little effect on the removal of most biological species present in the wastewater. However, some protozoa and parasite ova and cysts will settle out during primary treatment, and some particulate-associated microorganisms may be removed with settleable matter. Primary treatment does not effectively reduce the level of viruses in sewage. Typical microorganism removal efficiencies of primary treatment are shown in Table 8. Generally, primary treatment by itself is not considered adequate for reuse applications.

2.4.2.3 Secondary Treatment

Secondary treatment follows primary treatment where the latter is employed and utilizes an aerobic biological treatment process for the removal of organic matter and, in some cases, nitrogen and phosphorus. Aerobic biological treatment occurs in the presence of oxygen whereby microorganisms oxidize the organic matter in the wastewater. Several types of aerobic biological treatment are utilized for secondary treatment, including: activated sludge, trickling filters, rotating biological contactors (RBCs), and stabilization ponds. Typical microorganism and other constituent removal efficiencies for selected secondary treatment processes are presented in Tables 7 and 8.

The activated sludge, trickling filter, and other attached growth processes are considered high-rate biological processes due to the high concentrations of microorganisms utilized for the metabolization of organic matter. These processes accomplish biological oxidation in relatively small basins and utilize sedimentation tanks (secondary clarifiers) after the aerobic process to separate the microorganisms and other settleable solids from the treated wastewater.

In the activated sludge process, treatment is provided in an aeration tank in which the wastewater and microorganisms are in suspension and continuously mixed through aeration. Trickling filters utilize media such as stones, plastic shapes or wooden slats in which the microorganisms become attached. RBCs are similar to trickling filters in that the organisms are attached to support media, which in this case are partially submerged rotating discs in the wastewater stream.

These high-rate processes are capable of removing up to 95 percent of BOD, COD, and SS originally present in the wastewater and significant amounts of many (but not all) heavy metals and specific toxic organic compounds. Trickling filters are not as effective as activated sludge processes in removing soluble organics because of less contact between the organic matter and microorganisms. Activated sludge treatment can reduce the soluble BOD fraction to 1 to 2 mg/L while the trickling filter process typically reduces the soluble BOD to 10 to 15 mg/L. Biological treatment, including secondary sedimentation, typically reduces the total BOD to 15 to 30 mg/L, COD to 40 to 70 mg/L, and TOC to 15 to 25 mg/L. Very little dissolved minerals are removed during conventional secondary treatment.

Stabilization ponds require relatively large land areas and are most widely used rural areas and in warm climates and/or where land is available at reasonable cost. They are often arranged in a series of anaerobic, facultative, and maturation ponds with an overall hydraulic detention time of 10-50 days, depending on the design temperature and effluent quality required (Mara and Cairncross, 1989). Most organic matter removal occurs in the anaerobic and facultative ponds. Maturation ponds, which are largely aerobic, are designed primarily to remove pathogenic microorganisms following biological oxidation processes. Well-designed stabilization pond systems are capable of reducing the BOD to 15-30 mg/L, COD to 90-135 mg/L, and SS to 15-40 mg/L (Shuval *et al.,1986).*

Stabilization ponds utilize algae to provide oxygen for the system. This process is considered a low-rate biological process. However, stabilization ponds are capable of providing considerable nitrogen removal under certain conditions, e.g., high temperature and pH and long detention times. Stabilization ponds are effective in removing microorganisms from wastewater. Well designed and operated pond systems are capable of achieving a 6-log reduction of bacteria, a 3-log reduction of helminths, and a 4-log reduction of viruses and cysts (Mara and Cairncross, 1989).

Conventional secondary treatment processes reduce the concentration of microorganisms by predation or adsorption to particulates that are subsequently removed by sedimentation. Biological treatment is capable of removing over 90 percent of the bacterial organisms and viruses. Removal by lagoon systems can be erratic, but stabilization pond systems having long retention times can effectively reduce pathogen concentrations to very low levels.

Secondary treatment may be acceptable for reuse applications where the risk of public exposure to the reclaimed water is low, such as in irrigation of non-food crops as well as landscape irrigation where public access is limited.

2.4.2.4 Disinfection

The most important process for the destruction of microorganisms is disinfection. In the United States, the most common disinfectant for both water and wastewater is chlorine. Ozone and ultraviolet light are other prominent disinfectants used at wastewater treatment plants. Factors that should be considered when evaluating disinfection alternatives include disinfection effectiveness and reliability, capital and operating and maintenance costs, practicality (e.g., ease of transport and storage or onsite generation, ease of application and control, flexibility, complexity, and safety), and potential adverse effects such as toxicity to aquatic life or formation of toxic or carcinogenic substances. The predominant advantages and disadvantages of disinfection alternatives are well know and have been summarized by EPA in its design manual on municipal wastewater disinfection (EPA, 1986). Table 9 presents information to help assess chlorination, chlorination followed by dechlorination, ozonation, and ultraviolet radiation with respect to non-monetary factors. Some of these factors are further discussed below.

The efficiency of disinfection with chlorine is dependent upon the water temperature, pH, degree of mixing, time of contact, presence of interfering substances, concentration and form of the chlorinating species, and the nature and concentration of the organisms to be destroyed. In general, bacteria are less resistant to chlorine than are viruses, which in turn are less resistant than parasite ova and cysts.

The chlorine dosage required to disinfect a wastewater to any desired level is greatly influenced by the constituents present in the wastewater. Some of the

Table 9. Applicability of Alternative Disinfection Techniques

Consideration	Chlorination	Chlorination/ Dechlorination	Ozone	Ultraviolet
Size of plant	all sizes	all sizes	medium to large	small to medium
Applicable level of treatment prior to disinfection	all levels	all levels	secondary	secondary
Equipment reliability	good	fair to good	fair to good	fair to good
Process control	well developed	fairly well developed	developing	developing
Relative complexity of technology	simple to moderate	moderate	complex	simple to moderate
Safety concerns in transportation	yes	yes	no	no
Safety concerns onsite	substantial	substantial	moderate	minimal
Bactericidal	good	good	good	good
Virucidal	poor	poor	good	good
Fish toxicity	toxic	non-toxic	none expected	non-toxic
Hazardous byproducts	yes	yes	none expected	no
Persistent residual	long	none	none	none
Contact time	long	long	moderate	short
Contributes dissolved oxygen	no	no	yes	no
Reacts with ammonia	yes	yes	yes (high pH only)	no
Color removal	moderate	moderate	yes	no
Increased dissolved solids	yes	yes	no	no
pH dependent	yes	yes	slight (high pH)	no
O&M sensitive	minimal	minimal	high	moderate
Corrosive	yes	yes	yes	no

Source: EPA, 1986.

interfering substances are organic constituents, which consume the disinfectant; particulate matter, which protects microorganisms from the action of the disinfectant; and ammonia, which reacts with chlorine to form chloramines, a much less effective disinfectant species than free chlorine. In practice, the amount of chlorine added is determined empirically, based on desired residual and effluent quality. Chlorine, which in low concentrations is toxic to many aquatic organisms, is easily controlled in reclaimed water by dechlorination, typically with sulfur dioxide.

Ozone (O_3), is a powerful disinfecting agent and a powerful chemical oxidant in both inorganic and organic reactions. Due to the instability of ozone, it must be generated onsite from air or oxygen carrier gas. Ozone destroys bacteria and viruses by means of rapid oxidation of the protein mass, and disinfection is achieved in a matter of minutes. Some disadvantages are that the use of ozone is relatively expensive and energy intensive, ozone systems are more complex to operate and maintain than chlorine systems, and ozone does not maintain a residual in water. Ozone is a highly effective disinfectant for advanced wastewater treatment plant effluent, removes color, and contributes dissolved oxygen.

Ultraviolet (UV) is a physical disinfecting agent. Radiation at a wave length of 254 mm penetrates the cell wall and is absorbed by the cellular nucleic acids. This can prevent replication and cause death of the cell. UV radiation is receiving increasing attention as a means of disinfecting reclaimed water because it may be less expensive than disinfection with chlorine, it is safer to use than chlorine gas, and—in contrast to chlorine—it does not result in the formation of chlorinated hydrocarbons. The effectiveness of UV radiation as a disinfectant (where fecal coliform limits are on the order of 200/100 mL), has been well established as evidenced by its use at more than 120 small- to medium-sized wastewater treatment plants in the United States (EPA, 1986). Little information is available on the ability of UV disinfection to achieve high levels of disinfection; however, in one pilot plant study, a UV dose of 60 mw-s/cm^2 or greater consistently disinfected unfiltered secondary effluent to a total coliform level of 23/100 mL or less, and a UV dose of at least 97 mw-s/cm^2 consistently disinfected filtered secondary effluent to a total coliform level of 2.2/100 mL or less (Snider *et al.*, 1991). The study also indicated that filtration, which was effective in removing significant amounts of SS and providing an effluent with a turbidity of less than 2 NTU, enhanced the performance of the UV disinfection.

Other disinfectants, such as gamma radiation, bromine, iodine, and hydrogen peroxide, have been considered for the disinfection of wastewater but are not generally used because of economical, technical, operational, or disinfection efficiency considerations.

2.4.2.5 Advanced Wastewater Treatment

Advanced wastewater treatment processes are generally utilized when a high quality reclaimed water is necessary, such as for the irrigation of urban landscaping and food crops eaten raw, contact recreation, and many industrial applications. Individual unit processes capable of removing the above mentioned constituents are shown in Figure 12.

The principal advanced wastewater treatment processes for water reclamation are:

- Filtration - Filtration is a common treatment process used to remove particulate matter prior to disinfection. Filtration involves the passing of wastewater through a bed of granular media, which retain the solids. Typical media include sand, anthracite, and garnet. Removal efficiencies can be improved through the addition of certain polymers and coagulants. Table 10 presents average constituent removal efficiencies for filtration.

- Nitrification - Nitrification is the term generally given to any wastewater treatment process that biologically converts ammonia nitrogen sequentially to nitrite nitrogen and nitrate nitrogen. Nitrification does not remove significant amounts of nitrogen from the effluent; it only converts it to another chemical form. Nitrification can be done in many suspended and attached growth treatment processes when they are designed to foster the growth of nitrifying bacteria. In the traditional activated sludge process it is accomplished by designing the process to operate at a solids retention time that is long enough to prevent the slow-growing nitrifying bacteria from being wasted out of the system. Nitrification will also occur in trickling filters that operate at low BOD/TKN ratios either in combination with BOD removal, or as a separate advanced process following any type of secondary treatment. A well designed and operated nitrification process will produce an effluent containing 1.0 mg/L or less ammonia nitrogen. Ammonia nitrogen can also be removed from effluent by several chemical or physical treatment methods such as air stripping, ion exchange, RO and breakpoint

Table 10. Typical Filtration Process Removal

Constituent	Average Performance (%)* Following Biological Secondary Treatment[a]	Following Physical-Chemical Treatment[b]
BOD	39	36
COD	34	22
TSS	73	42
NH_3-N	33	—
NO_3N	56	—
Phosphorus	57	—
Alkalinity	83	—
Arsenic	67	0
Cadmium	32	38
Chromium	53	9
Iron	56	—
Lead	16	26
Manganese	80	—
Mercury	33	0
Selenium	90	0
Color	31	—
Turbidity	71	31
TOC	33	26

* Note: Actual percent removal will vary.
a Values given in terms of percent removal from secondary effluent.
b Values given in terms of percent removal from chemically clarified secondary effluent.

Source: Adapted from WPCF, 1989.

chlorination. However, these methods have generally proven to be uneconomical or too difficult to operate for ammonia removal in most municipal applications. Ammonia removal may be required for discharges to surface waters for any of three basic reasons. These are the toxicity of ammonia to aquatic organisms, the relatively high biological oxygen demand of ammonia, and its value as an aquatic plant nutrient. It is also the necessary first step for biological denitrification.

- Denitrification - Denitrification is any wastewater treatment method that completely removes total nitrogen. As with ammonia removal, denitrification is usually best done biologically for most municipal applications, in which case it must be preceded by nitrification. In biological denitrification, nitrate nitrogen is used by a variety of heterotrophic bacteria as the terminal electron acceptor in the absence of dissolved oxygen. In the process, the nitrate nitrogen is converted to nitrogen gas which escapes to the atmosphere. A carbonaceous food source is also required by the bacteria in these processes.

  Denitrification can be done using many alternative treatment processes. These include variations of many common suspended growth and some attached growth treatment processes provided they are designed to create the proper microbial environment. The denitrification reactor must contain nitrate nitrogen, a carbon source and facultative heterotrophic bacteria in the absence of dissolved oxygen. Biological denitrification processes can be designed to achieve effluent nitrogen concentrations between 2.0 mg/L and 12 mg/L nitrate nitrogen. The effluent total nitrogen will be somewhat higher depending on the concentration of VSS and soluble organic nitrogen present. Denitrification may be necessary where reclaimed water reaches potable water supply aquifers. It may also be required prior to using effluent for agricultural irrigation of certain crops during specific times in their growing cycle (such as sugar cane and corn).

- Phosphorus Removal - Phosphorus can be removed from wastewater by either chemical or biological methods, or a combination of the two. The choice of methods will depend on site specific conditions, including the amount of phosphorus to be removed and the desired effluent phosphorus concentration. Chemical phosphorus removal is done by precipitating the phosphorus from solution by the addition of iron, aluminum or calcium salts. Biological phosphorus removal relies on the culturing of bacteria that will store excess amounts of phosphorus when exposed to anaerobic conditions followed by aerobic conditions in the treatment process. In both cases, the phosphorus is removed from the treatment process with the waste sludge. Chemical phosphorus removal can attain effluent orthophosphorus concentrations less than 0.1 mg/L, while biological phosphorus removal will usually produce an effluent phosphorus concentration between 1.0 and 2.0 mg/L.

- Coagulation-Sedimentation - Chemical coagulation with lime, alum, or ferric chloride followed by sedimentation removes SS, heavy metals, trace substances, phosphorus, and turbidity. Table 11 presents average constituent removal efficiencies for the coagulation-sedimentation process.

- Carbon Adsorption - One of the most effective advanced wastewater treatment processes for removing biodegradable and refractory organic constituents is granular activated carbon. Carbon adsorption can reduce the levels of synthetic organic chemicals in secondary effluent by 75 to 85 percent. The basic mechanism of removal is by adsorption of the organic compounds onto the carbon. Carbon adsorption preceded by conventional secondary treatment and filtration can produce an effluent with a BOD of 0.1 to 5.0 mg/L, a COD of 3 to 25 mg/L, and a TOC of 1 to 6 mg/L.

  Carbon adsorption treatment will remove several metal ions, particularly cadmium, hexavalent chromium, silver, and selenium. Activated carbon has been used to remove un-ionized species, such as arsenic and antimony, from an acidic stream, and it also decreases mercury to low levels, particularly at low pH values.

- Other Processes - Other advanced wastewater treatment processes of constituent removal include ammonia stripping, breakpoint chlorination for ammonia removal, selective ion-exchange for nitrogen removal, and reverse osmosis for TDS reduction and removal of inorganic and organic constituents.

Table 11. Coagulation-Sedimentation Typical Constituent Removals

	Average Performance (%)*		
Constituent	Alum Addition	Lime Addition	Ferric Addition
BOD	65	65	62
COD	69	52	61
TSS	70	70	67
NH_3-N	—	22	14
Phosphorus	78	91	71
Alkalinity	16	—	36
Oil & grease	89	40	91
Arsenic	83	6	49
Barium	—	61	—
Cadmium	72	30	68
Chromium	86	56	87
Copper	86	55	91
Fluoride	44	50	—
Iron	83	87	43
Lead	90	44	93
Manganese	40	93	—
Mercury	24	0	18
Selenium	0	0	0
Silver	89	49	89
Zinc	80	78	72
Color	72	46	73
Foaming agents	55	39	42
Turbidity	86	70	88
TOC	51	73	66

*Values given in terms of percent removal from secondary effluent.
Note: Actual percent removal will vary.

Source: Adapted from WPCF, 1989.

Advanced wastewater treatment processes such as chemical coagulation, sand or mixed media filtration, and ion exchange are not designed to remove many organic substances, particularly soluble organics. When these processes follow conventional secondary treatment, they typically remove 40 to 85 percent of the total BOD, COD, and TOC.

Advanced treatment by chemical coagulation, sedimentation, and filtration unit processes has been demonstrated to remove more than 2 logs (99 percent) of seeded poliovirus (Sanitation Districts of Los Angeles County, 1977). This treatment chain reduces the turbidity of the wastewater to very low levels, thereby enhancing the efficiency of the subsequent disinfection process. Chemical coagulation and sedimentation alone can remove up to 2 logs (99 percent) of the viruses, although the presence of organic matter can significantly decrease the amount of viruses removed. Direct filtration, that is, chemical coagulation and filtration, has also been shown to remove up to 2 logs (99 percent) of seeded poliovirus (Sanitation Districts of Los Angeles County, 1977). In one study, sand and dual media filtration of secondary effluent, without coagulant addition prior to filtration, did not significantly reduce enteric virus levels (Noss *et al.*, 1989). The primary purpose of the filtration step is not to remove viruses but to remove floc and other suspended matter, which coincidentally may contain adsorbed or enmeshed viruses, thereby making the disinfection process more effective.

Chemical coagulation and filtration followed by chlorine disinfection to very low total coliform levels can remove or inactivate 5 logs (99.999 percent) of seeded poliovirus through these processes alone and subsequent to conventional biological secondary treatment can produce effluent essentially free of measurable levels of pathogens (Sanitation Districts of Los Angeles County, 1977; Sheikh, *et al.*, 1990). This abbreviated treatment chain, in conjunction with specific design and operational controls has been shown to produce reclaimed water free of measurable levels of viruses. Based in part on the two studies cited above, the State of California developed a policy statement that includes the following design and operational controls for direct filtration facilities producing reclaimed water for uses where an *essentially* virus-free water is deemed necessary (State of California, 1988):

- Coagulant addition unless secondary effluent turbidity is less than 5 NTU,
- Maximum filtration rate of 12 m/h (5 gpm/sq ft),
- Average filter effluent turbidity of 2 NTU or less,
- High-energy rapid mix of chlorine,
- Theoretical chlorine contact time of at least 2 hours with an actual modal contact time of at least 90 minutes,
- Minimum chlorine residual of 5 mg/L after the required contact time,
- Chlorine contact chamber length to width or depth ratio of at least 40:1,
- 7-day median number of total coliform organisms in the effluent of 2.2/100 mL or less, not to exceed 23/100 mL in any sample.

Virus inactivation under alkaline pH conditions can be accomplished using lime as a coagulant, but pH values of 11 to 12 are required before significant inactivation is obtained. The mechanism of inactivation under alkaline conditions is caused by denaturation of the protein coat and by disruption of the virus.

The removal of biological contaminants by advanced treatment processes designed to remove either inorganic or organic constituents is incidental and, generally, not too efficient. An exception is reverse osmosis, which can be very effective in removing most viruses and virtually all larger microorganisms. Activated carbon adsorption has been shown to adsorb some viruses from wastewater, but the adsorbed viruses can be displaced by organic compounds and enter the effluent.

2.4.3 Reliability in Treatment

A high standard of reliability is required at water reclamation plants. Because there is potential for harm in the event that improperly treated reclaimed water is delivered to the use area, water reuse requires strict conformance to all applicable water quality parameters. The need for reclamation facilities to reliably and consistently produce and distribute reclaimed water of adequate quality and quantity is essential and dictates that careful attention be given to reliability features during the design, construction, and operation of the facilities.

A number of fallible elements combine to make up an operating water reclamation system. These include the power supply, individual treatment units, mechanical equipment, the maintenance program, and the operating personnel. There is an array of design features and non-design provisions which can be employed to improve the reliability of the separate elements and the system as a whole. Backup systems are important in maintaining reliability in the event of failure of vital components. Particularly critical units include the disinfection system, the power supply, and the various treatment unit processes.

For reclaimed water production, EPA Class I reliability is recommended. Class I reliability requires redundant facilities to prevent treatment upsets during power and equipment failures, flooding, peak loads, and maintenance shutdowns. Reliability for water reuse should also consider:

- Operator certification to ensure that qualified personnel operate the water reclamation and reclaimed water distribution systems.
- Instrumentation and control systems for on-line monitoring of treatment process performance and alarms for process malfunctions.
- A quality assurance program to ensure accurate sampling and laboratory analysis protocol.
- Adequate emergency storage to retain reclaimed water of unacceptable quality for re-treatment or alternative disposal.
- Supplemental storage to ensure that the supply can match the user's demands.
- An industrial pretreatment program and enforcement of sewer use ordinances to prevent illicit dumping of hazardous materials into the collection system.

2.4.3.1 EPA Guidelines for Reliability

EPA, under its predecessor agency the Federal Water Quality Administration, recognized the importance of treatment reliability more than 20 years ago, and issued guidelines entitled "Federal Guidelines: Design, Operation and Maintenance of Waste Water Treatment Facilities" (Federal Water Quality Administration, 1970). These guidelines provided an identification and description of various reliability provisions and included the following concepts or principles regarding treatment plant reliability:

a. All water pollution control facilities should be planned and designed to provide for maximum reliability at all times.

b. The facility should be capable of operating satisfactorily during power failures, flooding, peak loads, equipment failure, and maintenance shutdowns. A minimum of primary treatment may be required where necessitated by the uses of the receiving waters.

c. Such reliability can be obtained through the use of various design techniques which will result in a facility which is virtually "failsafe" (Federal Water Quality Administration, 1970).

The following are the more specific subjects for consideration in the preparation of final construction plans and specifications which will aid in accomplishing the above principles:

The following design features were defined as necessary for ensuring reliability:

- Duplicate sources of electric power.
- Standby power for essential plant elements.
- Multiple units and equipment.
- Holding tanks or basins to provide for emergency storage of overflow and adequate pump-back facilities.
- Flexibility of piping and pumping facilities to permit rerouting of flows under emergency conditions.
- Provision for emergency storage or disposal of sludge (Federal Water Quality Administration, 1970).

The non-design reliability features in the federal guidelines include provisions for qualified personnel, an effective monitoring program, and an effective maintenance and process control program. In addition to plans and specifications, the guidelines specify submission of a preliminary project planning and engineering report which will clearly indicate compliance with the guideline principles.

In summary, the federal guidelines identify eight design principles and four other significant factors which appear appropriate to consider for reuse operations:

<u>Design factors</u>
Duplicate power sources
Standby power
Multiple units and equipment
Emergency storage
Piping and pumping flexibility
Dual chlorination
Automatic residual control
Automatic alarms

<u>Other factors</u>
Engineering report
Qualified personnel
Effective monitoring program
Effective maintenance and process control program

EPA subsequently published "Design Requirements for Mechanical, Electric, and Fluid Systems and Component Reliability" in 1974 (EPA, 1974). While the purpose of that publication was to provide reliability design criteria for wastewater treatment facilities seeking federal financial assistance under PL 92-500, the criteria are useful for the design and operation of all wastewater treatment plants. These requirements established minimum standards of reliability for wastewater treatment works. Other important reliability design features include on-line monitoring, e.g., turbidimeters and chlorine residual analyzers, and chemical feed facilities.

Table 12 presents a summary of the equipment requirements under the EPA guidelines for Class I reliability treatment facilities.

As given in Table 12, the integrity of the treatment system is enhanced by providing redundant or oversized unit processes. This reliability level was originally specified for treatment plants discharging into water bodies that could be permanently or unacceptably damaged by improperly treated effluent. Locations where Class I facilities might be necessary are given as facilities discharging near drinking water reservoirs, into shellfish waters, or in proximity to areas used for water contact sports (EPA, 1974).

Given the original intent of a Class I reliability requirements, similar requirements for water reclamation facilities are often desirable. For example, chemical addition facilities are a desirable reliability design feature. These facilities can provide greater operational flexibility by assisting during treatment plant upsets. In addition to unit processes, storage facilities may also be required to provide assurance that the product will be available in adequate supply to meet demand.

Table 12. Summary of Class I Reliability Requirements

Unit	Class I Requirement
Mechanically-Cleaned Bar Screen	A backup bar screen shall be provided (may be manually cleaned).
Pumps	A backup pump shall be provided for each set of pumps which performs the same function. Design flow will be maintained with any one pump out of service.
Comminution Facilities	If comminution is provided, an overflow bypass with bar screen shall be provided.
Primary Sedimentation Basins	There shall be sufficient capacity such that a design flow capacity of 50 percent of the total capacity will be maintained with the largest unit out of service.
Filters	There shall be a sufficient number of units of a size such that a design capacity of at least 75 percent of the total flow will be maintained with one unit out of service.
Aeration Basins	At least two basins of equal volume will be provided.
Mechanical Aerator	At least two mechanical aerators shall be provided. Design oxygen transfer will be maintained with one unit out of service.
Chemical Flash Mixer	At least two basins or a backup means of mixing chemicals separate from the basins shall be provided.
Final Sedimentation Basins	There shall be a sufficient number of units of a size such that 75 percent of the design capacity will be maintained with the largest unit out of service.
Flocculation Basins	At least two basins shall be provided.
Disinfectant Contact Basins	There shall be sufficient number of units of a size such that the capacity of 50 percent of the total design flow may be treated with the largest unit out of service.

Source: Adapted from U.S. Environmental Protection Agency, 1974.

2.4.3.2 Design Elements of Reliability

a. Power Supply

A standby power source should be provided at all water reclamation plants, except those few that operate entirely by gravity and have no critical processes relying on electric power (restricted to primary treatment and pond systems).

The standby power source should be of sufficient capacity to provide necessary service during failure of the normal power supply. Standby sources typically include gasoline or diesel operated generators or connections to another completely separate power system. Separate transformers should be provided for each power source. Many reclamation plants provide standby power with fuel-driven generators that require manual starting. Added reliability is attained by installing battery-operated switchover mechanisms together with an automatic starter. Standard operating procedure should require testing all of the equipment at least once a week.

It may be necessary for the primary power source to sustain only the critical loads in the standby or emergency mode of operation. These include pumps, important unit processes, instrumentation and controls, and critical lighting and ventilation. A single source of electrical power should normally be sufficient to provide for the needs of non-critical operations.

Power distributed to main control centers or control panels within the plant for the critical loads should be supplied from motor control centers connected to in-plant unit substations. Substations and feeders to motor control centers should be redundant. Critical in-plant power loads should be divided within the motor control center by tie breakers. The motor control center should be supplied with power at all times to treat the reclaimed water. Instrumentation and control panels associated with the operation of process critical loads should be provided with similar redundancy.

It may be acceptable to connect non-critical process loads to only one power source. However, non-critical loads within a unit operation should be divided as equally as possible between motor control centers so that a single failure will not result in complete unit operation loss.

b. Multiple Units and Equipment

When process units are taken out of service for maintenance, repair, or unanticipated breakdown, multiple units or standby unit processes should be available to continue treatment.

Multiple units means two or more process units such as tanks, ponds, compartments, blowers, or chemical feeders which are needed for parallel operation. The multiple units are a part of the normal treatment system and the total should be of sufficient capacity to enable effective operation with any one unit out of service. For example, with several aeration basins operated in parallel, it may be quite possible to continue to provide effective biological treatment while one basin is shut down for maintenance. A duplicate of the largest unit is usually provided for multi-unit pumping or chemical feed equipment.

A standby unit process means a complete unit process, such as a primary treatment system, a filtration system, or a disinfection system, which is maintained in operable condition and is capable of successfully replacing the usually operated system.

2.4.3.3 Additional Requirements for Reuse Applications

Different degrees of hazard are posed by process failures. From a public health standpoint, it is logical that a greater assurance of reliability should be required for a system producing reclaimed water for uses where direct or indirect human contact with the water is likely than for one producing water for uses where the possibility of contact is remote. Similarly, where specific constituents in reclaimed water may affect the acceptability of the water for any use, e.g., industrial process water, reliability directed at those constituents is important.

A unit process may be deficient in different degrees and for many reasons, including operational and mechanical deficiencies over- and under-loading, toxic substances, and breakdown of individual components. There are usually several alternatives available to meet reliability provisions. For example, California's Wastewater Reclamation Criteria (State of California, 1978) require that a biological treatment unit process be provided with any one of the following reliability factors:

- Alarm and multiple biological treatment units capable of producing oxidized wastewater with one unit not in operation;
- Alarm, short-term retention or disposal provisions, and standby replacement equipment;
- Alarm and long-term storage or disposal provisions; or
- Automatically actuated long-term storage or disposal provisions.

Standby units or multiple units should be encouraged for the major treatment elements at all reclamation facilities. For small installations, the cost may be prohibitive and provision for emergency storage or disposal is a suitable alternative.

a. Piping and Pumping Flexibility

Process piping, equipment arrangement, and unit structures should allow for efficiency and ease of operation and maintenance and provide maximum flexibility of operation. Flexibility should permit the necessary degree of treatment to be obtained under varying conditions. All aspects of plant design should allow for routine maintenance of treatment units without deterioration of the plant effluent.

No pipes or pumps should be installed that would circumvent critical treatment processes and possibly allow inadequately treated effluent to enter the reclaimed water distribution system. The facility should be capable of operating during power failures, peak loads, equipment failures, treatment plant upsets, and maintenance shutdowns. In some cases, it may be necessary to divert the wastewater to emergency storage facilities or discharge the wastewater to approved, non-reuse areas. During power failures or equipment failure, standby portable diesel driven pumps can also be utilized.

b. Emergency Storage or Disposal

The term "emergency storage or disposal" means a provision for the containment or alternative treatment and disposal of reclaimed whenever the quality is not suitable for use. It refers to something other than the normal operational or seasonal storage which may be provided for reclaimed water until it is needed for use. Provisions for emergency storage or disposal may be considered to be a basic reliability provision for reclamation facilities. Where such provisions exist, they may substitute for multiple or standby units and other specific features.

Provisions for emergency storage or disposal may include:

- Holding ponds or tanks.
- Approved alternative disposal provisions such as percolation areas, evaporation-percolation ponds, or spray disposal areas.
- Pond systems having an approved discharge to receiving waters or discharge to a reclaimed water use area for which the lower quality water is acceptable.
- Provisions to return the wastewater to a sewer for subsequent treatment and disposal at the reclamation or other facility.
- Any other facility reserved for the purpose of emergency storage or disposal of untreated or partially treated wastewater.

Automatically actuated emergency or disposal provisions should include all of the necessary sensors, instruments, valves, and other devices to enable fully automatic diversion of the wastewater in the event of failure of a treatment process and a manual reset to prevent automatic restart until the failure is corrected. For either manual or automatic diversion, all of the equipment other than the pump back equipment should either be independent of the normal power source or provided with a standby power source. Irvine Ranch Water District in California automatically diverts its effluent to a pond when it exceeds a turbidity of 2 NTU and subsequently recirculates it to the reclamation plant influent. The City of St. Petersburg diverts its effluent to deep wells for disposal when the chlorine residual is less than 4 mg/L, turbidity exceeds 2.5 NTU, TSS exceeds 5 mg/L or chlorides exceed 600 mg/L.

Where emergency storage is to be utilized as a reliability feature, storage capacity is an important consideration. Short-term retention capacity in holding facilities for 24 hours is often provided in systems depending on a single power source. This short-term provision is also suitable for situations where reserve parts and replacement are immediately available and corrective actions would take no longer. Such is not always the case, and where it is not, the emergency storage capacity should be 20 days or longer for effective plant reliability. This would allow sufficient time to carry out almost any necessary corrective measure. Where corrective measures cannot be accomplished by plant personnel, provisions for a pre-arranged repair service may be made. In any case, as the emergency storage capacity is increased, so is the reliability.

In Florida, a separate, off-line system for storage of reject water is required, unless another permitted reuse system or effluent disposal system is capable of discharging the reject water (Florida Department of Environmental Regulation, 1990). The minimum allowable reject water storage capacity is a volume equal to one day's flow at the average daily design flow of the treatment plant or the average daily permitted flow of the reuse system, whichever is less. In addition, provisions are necessary to recirculate the reject water for further treatment.

c. *Disinfection*

An undisinfected effluent may be suitable for certain limited uses of reclaimed water or where stabilization pond systems effectively reduce pathogen concentrations in the effluent to a level deemed acceptable for many nonpotable uses. For uses where direct or indirect human contact with reclaimed water is likely provisions for adequate and reliable disinfection are the most essential features of the reclamation process.

Chlorination, the most widely used disinfection process, can be interrupted by various causes, e.g., exhaustion of the chlorine supply, chlorinator failure, water supply failure, and most commonly, power failure. A variety of features can be implemented to provide chlorine disinfection systems with increasing degrees of reliability. These features include:

- Standby chlorine cylinders,
- Chlorine cylinder scales,
- Manifold systems,
- Alarm systems,
- Automatic cylinder changeover,
- Standby chlorinators,
- Multiple-point chlorination,
- Automatic control of chlorine dosage, and
- Automatic measuring and recording of chlorine residual.

Spare cylinders should be available if continuous chlorination is to be provided. Scales are necessary to identify the amount of chlorine remaining in a cylinder so that the need for changeover to a full cylinder can be anticipated. A manifold system allows a rapid changeover to a full cylinder can be anticipated. It also provides a greater chlorine reserve and greater intervals between cylinder changes. Automatic cylinder changeover devices on the manifold system provide for uninterrupted chlorination without operator attention, particularly where there is not full-time plant supervision.

An effective alarm system can minimize interruptions in the disinfection process. At a facility which received full-time operator attention, a simple visual-audio alarm which sounds at the plant and warns of malfunction is adequate. Where there is only part-time attendance at the plant, it is necessary to have an alarm system which will sound a warning at a continuously staffed location, such as a police or fire station.

d. Alarms

Alarm systems should be installed at all conventional water reclamation plants, particularly at plants that do not receive full-time attention from trained operators. If a critical process were to fail, the condition may go unnoticed for an extended time period, and an unsatisfactory reclaimed water would be produced for use. An alarm system will effectively warn of an interruption in treatment.

Minimum instrumentation should consist of alarms at critical treatment units to alert an operator of a malfunction. This concept requires that the plant either be attended constantly or that an operator be on call whenever the reclamation plant is in operation. In the latter case, a remote sounding device would be needed. If conditions are such that rapid attention to failures cannot be assured, automatically actuated emergency control mechanisms should be installed and maintained.

Requirements for warning systems should specify the measurement to be used as the control in determining a unit failure, e.g., dissolved oxygen in an aeration chamber, or the requirements could be general and merely specify the units or processes which should be included in a warning system. The latter approach appears more desirable because it allows more flexibility in the design. Alarms could be actuated in various ways, such as failure of power, high water level, failure of pumps or blowers, loss of dissolved oxygen or chlorine residual, loss of coagulant feed, high head loss on filters, high effluent turbidity, or loss of chlorine supply.

It is axiomatic that along with the alarm system there must be means available to take corrective action for each situation which has caused the alarm to be activated. As noted above, provisions must be available to otherwise treat, store, or dispose of the wastewater until the corrections have been made. Alternative or supplemental features for different situations might include an automatic switch-over mechanism to emergency power and a self-starting generator, or an automatic diversion mechanism which discharges wastewater from the various treatment units to emergency storage or disposal.

e. Instrumentation and Control

Major considerations in developing an instrumentation/control system for a reclamation facility include:

- Ability to analyze appropriate parameters,
- Monitoring and control of treatment of process performance,
- Monitoring and control of reclaimed water distribution,
- Methods of providing reliability, and
- Operator interface and system maintenance.

The potential uses of the reclaimed water determine the degree of instrument sophistication required in a water reuse system. For example, health risks may be insignificant for reclaimed water used for non-food crop irrigation. On the other hand, if wastewater is being treated for indirect potable reuse via groundwater recharge, risks are potentially high. Consequently, the instruments must be highly sensitive, so that even minor discrepancies in water quality are detected immediately.

Selection of monitoring instrumentation is governed by the following factors: sensitivity, accuracy, effects of interferences, frequency of analysis and detection, laboratory or field application, analysis time, sampling limitations, laboratory requirements, acceptability of methods, physical location, serviceability, and reliability (WPCF, 1989). Each water reclamation plant is unique and has its own requirements for an integrated monitoring and control instrumentation system. The process of selecting monitoring instrumentation should address aspects as frequency of reporting, parameters to be measured, sample point locations, sensing techniques, future requirements, availability of trained staff, frequency of maintenance, availability of spare parts, and instrument reliability (WPCF, 1989). Such systems should be designed to detect operational problems during both routine and emergency operations. If an operating problem arises, activation of a signal or alarm permits personnel to correct the problem before an undesirable situation is created.

System control methods should provide for varying degrees of manual and automatic operation. Functions of control include the maintenance of operating parameters within preset limits, sequencing of physical operations in response to operational commands and modes, and automatic adjustment of parameters to compensate for variations in quality or operating efficiency.

System control may be manual, automated, or a combination of manual and automated systems. For manual control, the operations staff members are required to physically carry out all work tasks such as closing and opening valves and starting and stopping pumps. For automated control no operator input is required except for the initial input of operating parameters into the control system. In an automated control system, the system automatically performs operations such as the closing and opening of valves and the starting and stopping of pumps. These automated operations can be accomplished in a predefined sequence and time frame and can also be initiated by a measured parameter.

Automatic controls can vary from simple float switches that start and stop pumps to highly sophisticated computer systems that gather data from numerous sources, compare the data to predefined parameters, and initiate actions in order to maintain system performance within required criteria. For example, in the backwashing of a filter, instrumentation that monitors head loss across a filter signals the automated control system that a predefined head loss value has been exceeded. The control system, in turn, initiates the backwashing sequence through the opening of valves and starting of pumps.

2.4.3.4 Operator Training and Competence

Regardless of the automation built into a plant, mechanical equipment is subject to breakdown, and qualified, well-trained operators are essential to insure that the reclaimed water produced will be acceptable for the intended uses. The facilities operation should be based on detailed process control with recording and monitoring facilities, a strict preventive maintenance schedule, and standard operating procedure contingency plans to assure the reliability of the product water quality.

The plant operator is held by many to be the most critical reliability factor in the wastewater treatment system. All available mechanical reliability devices and the best possible plant design are to no avail if the operator is not capable and conscientious. There are three particular considerations relative to operating personnel which influence reliability of treatment: operator attendance, operator competence, and operator training provisions. Most regulatory agencies require operator certification as a reasonable means of assuring competent operation. Operator competence is enhanced by frequent training via continuing education courses or other means.

2.4.3.5 Quality Assurance in Monitoring

Quality assurance in monitoring of a reclamation program includes: (1) selecting the appropriate parameters to monitor, and (2) handling the necessary sampling and analysis in an acceptable manner. Sampling techniques, frequency, and location are critical elements of monitoring and quality assurance. Standard procedures for sample analysis may be found in the following references:

- *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association, 1989).
- *Handbook for Analytical Quality Control in Water and Wastewater Laboratories*, (EPA, 1979a).
- *Methods for Chemical Analysis of Water and Wastes* (EPA, 1979b).
- *Handbook for Sampling and Sample Preservation of Water and Wastewater* (EPA, 1982).

Typically, the quality assurance (QA) plan associated with sampling and analysis is a defined protocol that sets forth data quality objectives and the means for developing quality control data that serve to quantify precision, bias, and other reliability factors in a monitoring program. Strict adherence to written procedures ensures that the results are comparable, and that the level of uncertainty is verifiable.

Quality assurance plans and quality control procedures are well documented in the referenced texts. QA/QC measures should be dictated by the severity of the consequences of acting on the "wrong answer" or on an "uncertain" answer. QA/QC procedures are often dictated by the regulatory agencies, and do constitute necessary operation overhead. For reuse projects, this overhead may be greater than for wastewater treatment and disposal.

Sampling parameters required for reclamation extend beyond those common to wastewater treatment. For example, turbidity measurements are sometimes required for reclamation, but not for treatment and disposal. Monitoring for chlorides may be necessary for reuse in coastal communities.

Keeping adequate records of operation is an essential part of the overall monitoring program. It is reasonable and compatible with usual practice and requirements to require routine reporting of plant operation and immediate notification of emergency conditions.

2.5 Seasonal Storage Requirements

Managing and allocating reclaimed water supplies may be significantly different from the management of traditional sources of water. For example, a water utility currently drawing from groundwater or surface impoundments uses the resource as source and storage facility. If all of the yield of the source is not required, the water is simply left for use at a later date. In the case of reuse, reclaimed water is continuously generated and what cannot be used immediately must be stored or disposed of in some manner.

Depending on the volume and pattern of the projected reuse demands, seasonal storage requirements may become a significant design consideration and have a substantial impact on the capital cost of the system. Seasonal storage systems will also impact operational expenses. This is particularly true if the quality of the water is degraded in storage by algae growth and retreatment is required to maintain the desired or required water quality.

The need for seasonal storage in reclaimed water programs generally results from one of two requirements. First, storage may be required during periods of low demand for subsequent use during peak demand periods. Second, storage may be required to reduce or eliminate the discharge of excess reclaimed water into surface water. These two needs for storage are not mutually exclusive, but different parameters are considered in developing an appropriate design for each.

Where resource management rather than pollution abatement is the primary consideration, the reclaimed water supply and user demands must be calculated, and the most cost effective means of allocating that resource must be determined. When reclaimed water is viewed as a resource or commodity, the users' needs must be anticipated and accommodated in a similar manner to potable water supplies. In short, the supply must be available when the consumer demands it.

While the concept of "safe yield" is commonly applied to surface water bodies in assessing available potable water supplies, the determination of the "safe yield" of a reclaimed water source is somewhat new. Typically, reuse agreements with individual customers and reuse ordinances for urban irrigation systems have avoided a guarantee on continuous delivery, primarily to allow for the interruption of service in the event of treatment plant upsets, but allowances for shortages have also been included. With water reuse assuming a greater role in conserving potable supplies, reclaimed water becoming a commodity, and water reuse systems emerging as a new utility, the considerations of safe yield indeed become necessary.

Where water reuse is being implemented to reduce or eliminate wastewater discharges to surface waters, state or local regulations usually require that adequate storage be provided to retain excess wastewater under a specific return period of low demand. In some cold climate states, storage volumes may be specified according to projected non-application days due to freezing temperatures. Failure to retain reclaimed water under the prescribed weather conditions may constitute a violation of an NPDES permit and result in penalties.

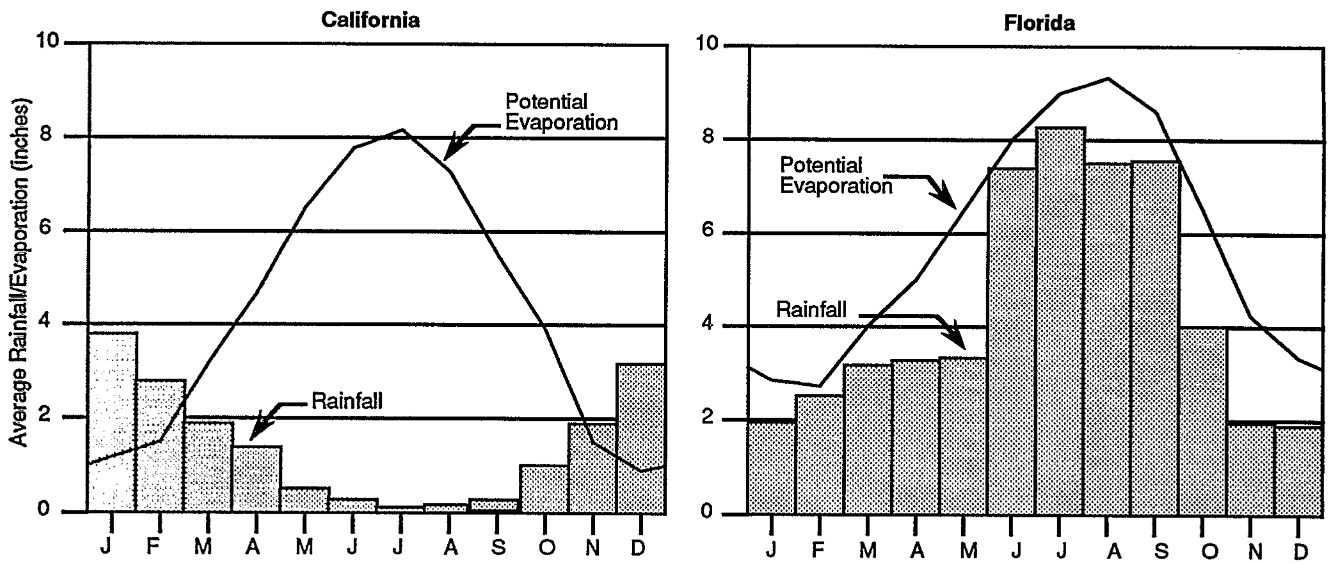
A method for preparing storage calculations under low demand conditions is given in the EPA *Process Design Manual: Land Treatment of Municipal Wastewater* (EPA, 1981 and 1984). In many cases, state regulations will also include a discussion on the methods to be used for calculating storage required to retain water under a given rainfall or low demand return interval.

The remainder of this section discusses the design considerations for both types of seasonal storage systems. For the purposes of discussion, the projected irrigation demands of pasture grass in a hot, humid location (Florida) and a hot, arid location (California) are used to illustrate storage calculations. Irrigation demands were selected for illustration because irrigation is a common use of reclaimed water and irrigation demands exhibit the largest seasonal fluctuations, which can affect system reliability. However, the general methodologies described in this section can also be applied to other uses of reclaimed water and other locations as long as the appropriate parameters are defined.

2.5.1 Identifying the Operating Parameters

The primary factors controlling the need for supplemental irrigation are evapotranspiration and rainfall. Evapotranspiration is strongly influenced by temperature and will be lowest in the winter months, highest in mid-summer. The magnitude of the evapotranspiration will vary according to local conditions, but a bell-shaped curve peaking in the summer months is common for all locations where seasonal changes in temperature occur. The need for irrigation at a specific location is a function of the vegetative cover receiving irrigation, stage of growth, irrigation system, and local rainfall patterns, all of which may vary considerably from site to site.

Figure 13. **Average Monthly Rainfall and Pan Evaporation**



In many cases, a water reuse system will provide reclaimed water to a diverse customer base. Urban reuse customers typically include golf courses and parks and may also include commercial and industrial customers. Such is the case in both the City of St. Petersburg and Irvine Ranch reuse programs, which provide water for cooling, wash down, and toilet flushing as well as for irrigation. Each water use has a distinctive seasonal demand pattern and thereby impact the need for storage.

Where uses other than irrigation are being investigated, other factors will be the driving force on demand. For example, demand for reclaimed water for industrial reuse will depend on the needs of the specific industrial facility. These demands could be estimated based on past water use records, if data are available, or a review of the water use practices of a given industry. When considering the demand for water in a man-made wetland, the system must receive water at the necessary time and rate to ensure that the appropriate hydroperiod is simulated. If multiple uses of reclaimed water are planned from a single source, the factors affecting the demand of each should be identified and integrated into a composite system demand.

Figure 13 presents the average monthly potential evaporation and average monthly rainfall in southwest Florida and Davis, California (Pettygrove and Asano, 1985). The average annual rainfall is approximately 52 in (132 cm)/yr, with an average annual potential evaporation of 71 in (180 cm)/yr in Florida. The average annual rainfall in Davis, California is approximately 17 in (43 cm)/yr with a total annual average potential evaporation rate of approximately 52 in (132 cm)/yr. In both locations, the shape of the potential evaporation curve is similar over the course of the year.

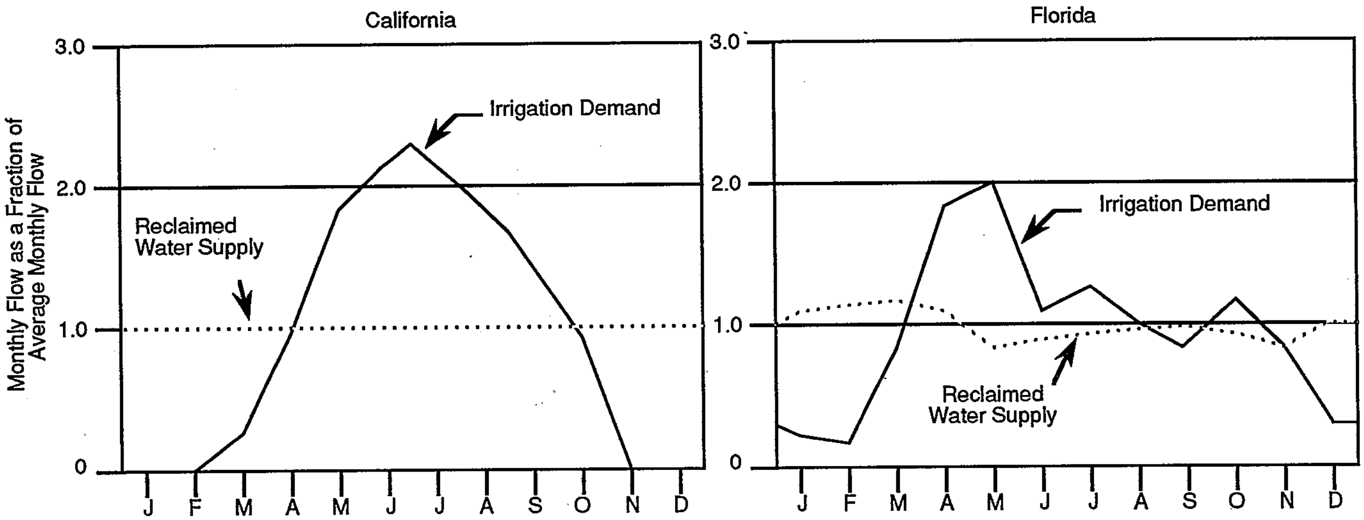
The distribution of rainfall at Florida and California sites differs significantly. In California, rainfall is restricted to the late fall, winter, and early spring, and little rainfall can be expected in the summer months when evaporation rates are greatest. The converse is true for the Florida location, where the major portion of the total annual rainfall occurs between June and September.

2.5.2 Storage to Meet Irrigation Demands

Once seasonal evapotranspiration and rainfall have been identified, reclaimed water irrigation demands throughout the seasons can be estimated. The expected fluctuations in the monthly need for irrigation of grass in Florida and California are presented in Figure 14. The figure also illustrates the seasonal variation in wastewater flows, the potential supply of irrigation water for both locations. In both locations the potential monthly supply and demand are expressed as a fraction of the average monthly supply and demand.

Defining the expected fluctuations in the supply of reclaimed water at the Florida site is accomplished by averaging the historic flows for each month from the available data. A long record of data is desirable for developing this average. However, the user must also be careful to select data representative of future

Figure 14. Average Pasture Irrigation Demand and Potential Supply



conditions. The fractional monthly reclaimed water supply for the Florida example indicates elevated flows in the late winter and early spring with less than average flows in the summer months, reflecting the region's seasonal influx of tourists. The seasonal irrigation demand for reclaimed water in Florida was calculated using the Thornthwaite equation. (Withers and Vipond, 1980). It is interesting to note that even in months where rainfall is almost equal to the potential evapotranspiration, a significant amount of supplemental irrigation may still be required. This occurs as a result of high intensity short duration rainfalls in Florida coupled with the relatively poor water holding capacity of the surficial soils.

The average monthly irrigation demand for California, shown in Figure 14, is based on data developed by Pruitt and Snyder (Pettygrove and Asano, 1985). Because significant rainfall is absent through the majority of the growing season, the seasonal pattern of supplemental irrigation for the California site is notably different from that of Florida. For the California example it has been assumed that there is very little seasonal fluctuation in potential supply of reclaimed water.

If the expected annual average demands of a reclaimed water system are approximately equal to the average annual available supply, storage is required to hold water for peak demand months. Using monthly supply and demand factors, the required storage can be obtained from the cumulative supply and demand. The cumulative supply and demand for Florida and California are illustrated in Figure 15. The results of this analysis suggest that to make beneficial use of all available water under average conditions, the Florida reuse program will require approximately 90 days of storage, while 150 days will be needed in California.

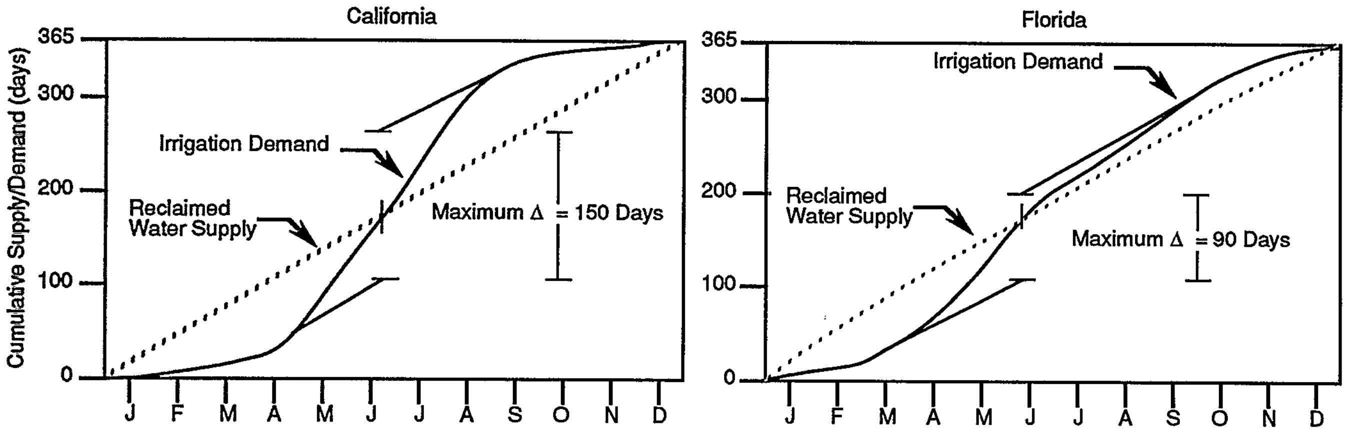
These calculations are based on only the estimated consumptive demand of the turf grass. In actual practice, the estimate would be refined based on site-specific conditions. Such conditions may include the need to leach salts from the root zone or the intentional over-application of water as a means of disposal. The vegetative cover receiving irrigation will also impact the condition under which supplemental water will be required. Drought conditions will result in an increased need for irrigation. The requirements of a system to accommodate annual irrigation demands greater than the average expected demands should also be examined.

Where reclaimed water serves to provide irrigation, periodic shortages may be tolerable. In general, the level of assurance should be established in discussions with the customers. Depending on the nature of the customer base, storage considerations must include non-application periods associated with system maintenance and harvest.

2.5.3 Storage to Prevent Surface Water Discharge

In cold climate states, storage volumes may be specified based primarily on the projected non-application days due to freezing temperatures and frozen ground

Figure 15. Estimated Storage Required to Commit All Available Reclaimed Water for Pasture Irrigation (Average Condition)



conditions. The state of Illinois, for example, requires a minimum of 150 days of storage at design average flow for all reuse irrigation projects.

In many subtropical or warm climate states, however, storage volumes are calculated based on a specified return period of low demand. In the case of an irrigation program, this demand return interval is based on rainfall. For example, Florida and Missouri require storage volumes to be determined based on a 1-in-10 year return period of low demand, while Georgia requires storage volumes be determined on a 1-in-5 year monthly return of low demand.

Using a methodology similar to that defined by EPA (EPA, 1981 and 1981b), information regarding supply and demand factors can be used to analyze storage needs under a low demand event with a given probability. For the purposes of illustration, a 1-in-10 year low demand probability has been selected. The calculation is accomplished by reducing the monthly irrigation demand by the fraction associated with a 90 percent probability low demand year. By selecting this probability, it is assumed that the resulting storage will be able to retain all reclaimed water generated 9 out of 10 years.

Using the monthly demands associated with the Florida and California sites, the reduction in demand associated with the 1-in-10 year event is distributed to each month according to the average monthly distribution of demand. The calculated storage for a 1-in-10 year low demand event for the Florida example is approximately 140 days or 50 days greater than the projected storage requirements under average conditions (Figure 15). The results of the calculated storage required for California for a 1-in-10 year low demand event indicate approximately 190 days of storage are required or 40 days greater than projected under average conditions.

Results of a similar analysis for the Lakeway Municipal Utility District in Texas indicated 100 days of storage would be required to prevent discharge (Mullarkey and Hall, 1990). The Lakeborough, California Wastewater Management Plan studied reclaimed water use under 1-inch, 10-year rainfall conditions and estimated 144 days of storage would be required to prevent a discharge (Nolte and Associates, 1990). In describing the methodology used in the design of reclaimed water reservoirs under adverse weather conditions for the California Regional Water Quality Control Board, it was estimated that approximately 118 days of storage would be required to prevent discharge (Clow, 1992). In general, the estimate storage quantities in the examples cited are on the order of the 140 and 190 days calculated in the hypothetical Florida and California examples. However, specific consideration must be made according to actual site conditions. For example, in the Lakeborough project, a 10 percent increase in the calculated irrigation rate was included as a leaching requirement. This adjusted application rate (ET + leaching) was then divided by 0.80 reflecting the anticipated irrigation efficiency of the application system. Additional information on leaching requirements and irrigation efficiency is given in Section 3.4 Agricultural Irrigation.

Several alternative means of modeling storage requirements are available. The EPA manual *Land Treatment of Municipal Wastewater* (EPA, 1981 and

1984) also presents the use of the 1-in-5 year return period low demand month to develop a composite year. Summing the individual 1-in-5 year return months is, according to the EPA manual, equivalent to modeling on the 1-in-10 year return period. Pruitt and Snyder (Pettygrove and Asano, 1985) recommend synthesizing a 1-in-10 year event from normal year data using a coefficient for the spring and fall transition months (April and October) and a second coefficient for the dry summer months. In some cases, modelers have relied on actual weather data in estimating storage requirements. Buchberger and Mardment (1989a, 1989b) suggest the use of the Monte Carlo simulation, borrowed from stochastic reservoir analysis, as an appropriate means of sizing reclaimed water storage facilities. No single methodology will be adequate for all conditions and sites. Calculating storage requirements using a number of different methods is recommended.

2.5.4 Partial Commitments of Supply

Water reuse programs based on the need for disposal and requiring only a partial use of the resource are more common than a total use of the resource. As the reclaimed water becomes more valuable, this is expected to change.

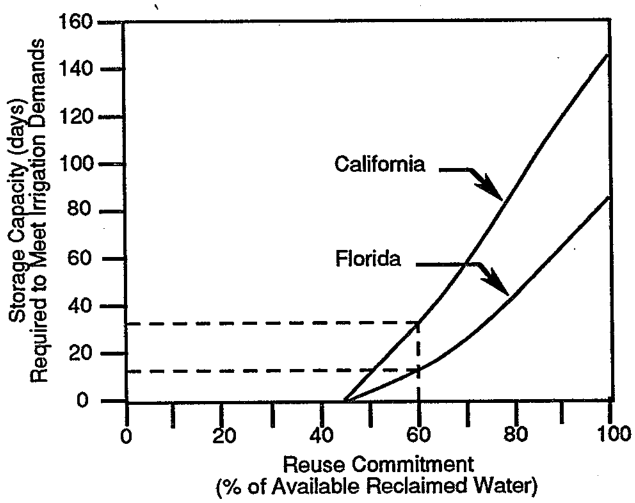
A partial reuse strategy is intended to reduce pollutant loading in critical periods of the year and discharge all or a portion of the effluent in periods when it can be assimilated without water quality degradation. Programs of this nature are intended primarily for pollution abatement and may have applications in locations where discharge is undesirable in certain times of the year. This strategy, in many cases, offers an alternative to developing the higher levels of treatment required for a year-round discharge.

A partial commitment of reclaimed water may also have applications in the following situations:

- The cost of providing storage for the entire flow is prohibitive,
- Sufficient demand for the total flow is not available,
- The cost of developing transmission facilities for the entire flow is prohibitive, and
- Total abandonment of existing disposal facilities is not cost effective.

The volume of storage required to facilitate a partial commitment of reclaimed water varies according to the fraction of reclaimed water intended for beneficial use. As illustrated in Figure 16, a reuse commitment of 60 percent of the available reclaimed water requires approximately 12 days of storage for the Florida location and 32 days for the California site.

Figure 16. Required Storage Capacity to Meet Irrigation Demands vs. Percent of Supply Committed



Systems designed to use only a portion of the reclaimed water supply are plentiful. The City of Modesto, California, has developed an agricultural irrigation program designed to eliminate effluent discharge in the summer months (Jenks, 1991). In a similar system in Santa Rosa, California, discharges are restricted to a percentage of the receiving water body flows (Fox *et al.*, 1987). The City of St. Petersburg, Florida, provides no significant seasonal storage for its urban reuse system. Underground storage by creating a reclaimed water lense on top of a saline aquifer, to be withdrawn in peak demand periods, was intended at the outset, but has not been developed. St. Petersburg is using approximately half of the total reclaimed water supply available. Excess reclaimed water is disposed of through a series of deep wells without any recovery.

The Irvine Ranch Water District reclamation program provides another illustration of the impacts storage has on the operation of a reuse system. Abandoned irrigation reservoirs currently provide seasonal storage for the system. The storage facilities do not have sufficient capacity to retain all excess reclaimed water. Because of this limited storage capacity, it is necessary to discharge reclaimed water in the low demand winter months. In addition, the seasonal storage facilities do not retain enough reclaimed water to assure that peak summer demands can be met and supplemental sources of water are required.

The use of open ponds to provide seasonal storage represents the only cost effective means of retaining large volumes of reclaimed water. However, water placed into such facilities will undergo quality degradation. The most common problem is the growth of algae. While such growth will occur in any exposed water body, the nutrients in reclaimed water tend to accelerate this process. The net result is that reclaimed water placed into seasonal storage may not meet water quality criteria when it is retrieved from storage. In general, reclaimed water quality criteria difficulties related to long-term storage will fall into the categories given below:

- Regulatory – many states specify water quality requirements for various uses. The growth of algae may result in a SS level in excess of a regulatory limit.

- Aesthetic – excessive algae growth may result in a product that is not aesthetically suitable for the intended use. Difficulties may include degradation in both appearance and odor.

- Functional – quality degradation may result in operational difficulties in downstream units. For example, sprinkler clogging in St. Petersburg was traced to the introduction of seeds in the open storage facilities.

The solution to water quality degradation as a result of storage varies according to local conditions. In St. Petersburg, the absence of seasonal storage results in a decreased ability to meet peak seasonal demands and permits a reuse commitment of less than 50 percent of the available water. At the Irvine Ranch Water District, reclaimed water is refiltered and chlorinated prior to introduction to the distribution network. The need to provide retreatment will vary with the intended use of the water, but the cost of such retreatment should be included in any present worth analysis.

Strategies for alternative disposal systems required where there is a partial commitment of the reclaimed water are discussed in Section 2.6.3.

2.6 Supplemental Water Reuse System Facilities

2.6.1 Conveyance and Distribution Facilities

The distribution network includes pipelines, pump stations, and storage facilities. No single factor is likely to influence the cost of water reclamation more than the conveyance or distribution of the reclaimed water from its source to its point of use. The design requirements of reclaimed water conveyance systems vary according to the needs of the users. The design requirements will also be affected by the policies governing the reclamation system (e.g., what level of shortfall, if any, can be tolerated). Where a dual distribution system is created, the design will be similar to that of a potable system in terms of pressure and volume requirements. However, if the reclaimed water distribution system does not provide for an essential service such as fire protection or sanitary uses, the reliability of the reclamation system need not be as stringent. This, in turn, would reduce the need for backup systems, thereby reducing the cost of the system. In addition, an urban reuse program providing primarily for irrigation will experience diurnal and seasonal flows as well as peak demands that have differing design parameters than the fire protection requirements generally used in the design of potable water systems.

The target customer for many reuse programs may be those traditionally not part of municipal water/wastewater systems. Such is the case of agricultural and large green space areas such as golf courses that often rely on wells to provide for nonpotable water uses. Even where these sites are not directly connected to municipal water supplies, reclaimed water service to these sites may be desirable for the following reasons:

- The potential user currently draws water from the same source as that used for potable water creating an indirect demand on the potable system.

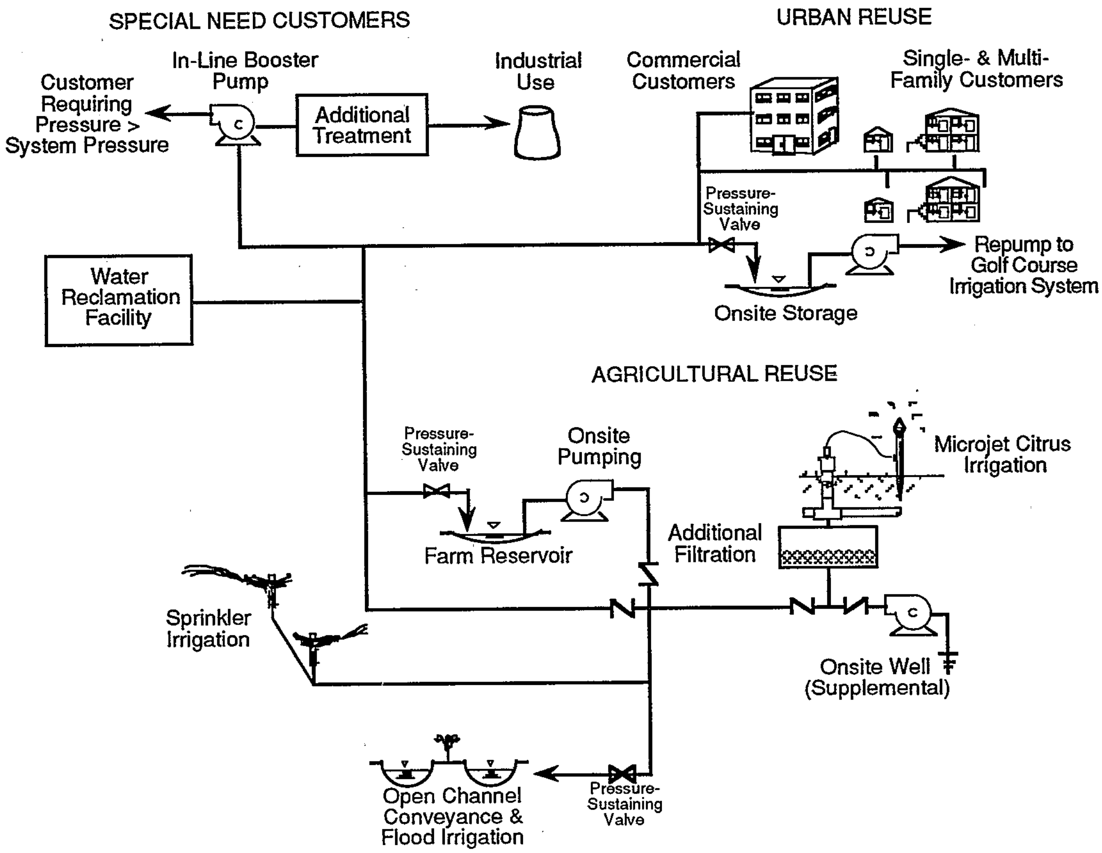
- The potential user has a significant demand for nonpotable water and may provide a cost effective means of reducing or eliminating reliance on existing effluent disposal methods.

- The potential user is seeking reclaimed water service to enhance the quality or quantity (or both) of the water available.

- A municipal supplier is seeking an exchange of nonpotable reclaimed water for raw water sources currently controlled by the prospective customer.

The conveyance and distribution needs of these sites may vary widely and be unfamiliar to a municipality. For example, a golf course may require flows of 500 gpm (38 L/s) at pressures of 120 psi (830 kPa). However, if the golf course has the ability to store and repump irrigation

Figure 17. **Example of a Multiple Reuse Distribution System**



water, as is often the case, reclaimed water can be delivered at atmospheric pressure to a pond at approximately one-third the instantaneous demand. Where frost-sensitive crops are served, an agricultural customer may wish to provide freeze protection through the irrigation system. Accommodating this may increase peak flows by an order of magnitude. Where customers that have no history of usage on the potable system are to be served with reclaimed water, detailed investigations are warranted to ensure that the service provided will be compatible with the user needs. These investigations should include an interview with the system operator as well as an inspection of the existing facilities.

Figure 17 provides a schematic of the multiple reuse conveyance and distribution systems that may be encountered. The actual requirements of a system will be dictated by the final customer base and are discussed in Chapter 3. The remainder of this section discusses issues pertinent to all reclaimed water conveyance and distribution systems.

Clustering or concentration of users results in lower unit costs than a delivery system to dispersed users. Initially a primary skeletal system is generally designed to serve large institutional users who are clustered and closest to the treatment plant. A second phase may then expand the system to more scattered and smaller users which receive nonpotable water from the central arteries of the nonpotable system. Such an approach was successfully implemented in the City of St. Petersburg, Florida. The initial customers were institutional (e.g. schools, golf courses, urban green space, and commercial). However, the lines were sized to make allowance for future service to residential customers. The growth of the St. Petersburg system was and continues to be service to residential customers who are supplied from major trunk mains which were installed as part of the skeletal system.

As illustrated in St. Petersburg, and elsewhere, once reclaimed water is made available to large users, a secondary customer base of smaller users often seek service. To ensure that expansion can occur to the projected future markets, the initial system design should model sizing of pipes to satisfy future customers within any given zone within the service area. At points in the system where future network of connections is anticipated, such as a neighborhood, turnouts should be installed. Pump stations and other major facilities involved in conveyance should be designed to allow for planned expansion. Space should be provided for additional pumps, or the capacities of the pumps may be expanded by changes to impellers and motor size. Increasing a pipe diameter by one size is economically justified since over half the initial cost of installing a pipeline is for excavation, backfill and pavement. Some thought should also be given to modifications in the delivery system that may be needed as the water use changes. This could include the need to improve system pressures as the customer base shifts from flood irrigation to sprinkler irrigation or quality improvements that may be required as customers shift to drip irrigation systems, for example.

A potable water supply system is designed to provide round-the-clock, "on-demand" service. Some nonpotable systems allow for unrestricted use (City of St. Petersburg), while others place limits on the hours when service is available. A decision on how the system will be operated will significantly affect system design. Restricted hours for irrigation (i.e. to evening hours) may shift peak demand and require greater pumping capacity than if the water was used over an entire day or may necessitate a programmed irrigation cycle to reduce peak demand. The Irvine Ranch Water District, though it is an "on-demand" system, restricts landscape irrigation to the hours of 9 p.m. to 6 a.m. to limit public exposure. Due to the automatic timing used in most applications, the peak hour demand was found to be six times the average daily demand and triple that of the domestic water distribution system (Young, *et al.*, 1988). As noted previously, attributes such as freeze protection may result in similar increases in peak demands of agricultural systems.

System pressure should be adequate to meet the user's needs within the reliability limits specified in a user agreement or by local ordinance. The Irvine Ranch Water District runs its system at a minimum of 90 psi (600 kPa) . The City of St. Petersburg currently operates its system at a minimum pressure of 60 psi (400 kPa). However, the City of St. Petersburg is recommending users to install low-pressure irrigation devices which operate at 50 psi (340 kPa) as a way of transferring to a lower pressure system in the future to reduce operating costs.

When there are significant differences in elevations within the service area, the system should be divided into pressure zones. Within each zone, a maximum and minimum delivery pressure is established. Minimum delivery pressure may be as low as 10 psi (70 kPa) and maximum delivery pressure may be as high as 150 psi (1,000 kPa) depending on the primary uses of the water.

Several existing guidelines recommend that operating the nonpotable system at pressures lower than the potable (10 psi, 70 kPa lower) in order to mitigate any cross connections (American Water Works Association, 1989). If the system is operated as a low pressure system (below 40 psi, 280 kPa) standards have to be set for the user to install only low-pressure irrigation devices. In turn this requires coordination with plumbers and irrigation vendors to ensure that the proper devices are installed from the outset.

2.6.1.1 Public Health Safeguards

The major concern which guides design, construction, and operation of a reclaimed water distribution system is the prevention of cross-connections. A cross connection is a physical connection between a potable water system used to supply water for drinking purposes and any source containing nonpotable water through which potable water could be contaminated.

Another major concern is to prevent improper use or inadvertent use of reclaimed water as a potable water. To protect the public health from the outset, a reclaimed water distribution system should be accompanied by health codes, procedures for approval (and disconnection) of service, regulations governing design and constructions specifications, inspections and operation and maintenance staffing. Among some of the public health protection measures that have been identified (American Water Works Association, 1983) and should be addressed in the planning phase are:

- ❑ Establish that public health is the overriding concern.
- ❑ Devise procedures and regulations to prevent cross connections.
- ❑ Develop a uniform system to mark all nonpotable components of the system.
- ❑ Prevent improper or unintended use of nonpotable water.
- ❑ Provide for routine monitoring, and surveillance of the nonpotable system.
- ❑ Establish special staff responsible for operations, maintenance, inspection, and approval of reuse connections.

- Develop construction and design standards.
- Provide for the physical separation of the potable water, reclaimed water, and sewer lines and appurtenances.

The following are some of the steps which have been successfully implemented to achieve these measures.

a. Identification of Pipes and Appurtenances

All components and appurtenances of the nonpotable system should be clearly and consistently identified throughout the system. Identification should be through color coding and marking. The nonpotable system (pipes, pumps, outlets, valve boxes, etc.) should be easily set apart from the potable system. The methods most commonly used are: unique colorings, labeling, and markings.

At the Irvine Ranch Water District, nonpotable piping and appurtenances are painted purple (American Water Works Association. California-Nevada Section, 1989) or can be integrally stamped or marked "CAUTION NON-POTABLE WATER – DO NOT DRINK" or "CAUTION: RECLAIMED WATER – DO NOT DRINK", or the pipe may be wrapped in purple polyethylene vinyl wrap. The City of St. Petersburg uses brown coloring to distinguish reclaimed water piping.

Another identification method is marking pipe with colored marking tape or adhesive vinyl tape. When tape is used, the letters (e.g., "CAUTION: RECLAIMED WATER – DO NOT DRINK") should be equal to the diameter of the pipe and placed longitudinally at 3-ft (0.9- m) intervals. Other methods of identification and warning are: stenciled pipe with 2-3-in (5-8 cm) letters on opposite sides, every 3-4 ft (0.9-1.2 m); for pipe less than 2-in (5 cm), lettering should be at least 5/8-in (1.6 cm) at 1-ft (30 cm) intervals); plastic marking tape (with or without metallic tracer) with lettering equal to the diameter of pipe, continuous over the length of pipe at no more than five ft (1.5 m) intervals; vinyl adhesive tape may be placed at the top of the pipe for diameters 2.5 to 3 in (6-8 cm) and along opposite sides of the pipe for diameters 6 to 16-in (15-40 cm), and along both sides and on top of the pipe for diameters of 20-in (51 cm) or greater (American Water Works Association, 1983).

Valve boxes for hydraulic and electrical components should be colored and warnings should be stamped on the cover. The valve covers for nonpotable transmission lines should not be interchangeable with potable water covers. Blow off valves should be painted and carry markings similar to other system piping. Irrigation and other control devices should be marked both inside and outside. Any constraints or special instructions should be clearly noted and placed in a suitable cabinet. If fire hydrants are part of the system, they should be painted or marked and the stem should require a special wrench for opening.

b. Horizontal and Vertical Separation of Potable from Nonpotable

The general rule is that a 10-ft (3-m) horizontal interval and a 1-ft (0.3-m) vertical distance should be maintained between potable (or sewer) lines and nonpotable lines that are parallel to each other. When these distances cannot be maintained, special authorization may be required, though a minimum lateral distance of 4 ft (1.2 m) (St. Petersburg) is generally mandatory. The State of Florida specifies a 5-ft (1.5-m) separation between reclaimed water lines and water or force mains, with a minimum of 3 ft (0.9 m) separation from pipe wall to pipe wall (Florida Department of Environmental Regulation, 1990). This arrangement allows for the installation of reclaimed water lines between water and force mains that are separated by 10 ft (3 m). The potable water should be placed above the nonpotable if possible. Under some circumstances, using a reclaimed water main of a different depth than that of potable or force mains might be considered to provide further protection from inadvertent cross-connection. Nonpotable lines are usually required to be at least 3 ft (90 cm) below ground. Figure 18 illustrates Florida's separation requirements for nonpotable lines.

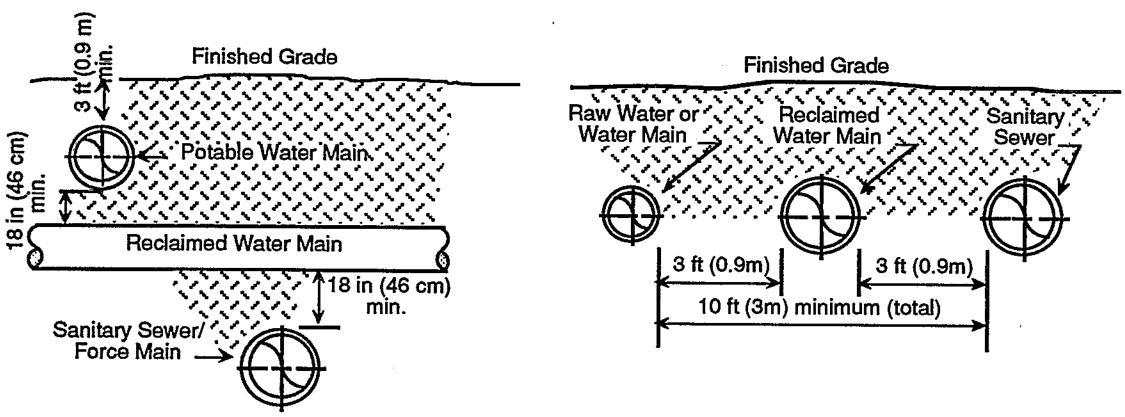
c. Prevent Onsite Ability to Tie into Reclaimed Water Line

The Irvine Ranch Water District has regulations mandating the use of special quick coupling valves for onsite irrigation connections. For reclaimed water these valves are operated by a key with an Acme thread. This thread is not allowed for the potable system. The cover on the reclaimed water coupler is different in color and material from that used on the potable system. Hose bibbs are generally not be permitted on nonpotable systems because of the potential for incidental use and possible human contact of the reclaimed water (Parsons, 1989). Below ground bibbs in a locking box or requiring a special tool to operate are allowed by Florida regulations (Florida Department of Environmental Regulation, 1990).

d. Backflow Prevention

Except in special cases, some form of backflow prevention is needed to protect potable water line in areas where reclaimed water is used. As an example of when backflow prevention devices are not required, the State of California will waive its backflow prevention device requirements ". . . when rules of service that are

Figure 18. Florida Separation Requirements for Reclaimed Water Mains



acceptable to the Department are incorporated, and when either of the following conditions can be satisfied:

1. The potable water and the reclaimed water systems are under the control of the water supplier and the following requirements are met:

   a. Only the water supplier or others approved by the water supplier are allowed to work on either the potable water or the reclaimed water system piping, and

   b. The reclaimed water system conforms to AWWA California-Nevada Section's *Guidelines for Distribution of Nonpotable Water*, and

   c. The water supplier conducts annual cross-connection surveys to assure conformance with the rules of service, or

2. The potable water and the reclaimed water piping are horizontally separated by a minimum distance of 200 ft, and the water supplier conducts annual cross-connection surveys to assure conformance with the rules of service." (California Department of Health Services, 1990).

Where the possibility of cross-connection between potable and reclaimed water lines does exist, backflow prevention devices should be installed onsite when both potable and reclaimed water services are provided to a user. The backflow prevention device is placed on the potable water service line to prevent potential backflow from the reclaimed water system into the potable water system if the two systems are illegally interconnected. Accepted methods of backflow prevention include:

- Air gap,
- Reduced-pressure principal backflow prevention assembly,
- Double-check valve assembly,
- Pressure vacuum breaker and,
- Atmospheric vacuum breaker.

The AWWA recommends the use of a reduced-pressure principal backflow prevention assembly where reclaimed water systems are present. However, many communities have successfully used double-check valve assemblies.

The backflow prevention device will prevent water expansion into the water distribution system. At some residences, the tightly closed residential water system can create a pressure buildup that causes the safety relief on a water heater to periodically discharge. This problem was solved by the City of St. Petersburg by providing separate pressure release valves which allow for release of water through an outdoor hose bibb.

If potable water is used as make up water for lakes or reservoirs, there should be a physical break between the potable water supply pipe and a receiving reservoir. The air gap separating the potable water from the reservoir containing nonpotable water should be at least two pipe diameters. There should never be any permanent connection between nonpotable and potable lines in the system.

In most cases, backflow prevention devices are not provided on the reclaimed water system. However, where a reclaimed water user wishes to inject chemicals into the reuse irrigation system, provisions for backflow prevention may be warranted.

e. Safeguards when Converting Existing Potable Lines to Nonpotable Use

In cases where the parts of the system are being upgraded and some of the discarded potable water lines are transferred over to the nonpotable system, care must be taken to prevent any cross connection. As each section is completed, the new system should be shut down and drained and each water user checked to ensure that there are no connections. Additionally a tracer, such as potassium permanganate may be introduced into the nonpotable system to test whether any of it shows up at any potable fixture.

In existing developments where an in-place irrigation system is being converted to carry reclaimed water, the new installation must be inspected and tested with tracers or some other method to ensure separation of the potable from the nonpotable supply.

2.6.1.2 Operations and Maintenance

The maintenance requirements for the nonpotable components of the reclaimed water distribution system are often the same as those for the potable. As the system matures, any disruption of service due to operational failures will upset the users. From the outset, such items as isolation valves, which allow for repair on parts of the system without affecting a large area, should be designed into the nonpotable system. Flushing the line after construction should be mandatory to prevent sediment from accumulating and hardening and becoming a serious future maintenance problem.

Differences in maintenance procedures for potable and nonpotable cannot generally be forecast prior to the operation of each system. The City of St. Petersburg, for instance, flushes its nonpotable lines twice a year during the off season months. The amount of water used in the flushing is equal to a day's demand of reclaimed water. The IRWD reports no significant difference in the two lines, though the reclaimed lines are flushed more frequently (every 2-3 years vs. every 5-10 for potable) due to suspended matter and sediment picked up in lake storage.

a. Blow Offs

Even with sufficient chlorination, residual organics and bacteria may grow at dead spots in the system. This may lead to odor and clogging problems. Blow-off valves and blow-off periodic maintenance of the system can significantly allay the problem. In most cases, the blow-off flow is directed into the sewage system.

b. Flow Recording

Even when a system is unmetered, accurate flow recording is essential to manage the growth of the system. Flow data are needed to confirm total system use and spatial distribution of water supplied. Such data allow for efficient management of the reclaimed water pump stations and formulations of policies to guide system growth. Meters placed at the treatment facility may record total flow and flow monitoring devices may be placed along the system particularly in high consumption areas.

c. Permitting and Inspection

The permitting process includes plan and field review followed by periodic inspection of facilities. The oversight includes inspection of both onsite and offsite facilities. Onsite facilities are the user's nonpotable water facilities downstream from the reclaimed water meter. Offsite facilities are the agency's nonpotable water facilities up to and including the reclaimed water meter.

Though inspection and review regulation vary from system to system, the basic procedures are essentially the same. The steps are:

(1) Plan Review: A contractor (or resident) must request service and sign an agreement with the agency or department responsible for permitting reclaimed water service. Dimensioned plans and specifications for onsite facilities must conform to regulations. Usually the only differences from normal irrigation equipment will be identification requirements and special appurtenances to prevent cross connections. Some systems, however, require that special strainer screens be placed before the pressure regulator for protection against slime growths fouling the sprinkler system, meter, or pressure regulator.

The plans are reviewed and the agency works with the contractor to make sure that the system meets all requirements. Systems with cross-connections to potable water systems must not be approved. Temporary systems should not be considered. Devices for any purpose other than irrigation should be approved by special procedures.

Installation procedures called out on the plan notes are also reviewed because they provide the binding direction to the landscape contractor. All points of connection are reviewed for safety and compatibility. The approved record drawings ("as builts") are kept on file. The "as-builts" include all onsite and offsite nonpotable water facilities as constructed or modified and all potable water and sewer lines.

(2) Field Review: Field review is generally conducted by the same staff involved in the plan review. Improper connections, identification, insufficient depth of pipe installation are reviewed and corrected. There is a cross-connection control test and finally the actual onsite irrigation system is operated to ensure that overspraying and overwatering is not occurring. There are usually follow-up inspections and in some cases fixed interval (e.g. semi-annual) inspections and random inspections.

(3) Monitoring: Among the items monitored are:

- Ensuring that landscape contractors or irrigation contractors provide minimal education to their personnel so that they are familiar with the regulations governing reclaimed water installations.
- All modifications to approved facilities should be submitted to and approved by the responsible agency.
- Detection of any breaks in the transmission main.
- Random inspection at user sites to detect any faulty equipment, or violation or irrigation schedule.
- Installation of monitoring stations throughout the system for testing of pressure, chlorine residual, and other water quality parameters.

The procedures for connecting residential customers in St. Petersburg are illustrated in Figure 19. A reclaimed water supplier should reserve the right to withdraw service for any offending condition subject to correction of the problem. Such rights are often established as part of a user agreement or a reuse ordinance. Chapter 5 provides a discussion of the legal issues associated with reclaimed water projects.

2.6.2 *Operational Storage*

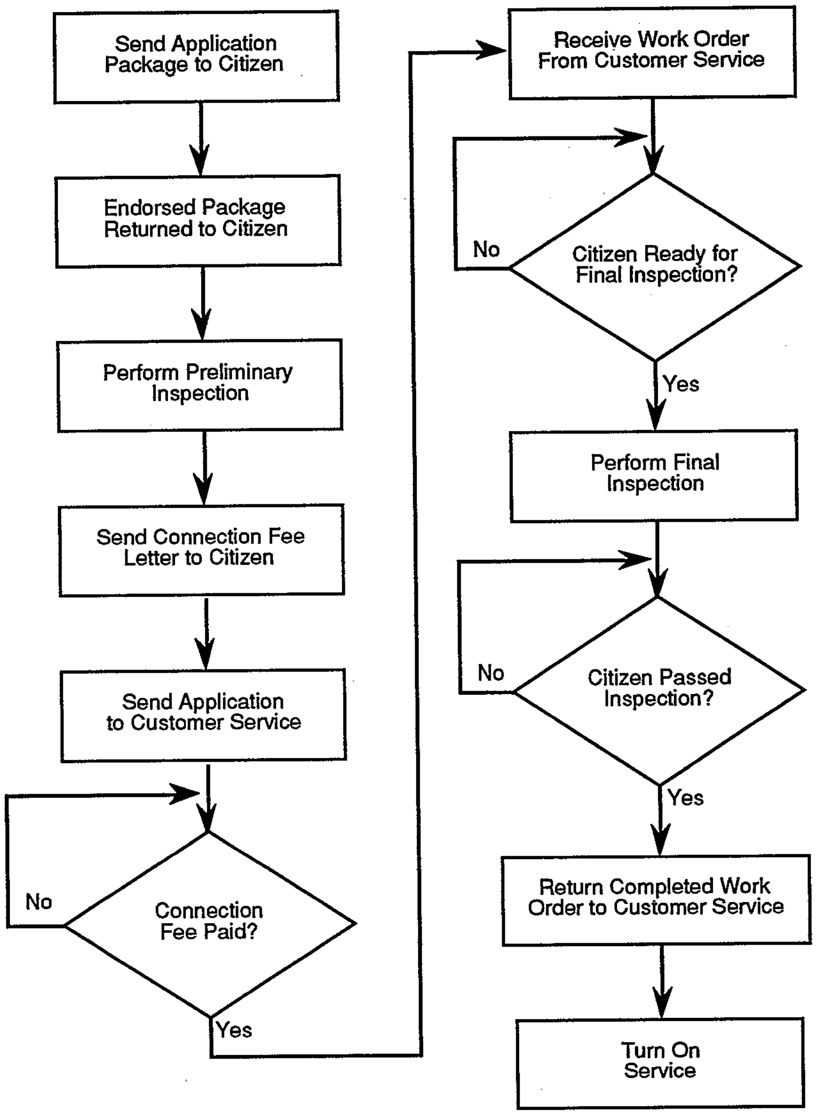
As with potable water distribution systems, a reclaimed water system must provide sufficient operational storage to accommodate diurnal fluctuations in demand and supply. The volume required to accommodate this task will depend on the interaction of the supply and demand over a 24-hour period.

Designs are dependent on assessments of the diurnal demand for reclaimed water. Such assessments, in most cases, require a detailed investigation of the proposed user or users. When possible, records of actual historical use should be examined as a means of developing demand requirements. Where records are absent, site-specific investigations are in order. In some cases, pilot studies may be warranted prior to initiating a full-scale reuse program.

Figure 20 presents the anticipated diurnal fluctuation of supply and urban irrigation demand for a proposed reclaimed water system in Boca Raton, Florida (Camp Dresser & McKee Inc., 1991). This information was developed based on the historic fluctuations in wastewater flow experienced in Boca Raton and the approximate fluctuations in the reclaimed water urban irrigation demand experienced in the St. Petersburg, Florida urban reuse program. A hydrograph of the cumulative supply and demand is presented in Figure 21, indicating the system will require approximately 5 million gal ($19 \times 10^3 m^3$) of storage. In this example, the diurnal storage volume required is equal to 30 to 35 percent of the daily flow. Actual service storage needs of a reclamation system reflect the final uses of the water.

Operational storage may be provided at the reclamation facility, as remote storage out in the system, or a combination of both. For example, the City of Altamonte Springs, Florida, maintains ground storage facilities at the reclamation plant and elevated storage tanks on the reclaimed water system. The selection of this configuration was based on a cost analysis of the transmission and pumping requirements for a variety of storage schemes (Howard Needles Tammen & Bergendoff, 1986). Large sites, such as golf courses, commonly have onsite ponds capable of receiving water throughout the day. Such onsite facilities reduce operational storage requirements that need to be provided by the utility. In the City of Naples, Florida, where reclaimed water is provided to nine golf courses, remote booster pumping stations deliver reclaimed water to the users from a covered storage tank located at the reclamation plant (Camp Dresser & McKee Inc., 1983). Operational storage facilities are generally covered tanks or open ponds. Covered storage in ground or elevated tanks is used for unrestricted urban reuse where

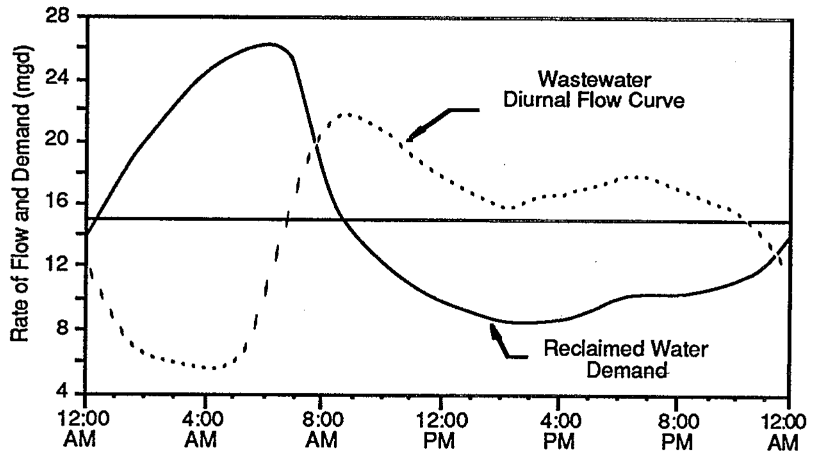
Figure 19. City of St. Petersburg Customer Connection Protocol



aesthetic considerations are important. Ponds are less costly, in most cases, but generally require more land per gallon stored. Where property costs are high or sufficient property is not available, ponds may not be feasible. Open ponds also result in water quality degradation from biological growth, and a chlorine residual is difficult to maintain, as noted previously in the discussion on seasonal storage. Ponds are appropriate for onsite applications such as agricultural irrigation and golf courses.

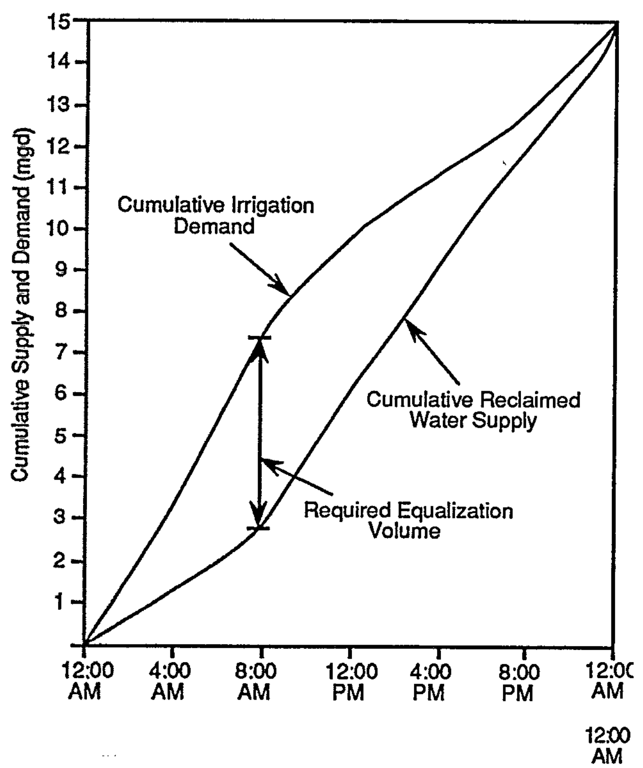
When providing reclaimed water to large users such as golf courses or parks, it is often possible to deliver water to onsite ponds over a 24-hour period. The user would then withdraw water for irrigation with an onsite pumping system over a 4 to 6 hour period at night. Under these conditions, the operational storage needs of the large customer are addressed onsite. However, as with seasonal storage ponds, onsite impoundments may result in a degradation of water quality. The most common form of degradation is increased algae growth due to nutrients. In the case of ponds located in highly maintained areas such as golf courses, it is not uncommon for owners to experience aesthetic problems prior to and apart from the storage of reclaimed water. Where irrigation systems have historically used water

Figure 20. Anticipated Daily Reclaimed Water Demand Curve vs. Diurnal Reclaimed Water Flow Curve



withdrawn from onsite successfully, the introduction of reclaimed water into the pond would not be expected to significantly increase operational problems (i.e., clogging of sprinkler heads).

Figure 21. Hydrograph for Diurnal Flows



Apart from the biological aspects of storing reclaimed water in onsite impoundments, the concentration of various constituents due to surface evaporation may present a problem. Reclaimed water often has a more elevated concentration of TDS than other available sources of water. Where evaporation rates are high and rainfall is low, the configuration of onsite storage ponds was found to have significant impacts on water quality in terms of TDS (Chapman and French, 1991). Shallow ponds with a high area-to-volume ratio will experience greater concentrations of dissolved solids due to surface evaporation. Dissolved solids increase in all ponds, but deeper ponds can serve to mitigate the problem. Figure 22 summarizes the expected concentration of TDS with pond depth for reclaimed water of 1,112 mg/L and 1,500 mg/L of TDS, assuming water is lost from a storage through evaporation only.

2.6.3 Alternative Disposal Facilities

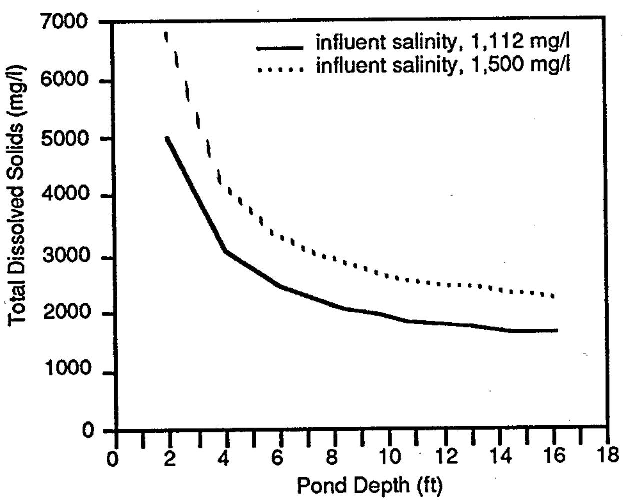
While water reclamation and reuse often provide the secondary benefit of reducing the water quality impacts of effluent discharge, reuse of 100 percent of the effluent may not always be feasible. In such cases, some form of alternative use or disposal of the excess water is necessary.

Where reclamation programs incorporate existing WWTFs, an existing disposal system will likely be in place and can continue to be used for partial or intermittent disposal. Common alternative disposal systems include surface water discharge, injection wells, land application, and wetlands application.

2.6.3.1 Surface Water Discharge

An intermittent surface water discharge may represent an acceptable method for the periodic disposal of excess reclaimed water. While demand for reclaimed water normally declines during wet weather periods, surface waters are then generally more able to assimilate the nutrients in reclaimed water without adverse water quality impacts. Conversely, during the warm summer months when surface water bodies are often most susceptible to the water quality impacts of effluent discharges, the demand for irrigation water is high and an excess of reclaimed water is less likely. Thus, the development of water reuse program with intermittent discharge can reduce or eliminate wastewater discharges during periods when waters are most sensitive to nutrient concentrations while allowing for a discharge in periods where adverse impacts are less likely. By eliminating discharges for a portion of the year through water reuse, a municipality may also be able to avoid the need for the costly AWT nutrient removal processes often required for a continuous discharge.

Figure 22. **TDS Increase Due to Evaporation for One Year as a Function of Pond Depth**



Source: Chapmen and French, 1991.

The City of Santa Rosa, California, developed an agricultural reuse program in response to a permit limiting discharge of wastewater to a percentage of the base stream flow, with discharge prohibited for stream flows of less than 1,000 cfs [28 m^3/s) (Donald *et al.*, 1987). The City of Modesto, California, utilizes a winter discharge to the San Joaquin River as part of an agricultural reuse program. The Lodi, California reuse program includes a 150-d/yr maximum allowance for discharge to White Slough (Boyle Engineering Corporation, 1981).

According to the Florida Department of Environmental Regulation (1990), allowing limited discharge of excess reclaimed water during wet weather periods will facilitate implementation of reuse projects. Florida's reuse regulations allow for limited wet weather discharge to surface waters with minimal water quality review under restricted conditions. Discharge normally is limited to a maximum of 25 percent of the year as long as required dilution ratios are maintained. Dilution requirements are based on the frequency of discharge, quality of reclaimed water produced, and travel time to sensitive, downstream water bodies.

2.6.3.2 Injection Wells

Injection wells, which convey reclaimed water into subsurface formations, are also used as an alternative means of disposal. In some cases, the injection of reclaimed water may even be considered reuse when intended to create a barrier to saltwater intrusion. According to EPA (n.d.), technical requirements for injection wells include:

- Wells are sited to inject into a formation which is beneath the lower-most formation containing an underground source of drinking water.
- It is demonstrated through hydrogeological investigations that the injection zone is separated from potable aquifers or aquifers that may serve as a source of potable water by an impermeable formation.
- The injection well is constructed such that it will not allow the movement of water between isolated formations.
- Ongoing monitoring of the appropriate formation is required to ensure system integrity.

Injection wells are a key element of the urban reuse program in City of St. Petersburg, Florida (Waller and Johnson, 1989). The city operates 10 wells which inject excess reclaimed water into a saltwater aquifer at depths between 700 and 1,000 ft (210 and 300 m) below land surface. Approximately 50 percent of the available reclaimed water is disposed of through injection. While the primary use of the wells is for the management of excess reclaimed water, the wells are also employed to dispose of any reclaimed water not meeting water quality standards.

Under suitable circumstances, excess reclaimed water can be stored in aquifers. This has an advantage over surface storage in that little or no reclaimed water quality degradation occurs.

2.6.3.3 Land Application

In water reuse irrigation systems, reclaimed water is applied in quantities to meet an existing water demand; in land treatment systems, effluent may be applied in excess of the needs of the crop. Land application may have a reuse benefit, as irrigation and/or where beneficial groundwater recharge is achieved. However, in many cases the design of land application systems is concerned with avoiding the detrimental impacts on groundwater resulting from the application of nutrients or toxic compounds.

In some cases, a site may be amenable to both reuse and "land application." Such are the conditions of the Tallahassee, Florida sprayfield system. The system is located on a sand ridge, where only drought-tolerant flora survives without irrigation. By providing reclaimed water for irrigation, the site is made suitable for agricultural production and has been leased by a farmer for that use. However, because of the extreme infiltration and percolation rates, it is possible to apply up to 3 in/week of reclaimed water without significant detrimental impacts to the crop (Allhands and Overman, 1989).

The City of Santa Maria, California, operates a similar agricultural reuse program where the lease farmer is required to take all of the water generated. An inspection of this facility in 1981 indicated that the reuse site was experiencing operational difficulties due in part to an over-application of irrigation water (Boyle Engineering Corporation, 1981).

Where some form of land application is used as alternative disposal, it is common to have separate sites dedicated to reuse and land application. The City of Santa Rosa, California, developed an agricultural reuse program with a conditional seasonal discharge. When unable to meet its surface water discharge permit conditions, the City expanded the reuse irrigation capacity, requested a less restrictive discharge permit, and developed dedicated land application areas where application rates could be maximized (Donald *et al.*, 1987). The Cities of Apopka and Venice, Florida, have also established dedicated land application sites as part of their urban reuse programs (Godlewski *et al.*,1990; Ammerman and Moore, 1991).

A joint water reuse program between the City of Orlando and Orange County, Florida, provides reclaimed water for citrus irrigation with a system of 60 rapid infiltration basins for land application of excess reclaimed water. The basins provide some reuse benefit through groundwater recharge. With the decline in citrus acreage resulting from a series of severe freezes in the late 1980s, this land application back-up system has become critical to the reuse program. New irrigation customers and crop diversification are being investigated to reduce reliance on the land application system (Ammerman and Hobel, 1991).

The City of Fresno, California, provides reclaimed water for irrigation to leased and private farming operations. If required, the total volume of reclaimed water generated may be diverted to a series of percolation beds. The percolation site includes a series of extraction wells which ultimately discharge into the Fresno Irrigation District's agricultural supply system, thus allowing for the recovery and additional treatment of the reclaimed water (Boyle Engineering Corporation, 1981).

The use of land application as an alternative means of disposal is subject to hydrogeological considerations. The EPA manual *Land Treatment of Municipal Wastewater* (EPA, 1981) provides a complete discussion of the design requirements for such systems. The use of land application systems for wet weather disposal is limited unless high infiltration and percolation rates are possible, such as rapid infiltration basins or manmade wetlands.

In cases where manmade wetlands are created, damaged wetlands are restored, or existing wetlands are enhanced, wetlands application may be considered a form of water reuse, as discussed in Section 3.5.1. Partial or intermittent discharges to wetlands systems have also been incorporated as alternative disposal means in water reuse systems, with the wetlands providing additional treatment through filtration and nutrient uptake.

In 1978, the creeks and canals in the vicinity of Hilton Head Island, South Carolina, were closed to shellfishing by the State Department of Health. In 1982, a moratorium on new or expanded wastewater treatment was imposed. In response, the resort community initiated an urban reuse program to serve local golf courses and landscaped areas. The selected means of alternative disposal for this program was the development of a discharge to wetlands so that additional treatment of the excess reclaimed water is achieved as it passes through the wetlands system (Hirsekorn and Ellison, 1987). A similar wetlands discharge is used in Orange County, Florida, where a portion of the reclaimed water generated by the Eastern Service Area WWTF is reused for power plant cooling and the remainder is discharged by overland flow to a system of manmade and natural wetlands. Application rates are managed to simulate natural hydroperiods of the wetland systems (Schanze and Voss, 1989).

2.7 Environmental Impacts

Elimination or reduction of a surface water discharge by reclamation and reuse generally reduces adverse water quality impacts to the receiving water. However, moving the discharge from a disposal site to a reuse system may have secondary environmental impacts. An environmental assessment may be required to meet state or local regulations and is required wherever federal funds are used. Development of water reuse systems may have secondary environmental impacts related to land use, stream flow, and groundwater quality. Formal guidelines for the development of an environmental impact statement (EIS) have been established by the EPA. Such studies are generally associated with projects receiving federal funding or new NPDES permits and are not specifically associated with reuse programs. Where an investigation of environmental impacts is required, it may be subject to state policies.

The following conditions are given as those that would induce an EIS in a federally funded project:

- The project may significantly alter land use;
- The project is in conflict with any land use plans or policies,
- Wetlands will be adversely impacted;
- Endangered species or their habitat will be affected;
- The project is expected to displace populations or alter existing residential areas;
- The project may adversely affect a flood plain or important farm lands;
- The project may adversely affect park lands, preserves or other public lands designated of scenic, recreational, archaeological or historical value;
- The project may have a significant adverse impact upon ambient air quality, noise levels, surface or groundwater quality or quantity; and
- The project may have adverse impacts on water supply, fish, shellfish, wildlife and their actual habitats.

The types of activities associated with federal EIS requirements are outlined below. Many of the same requirements are incorporated into environmental assessments required under state laws.

In addressing the requirements of the EIS, the purpose and need of the proposal action is to be stated. A thorough evaluation of the alternative under consideration, including required facilities, capital and operating costs and the anticipated environmental impacts of the project, is to be presented. In addition, the EIS process is open to public and agency review and comment as the study progresses. This process includes the submittal of the appropriate documentation to the affected parties and the presentation of workshops open to the public.

A formal EIS may be a very involved process and in most cases will not be required of reclamation projects. This does not mean, however, that the potential environmental issues associated with reuse can be neglected. The more common environmental impacts associated with reuse projects are discussed below.

2.7.1 Land Use Impacts

Water reuse can induce land use changes that could be considered either beneficial or detrimental. If a community's growth had been limited by the capacity of the water supply, and if, through water reuse, the portion of the potable supply available to residents were increased, then development that had previously been excluded could occur. In most cases, the decision-making process involved in implementing reclamation and reuse also impels examination of community goals. In Westminster, Colorado, for example, a water-exchange program between the city and area farmers were tied directly into a comprehensive six-point growth and resource-management plan that includes establishment of land-use priorities, fiscal impact planning, and conservation programs (Thurber, 1979).

Water reuse can encourage a more intensive use of land in a municipality. For example, parks or golf courses can be developed on previously undeveloped land. In a developed urban environment, landscaping of green space may be enhanced. A water reuse program might result in a more dramatic change in land use. For example, a small manufacturing facility, attracted by the availability of water, might be developed on a site not previously dedicated to industrial use. The availability of reclaimed water can also provide an opportunity for new residential development by extending potable supplies.

In some cases, more intensive use can be made of agricultural land by virtue of having more irrigation water available. A farmer may be able to extend planting from one crop season to two crop seasons or plant a higher value crop.

2.7.2 Stream Flow Impacts

In the past, leaving water in a stream was considered a waste of a resource, and most states did not regulate in-stream flows for the maintenance of habitat. Today, however, in-stream flows are considered valuable to the environmental system (National Research Council, 1989). Where wastewater discharges have occurred over an extended period of time, the indigenous flora and fauna have adapted and, in some cases, become dependent on that water. In some cases, water reuse projects have been halted over concerns related to water rights because the elimination of an existing discharge was expected to result in a decreased volume of water available to downstream users.

In developing an urban reuse plan around an existing 12.5-mgd (548 L/s) WWTF, the City of Altamonte Springs, Florida, intends to commit 10 mgd (438 L/s) of the available reclaimed water to urban use, greatly reducing the hydraulic and nutrient loadings into the Little Wekiva River from its previous practice of effluent discharge. However, the remaining 2.5 mgd (110 L/s will receive advanced treatment and continue to be discharged to the river to maintain a minimum hydraulic input to the system. In periods of low reclaimed water demand, the entire flow may be discharged, providing the reclaimed water meets water quality standards (Howard, Needles, Tammen & Bergendoff, 1986).

The City of Phoenix has reuse agreements with the Palo Verde nuclear power plant and with irrigation customers downstream of the WWTF's discharge into the Salt River. Reclaimed water is delivered to the power plant through a reuse main. The irrigation water is conveyed to the users through the natural river channel. Future plans call for a halt to all surface water discharges and the construction of a reuse main to the irrigation customers. Any excess reclaimed water would be diverted to a proposed groundwater recharge project. Environmental groups have expressed concern over adverse impacts on the habitat the withdrawal of the discharge may cause. However, previous rulings in Arizona have designated that reclaimed water is the property of producer and may be discharged or not as the producer wishes.

2.7.3 Hydrogeological Impacts

As a final environmental consideration of water reuse, the groundwater quality effects of the reclaimed water for the intended use must be reviewed. The exact concerns of any project are evaluated on a case-by-case basis. One of the better known sources of potential groundwater pollution is nitrate, which may be found in or result from the application of reclaimed water. However, additional physical, chemical, and biological constituents found in reclaimed water may pose an environmental risk. In general, these concerns increase when there are significant industrial wastewater discharges to the water reclamation facility.

The impacts of these constituents are influenced by the hydrogeology of the reuse application site. Where karst conditions exist, for example, there is a potential for constituents within the reclaimed water to ultimately reach the aquifer. *Irrigation with Reclaimed Municipal Wastewater: A Guidance Manual* (Pettygrove and Asano, 1985) provides chapters on the fate of nutrients, trace elements, pathogens, and trace organics in the soil.

In many reclaimed water irrigation programs, a groundwater monitoring program is required to detect the impacts of reclaimed water constituents, but such programs will also detect other sources of pollution. For example, the monitoring program for the reclaimed water agricultural irrigation system in Tallahassee, Florida, detected elevated nitrates in the groundwater. Ultimately, a nutrient balance of the system indicated the cause of the nitrates was fertilizer applications to the site (Allhands and Overman, 1989). The city was able to coordinate with the farmer to address this issue. It is interesting to note, however, that such a problem may have gone undetected were it not for the reuse program and the associated monitoring plan.

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CHAPTER 3

Types of Reuse Applications

3.1 Introduction

While Chapter 2 provides a discussion of the key elements of water reuse common to most reuse projects (i.e., supply and demand, treatment requirements, storage, distribution), this chapter provides information specific to the major types of reuse applications:

- Urban
- Industrial
- Agricultural
- Recreational
- Habitat restoration/enhancement
- 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 traditional sources of water. A brief discussion of potable reuse is also presented. Case studies of reuse applications are provided in Section 3.8.

3.2 Urban Reuse

Urban reuse systems provide reclaimed water for various nonpotable purposes within an urban area, 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 the landscaped areas of single-family and multi-family residences, general washdown, 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, window washing, 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 on construction projects.

- Fire protection.

- Toilet and urinal flushing in commercial and industrial buildings.

Urban reuse can include systems serving large users, such as parks, playgrounds, athletic fields, highway medians, golf courses, and recreational facilities; major water-using industries or industrial complexes; and a comprehensive combination of residential, industrial, and commercial properties through "dual distribution systems."

In dual distribution systems, the reclaimed water is delivered to the customers by a parallel network of distribution mains separate from the community's potable water distribution system. The reclaimed water distribution system essentially becomes a community's third water utility (wastewater, potable water, reclaimed water) and is operated, maintained, and managed in a manner similar to the potable water system. The oldest municipal dual distribution 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.

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 utilized as the only source of fire protection in a community, an interruptible source of reclaimed water is acceptable. The City of St. Petersburg, Florida, for example, decided that an interruptible source of reclaimed water would be acceptable, and that reclaimed water would be utilized only as a backup for fire protection. If a community determines that a non-interruptible source of reclaimed water is needed, then reliability must be provided to ensure a continuous flow of reclaimed water. Reliability might include more than one water reclamation plant supplying the reclaimed water system, as well as additional storage to provide for fire protection needs in the case of a plant upset.

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, the water reuse system may be cost-effective if it eliminates or forestalls the need to obtain additional water supplies from considerable distances or to treat a raw water supply source of poor quality.

In newly developing urban areas, substantial cost savings may be realized by installing a dual distribution system as an integral part of the utility infrastructure as the area develops and by stipulating connection to the system as a requirement of the community's land development code. For example, in 1984 the City of Altamonte Springs enacted as part of its land development code the requirement for developers to install reclaimed water lines so that all properties within the development are provided service. The section of the code further states that: "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 use of reclaimed water was feasible for flushing toilets and urinals and priming floor drain traps for buildings of six stories and higher (Young and Holliman, 1990). Following this study, an ordinance was enacted requiring all new buildings over 55 ft (17 m) high to install a dual distribution system for flushing in areas where reclaimed water is available (Irvine Ranch Water District, 1990).

3.2.1 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, 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, and irrigation specialists. Reclaimed water demand estimates must also take into account any other permitted uses for reclaimed water within the system.

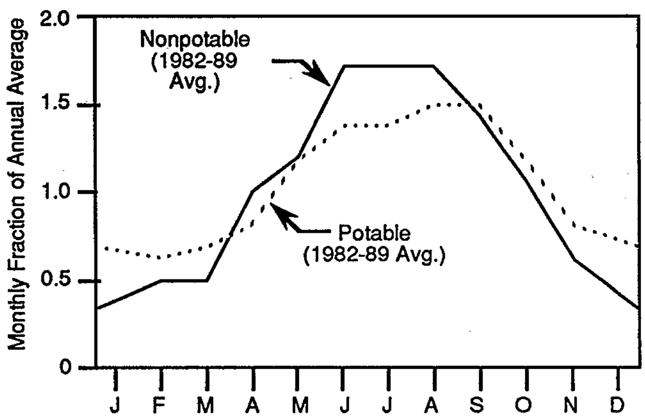
An estimation of the daily irrigation demand of reclaimed water can also be made by evaluating local water billing records. For example, in many locations, second water meters measure the volume of potable water used outside the home, primarily for irrigation. An evaluation of the water billing records in Manatee County, Florida, has shown that the average irrigation demand measured on the residential second meters is approximately 660 gpd (2.5 m^3/d), compared to 185 gpd (0.7 m^3/d) on the first meter, which measures the amount of water for in-house uses (CDM, 1990b). Using these data to estimate the daily demand for reclaimed water for residential use indicates that a 78-percent reduction in residential potable water demand could be accomplished in residential areas served by a dual distribution system for residential irrigation in Manatee County.

Water use records can also be used to estimate the seasonal variation in reclaimed water demand. Figure 23 shows the historic monthly variation in the potable and reclaimed water demand for the Irvine Ranch Water District, while Figure 24 shows the historic monthly variation in the potable and nonpotable water demand for St. Petersburg, Florida. Although the seasonal variation in demand is different between the two communities, both show a similar trend in the seasonal variation between the potable and nonpotable demand. Figures 23 and 24 illustrate how fluctuations in potable water demand may be influenced by nonpotable uses such as irrigation, even where a significant portion of the potable demand is met by an alternate source of water.

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

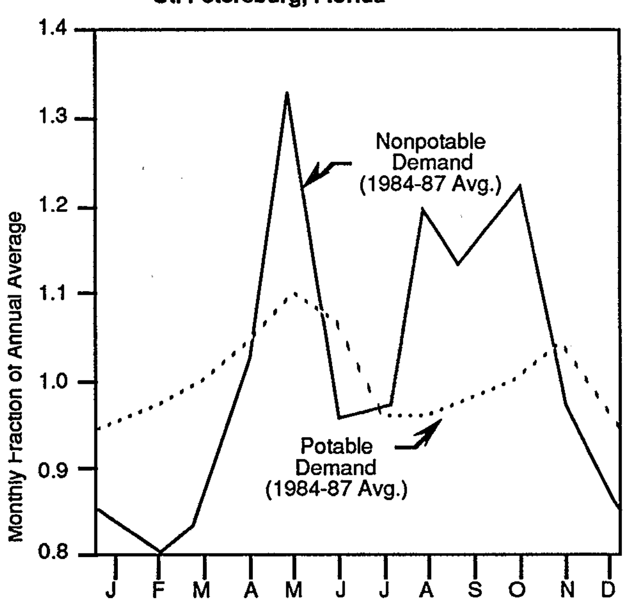
In assessing the reuse demand for an urban reuse system, demands for uses other than irrigation must also be determined. Demands for industrial users, as well as commercial users such as car washes, can be estimated from water use or billing records. Demands for recreational impoundments can be estimated by determining the volume of water required to maintain a desired water elevation in the impoundment.

Figure 23. **Potable and Nonpotable Water Use Monthly Historic Demand Variation Irvine Ranch Water District**



Source: Irvine Ranch Water District, 1991.

Figure 24. **Potable and Nonpotable Water Use Monthly Historic Demand Variation, St. Petersburg, Florida**



Source: Camp Dresser & McKee Inc., 1990b.

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 this demand. According to Grisham and Fleming (1989) toilet flushing can account for up to 45 percent of the indoor residential water demand. A study conducted by the Irvine Ranch Water District in 1987 on commercial high-rise water usage showed that 70 to 85 percent of the water used in an office high-rise is used for toilet and urinal flushing (Young and Holliman, 1990).

3.2.2 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 2.4. 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, and
- Prevention of improper use of nonpotable water.

To avoid cross connections, all equipment associated with reclaimed water systems must be clearly marked. National color standards have not been established, but accepted practice by manufacturers and many cities is purple. A more detailed discussion of distribution safeguards and cross connection control measures is presented in Section 2.6.1, Conveyance and Distribution Facilities.

3.2.3 Design Considerations

Urban water reuse systems have two major components:

- Water reclamation facilities for reclaimed water production;
- Reclaimed water distribution system, including operational storage and high-service pumping facilities.

3.2.3.1 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. On the other hand, where a large customer needs a higher quality reclaimed water than afforded by this treatment, the customer may have to provide the additional treatment onsite, as is commonly done with potable water. Treatment requirements are presented in Section 2.4. Figure 25 is a flow diagram for a typical water reclamation plant in the reuse system of the Sanitation Districts of Los Angeles County. Secondary treatment, filtration, and disinfection are provided, and the sludge is returned to the trunk sewer for processing at a central wastewater treatment plant.

3.2.3.2 Distribution System

Operational storage facilities and high-service pumping are usually located at the water reclamation facility. However in some cases, particularly for large cities, operational storage facilities may be located at appropriate locations on the system and/or near the reuse sites, and the latter may be provided by the utility or the customer. 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 in 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/d 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. Covered storage is preferred to preclude biological growth and maintain a chlorine residual. Refer to Section 2.6.2 for a discussion of operational storage.

Since variations in the demand of reclaimed water also occur seasonally, large volumes of seasonal storage may also be necessary if all available reclaimed water is to be used, although this may not be economically practical. The selected location of the seasonal storage facility will also have an effect on the design of the distribution system. A detailed discussion of seasonal storage requirements is given in Section 2.5.

The design of an urban distribution system is similar in many respects to that of the municipality's potable water distribution system, and the use of materials of equal quality for construction is recommended. System integrity should be assured; however, the reliability of the system need not be as stringent as 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. Also, no modifications other than identification of equipment or materials are required because reclaimed water is being used. However 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).

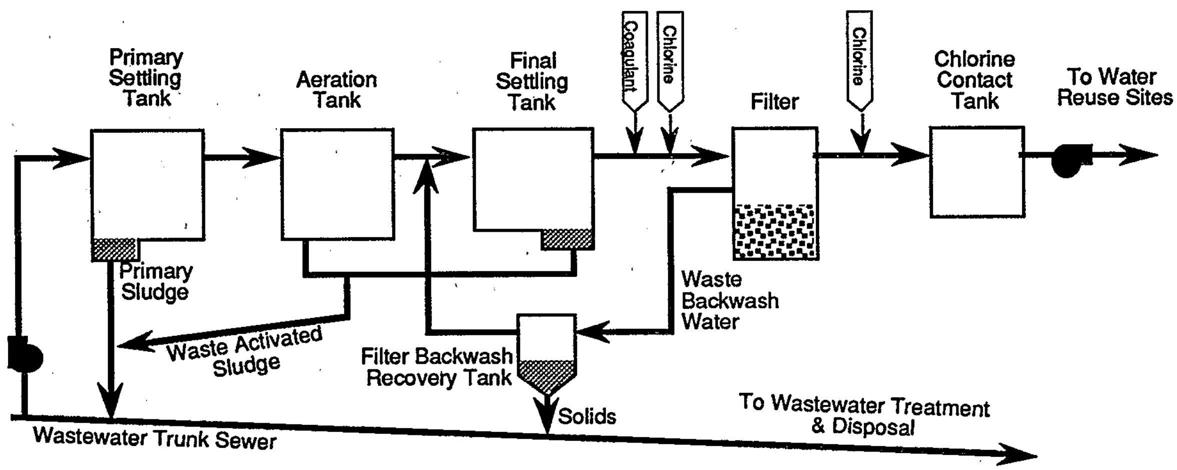
The peak hourly distribution mains rate of use, which is a critical consideration in sizing the delivery pumps and distribution mains, may best be determined by observing and studying local urban practices and considering time of day and rates of use by large users to be served by the system. The following 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 (IRWD, 1991)	
- Landscape Irrigation	6.80
- Golf Course and Agricultural Irrigation	2.00
Sea Pines, S. C. (Hirsekorn and Ellison, 1987)	2.00
St. Petersburg, Florida (CDM, 1987)	2.25

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

Figure 25. Typical Water Reclamation Plant Process for Urban Reuse



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 does 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 process 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 which utilize reclaimed water for irrigation. Other low pressure uses include delivery of reclaimed water to landscape or recreational impoundments.

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. 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. A minimum pressure of 50 psi (350 kPa) should also satisfy the requirements of car washes, toilet flushing, construction dust control, and some industrial users.

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 (100-200 psi [700 kPa-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 two 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 two 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.

3.3 Industrial Reuse

Industrial reuse represents a significant potential market for reclaimed water in the U.S. and other developed countries. Although industrial uses accounted for only about 8 percent of the total U.S. water demands in 1985, in some states, industrial demands accounted for as much as 43 percent of a state's total water demands. Reclaimed water is ideal for many industries where processes do not require water of potable quality. Also, industries are often located near populated areas where centralized wastewater treatment facilities already generate an available source of reclaimed water.

Reclaimed water for industrial reuse may be derived from in-plant recycling of industrial wastewaters and/or municipal water reclamation facilities.

Recycling within an industrial plant is usually an integral part of the industrial process and must be developed on a case-by-case basis. Industries, such as steel mills, breweries, electronics, and many others, treat and recycle their own wastewater either to conserve water or to meet or avoid stringent regulatory standards for effluent discharges. This document does not discuss in-plant recycling; however, ample information and guidelines are available from industrial associations and regulatory authorities.

Industrial uses for reclaimed water include:

- Evaporative cooling water,
- Boiler-feed water
- Process water, and
- Irrigation and maintenance of plant grounds.

Of these uses, cooling water is currently the predominant industrial reuse application. In most industries, cooling creates the single largest demand for water within a plant. According to Keen and Puckorius (1988), a small petroleum refinery (40,000 barrels/d) or a 250-MW utility power plant will need about 1 to 2 mgd (44-88 L/s) of makeup water for a recirculating cooling system. Worldwide, the majority of industrial plants using reclaimed water for cooling are utility power stations.

3.3.1 Cooling Water

3.3.1.1 Once-Through Cooling Systems

Once-through cooling systems use water to cool the process equipment and then discharge the heated water after a single use. Because once-through cooling systems use such large volumes of water, reclaimed water is rarely considered a feasible source. For instance, flow for a once-through cooling system at a typical 1,000-MW fossil fuel power plant would be approximately 650 mgd (28,500 L/s), as compared to recirculating systems, such as wet towers and cooling ponds that would use approximately 9 and 6.5 mgd (395 and 285 L/s), respectively (Breitstein and Tucker, 1986).

In the largest single industrial reuse project in the U.S., the Bethlehem Steel Company in Baltimore, Maryland, uses approximately 100 mgd (4,380 L/s) of treated wastewater effluent from Baltimore's Back River WWTF for processing and cooling in a once-through system (Water Pollution Control Federation, 1989). Generally, however, once-through cooling systems require too large a volume of water to rely on public water supplies. Because water quality requirements for these cooling systems are generally not restrictive, large lakes, rivers, and even saltwater can be used, in some cases with little, if any, treatment.

3.3.1.2 Recirculating Cooling Systems

Recirculating cooling systems use water to absorb process heat, then transfer the heat from the water by evaporation, and recirculate the water for additional cooling cycles. This recirculating cooling process may employ cooling towers or cooling ponds.

a. *Cooling Towers*

Cooling towers are designed to take advantage of the water's high heat of evaporation, i.e., one volume of evaporated water will cause 100 volumes to drop in temperature by approximately 10°F. Dry air is brought through the sides or bottom of the tower while water is pumped to the top of the tower's packing material. The water is broken into droplets to increase air/water contact, and then brought into contact with the upcoming air, which causes a portion of the water to evaporate. The cooled water droplets collect at the bottom of the tower and then are recycled.

Evaporation and wind action at the top of the tower (drift) result in a water loss that must be replaced. To prevent an unacceptable build-up of salt contaminants due to evaporation, a portion of the recirculating water is also continuously wasted as "blowdown," and a source of make-up water is required. Makeup water must be of high quality since any contaminants in the water are concentrated many times during the cooling cycle (Asano and Mujeriego, 1988).

Cooling tower make-up water constitutes a large percentage of the total water used (from 25 to 50 percent) in such industries as electric power stations, chemical plants, metal factories, and oil refineries. The cooling tower recirculating water system is almost always a closed loop system that is operated as a separate process with its own characteristic water quality requirements. The water quality is determined by ascertaining the concentration of the potential precipitants within the make-up.

The cycles of concentration, which is defined as the ratio of a concentration of a given ion or compound in the blowdown cooling water to the concentration in the make-up water, is indicative of the number of times that the cooling water is recirculated. According to Keen and Puckorius (1988), most cooling systems are operated in the range of 5 to 10 cycles of concentration. Above this range, the small amount of water conserved is rarely justified by the increased risk of scaling and SS deposition.

Regulatory constraints on waste discharges often require treatment of the blowdown water. Treatment methods vary according to the specific discharge standards and may include temperature and pH adjustments and ion exchange for metals removal. The discharge limits and the costs of removing the contaminants can place limits on the cycles of concentration.

b. *Cooling Ponds*

Cooling ponds may also be used as closed recirculating cooling systems. The pond water serves as the source of cooling water, and surface evaporation from the pond is the mechanism for cooling the heat-exchanged water. The critical parameter in pond design is the surface area required for cooling the heated water. The approximation used for power plant cooling ponds is 1 to 3 ac (2.5-7.5 ha)/MW of generated electricity (Gehm, 1976). Cooling ponds are attractive because of their low capital costs, large storage capacity, and ability to function without makeup water for extended periods. However, their drawbacks include potential groundwater contamination, large land requirements, and maintenance problems involving algae and weeds.

The City of Fort Collins, Colorado, supplies reclaimed water to the Platte River Power Authority for cooling the 250-MW Rawhide energy station (Fooks *et al.*, 1987). The recirculating cooling system includes a 5.2-billion gal (20 million m^3) cooling pond to supply 170,000 gpm (10,700 L/s) to the condenser and auxiliary heat exchangers. The water reclamation facility provides complete-mix activated sludge treatment with provisions for polymer addition, followed by final clarification, chlorination, and dechlorination with sulfur dioxide. Additional treatment for phosphorus removal is provided at the energy station to deliver a maximum phosphorus concentration of 0.2 mg/L. After about 2 years of operation, the cooling lake deteriorated in aesthetic appearance and chemical quality, and a limnological management program was instituted to provide aeration and minnow control in the cooling lake.

3.3.1.3 Cooling Water Quality Requirements

The most frequent water quality problems in cooling water systems are scaling, corrosion, biological growth, fouling, and foaming. These problems arise from contaminants in potable water as well as reclaimed water, but the concentrations of some contaminants in reclaimed water may be higher. Table 13 lists water quality criteria for cooling water supplies.

In Burbank, California, about 5 mgd (219 L/s) of municipal secondary effluent has been successfully utilized for cooling water make-up in the city's power generating plant since 1967. The effluent is of such good quality that treatment consisting of additional chlorine, acid, and corrosion inhibitors makes the reclaimed water nearly equal in quality to fresh water.

The City of Las Vegas and Clark County Sanitation District used 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

Table 13. Recommended Cooling Water Quality Criteria for Make-Up Water to Recirculating Systems

Parameter[a]	Recommended Limit[b]
Cl	500
TDS	500
Hardness	650
Alkalinity	350
pH[c]	6.9-9.0
COD	75
TSS	100
Turbidity[c]	50
BOD[c]	25
Organics[d]	1.0
NH4 - N[c]	1.0
PO_4[c]	4
SiO_2	50
Al	0.1
Fe	0.5
Mn	0.5
Ca	50
Mg	0.5
HCO3	24
SO4	200

[a]All values in mg/L except pH.
[b]Water Pollution Control Federation, 1989.
[c] From Goldstein *et al.*, 1979.
[d]Methylene blue active substances.

Company. The power company provides additional treatment consisting of two-stage lime softening, filtration, and chlorination prior to use as cooling tower make-up. A reclaimed water reservoir provides backup for the water supply.

In Odessa, Texas, three industries have used approximately 2.5 mgd (110 L/s) of municipal effluent for cooling tower make-up and boiler feed for over 20 years. Secondary effluent is treated by cold lime softening followed by filtration prior to use by the industries. This water is used directly for cooling tower make-up; water use for boiler feed is treated by two-bed demineralization before use (Water Pollution Control Federation, 1989).

a. Scaling

The cooling water must not lead to the formation of scale, i.e. hard deposits. Such deposits reduce the efficiency of the heat exchange. The principal causes of scaling are calcium (as carbonate, sulfate, and phosphate) and magnesium (as carbonate and phosphate) deposits.

Scale control for reclaimed water is achieved through chemical means and sedimentation. Acidification or addition of scale inhibitors can control scaling. Acids (sulfuric, hydrochloric, and citric acids and acid gases such as carbon dioxide and sulfur dioxide) and other chemicals (chelants such as EDTA and polymeric inorganic phosphates) are often added to increase the water solubility of scale-forming constituents, such as calcium and magnesium (Strauss and Puckorius, 1984).

Lime softening, commonly used to treat reclaimed water for cooling systems, significantly increases the cycles of concentration. The lime removes carbonate hardness and the soda ash removes the noncarbonate hardness. Other methods used to control scaling are alum treatment and sodium ion exchange, but the higher costs of these processes limit their use.

b. Corrosion

The recirculated water must not be corrosive to metal in the cooling system. High total dissolved solids (TDS) promotes corrosion by increasing the electrical conductivity of the water. The concentrations of TDS in municipally treated reclaimed water, generally two to five times higher than in potable water, can increase electrical conductivity and promote corrosion. Dissolved gases and certain metals with high oxidation states also promote corrosion.

Corrosion may also occur when acidic conditions develop in the cooling water. The Jones Station power plant in Lubbock, Texas, reported that the ammonia present in reclaimed water was converted to nitrates in the recirculating cooling water, resulting in a lowering of the pH from a range of 7.4 to 7.9 to a value of 6.5 or less. The pH was adjusted by adding carbon dioxide to increase the bicarbonate alkalinity of the cooling water (Treweek *et al.*, 1981).

Corrosion inhibitors such as chromates, polyphosphates, zinc, and polysillicates can also be used to reduce the corrosion potential of the cooling water. These substances may need to be removed from the blowdown prior to discharge. The alternative to chemical addition is ion exchange or reverse osmosis, but high costs limit their use (Strauss and Puckorius, 1984).

c. Biological Growth

Reclaimed water used in cooling systems must not supply nutrients or organics [biochemical oxygen demand (BOD)] that promote the growth of slime-forming organisms. The moist environment in the cooling tower is conducive to biological growth. Microorganisms can significantly reduce the heat transfer efficiency, reduce water flow, and in some cases generate corrosive by-products (Troscinski and Watson, 1970; California State Water Resources Control Board, 1980; Goldstein *et al.*, 1979).

The reduction of BOD and nutrients during treatment reduces the potential of the reclaimed water to sustain microorganisms. Chlorine is the most common biocide used to control biological growth because of its low cost, availability, and ease of operation. Chlorination is also used as a disinfectant to reduce potential pathogens in the reclaimed water. Frequent chlorination and shock treatment is generally adequate. Chlorine gas (purchased as liquid chlorine) is used most often, but it may also be applied as sodium hypochlorite as a liquid or solid. Chlorine dioxide is also frequently used.

At the City of Lakeland, Florida, which uses reclaimed water from a secondary treatment facility for power plant cooling, the system design of four to six cycles was reduced significantly due to biological growth and fouling of the cooling tower. Biological mass accumulated in the tower to such an extent that structural stability was threatened. The problem was solved by instituting a pretreatment program to reduce BOD, phosphorus, and SS (Libey and Webb, 1985).

On the other hand, the Orlando (Florida) Utilities Commission has reported no biological accumulation or fouling problems in the cooling system of the C.H. Stanton energy facility, which uses approximately 5 mgd (219 L/s) of highly treated reclaimed water (5 mg/L BOD, 5 mg/L TSS, 2 mg/L TN and 1 mg/L P) from an Orange County WWTF. Prior to use, the energy facility also provides pH adjustment, rechlorination, scale inhibitors, and anti-foaming agents.

In Hillsborough County, Florida, a municipal water reclamation facility provides reclaimed water for cooling a 1,200-ton/d, waste-to-energy facility and treats the blowdown water wasted from the cooling towers. The reclaimed water from the advanced treatment system meets the following water quality standards: BOD, 20 mg/L; TSS, 5 mg/L; total nitrogen, 20 mg/L; fecal coliform, <1/100 mL; and pH, 6 to 8.5. The reclaimed water is treated with additional chemicals at the waste-to-energy facility to prevent algae growth and biological buildup in the cooling system. Approximately 330,000 gpd (14 L/s) of used cooling water is discharged back to the wastewater treatment plant (Tortora and Hobel, 1990).

d. Fouling

Fouling is controlled by preventing the formation and settling of particulate matter. Chemical coagulation and filtration during the phosphorus removal treatment phase significantly reduce the contaminants that can lead to fouling. Chemical dispersants are also used as required.

3.3.2 Boiler-Feed Water

The use of reclaimed water differs little from the use of conventional public supplies for boiler-feed water; both require extensive additional treatment. Quality requirements for boiler-feed make-up water are dependent upon the pressure at which the boiler is operated as shown in Table 14. Generally the higher the pressure, the higher the quality of water required. Very high pressure boilers require makeup water of distilled quality.

In general, both potable water and reclaimed water used for boiler water makeup must be treated to reduce the hardness of the boiler-feed water to close to zero. Removal or control of insoluble salts of calcium and magnesium and control of silica and aluminum are required since these are the principal causes of scale build-up 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 superheater, reheater, and 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 the relatively small amounts of makeup required, make boiler-feed a poor candidate for reclaimed water.

3.3.3 Industrial Process Water

The suitability of reclaimed water for use in industrial processes depends upon 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, the potential users must be contacted to determine specific requirements for process water. Table 15 presents industrial process water quality requirements for a variety of industries. Table 16 summarizes some of the water quality concerns for industrial water reuse and potential treatment processes.

3.3.3.1 Pulp and Paper

Reuse of reclaimed water in the paper and pulp industry is a function of cost and grade of paper. The higher the quality of paper, the more sensitive to water quality. Impurities found in water, particularly certain metal ions and color bodies, can cause the paper produced to change color with age.

Table 14. **Recommended Industrial Boiler-Feed Water Quality Criteria**

Parameter*	Low Pressure (<150 psig)	Intermediate Pressure (150-700 psig)	High Pressure (>700 psig)
Silica	30	10	0.7
Aluminum	5	0.1	0.01
Iron	1	0.3	0.05
Manganese	0.3	0.1	0.01
Calcium	**	0.4	0.01
Magnesium	**	0.25	0.01
Ammonia	0.1	0.1	0.1
Bicarbonate	170	120	48
Sulfate	**	**	**
Chloride	**	**	**
Dissolved solids	700	500	200
Copper	0.5	0.05	0.05
Zinc **	0.01	0.01	
Hardness	350	1.0	0.07
Alkalinity	350	100	40
pH, units	7.0 - 10.0	8.2 - 10.0	8.2 - 9.0
Methylene blue active substances	1	1	0.5
Carbon tetrachloride extract	1	1	0.5
Chemical oxygen demand	5	5	1.0
Hydrogen sulfide	**	**	**
Dissolved oxygen	2.5	0.007	0.0007
Temperature, °F	**	**	**
Suspended Solids	10	5	0.5

* Recommended limits in mg/L except for pH (units) and temperature (°F).
** Accepted as received (if meeting other limiting values); has never been a problem at concentrations encountered.

Source: EPA, 1980b.

Major considerations associated with the use of reclaimed water in the pulp and paper industry include (Camp Dresser & McKee, 1982):

- Biological growth may cause clogging of equipment and odors and may affect the texture and uniformity of the paper. Chlorination (3 mg/L residual) has been found adequate to control micro-organisms.
- Corrosion and scaling of equipment may result from the presence of silica, aluminum, and hardness.
- Discoloration of paper may occur due to iron, manganese, or micro-organisms. Suspended solids may decrease brightness of paper.

3.3.3.2 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), moderately soft, with low turbidity, SS, and silica are required; dissolved solids and chloride content are not critical (Water Pollution Control Federation, 1989).

3.3.3.3 Textile Industry

Waters used in textile manufacturing must be nonstaining; 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.

3.3.3.4 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.

3.4 Agricultural Irrigation

Agricultural irrigation represents a significant fraction of the total demand for fresh water. As discussed in Chapter 2, agricultural irrigation is estimated to represent 40 percent of the total water demand nationwide (Solley *et al.*, 1988). In western states with significant agricultural production, the percentage of fresh water used for irrigation is markedly greater. For example, Figure 26 illustrates the total daily fresh water withdrawals, public water supply, and agricultural irrigation usage for

Table 15. Industrial Process Water Quality Requirements

Parameter*	Pulp & Paper: Mechanical pulping	Pulp & Paper: Chemical, unbleached	Pulp & Paper: Pulp & Paper, bleached	Chemical	Petrochem. & coal	Textiles: Sizing suspension	Textiles: Scouring, bleach & dye	Cement
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								1

*All values in mg/L except color and pH.
Source: Water Pollution Control Federation, 1989.

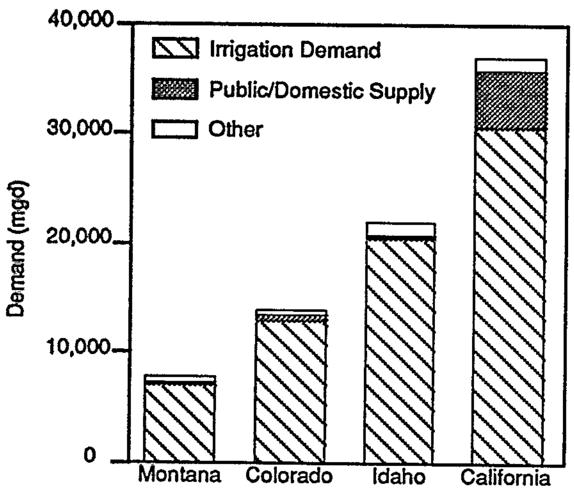
Table 16. Industrial Water Reuse Quality Concerns and Potential Treatment Processes

Parameter	Potential Problem	Advanced Treatment Process
Residual organics	Bacterial growth, slime/scale formation, foaming in boilers	Nitrification, carbon adsorption, ion exchange
Ammonia	Interferes with formation of free chlorine residual, causes stress corrosion in copper-based alloys, stimulates microbial growth	Nitrification, ion exchange, air stripping
Phosphorus	Scale formation, stimulates microbial growth	Chemical precipitation, ion exchange, biological phosphorus removal
Suspended solids	Deposition, "seed" for microbial growth	Filtration
Calcium, magnesium, iron, and silica	Scale formation	Chemical softening, precipitation, ion exchange

Source: Water Pollution Control Federation, 1989.

Montana, Colorado, Idaho, and California. These states are the top four consumers of water for agricultural irrigation, which accounts for more than 90 percent of their total water demand.

Figure 26. Comparison of Agricultural Irrigation, Public/Domestic, and Total Freshwater Withdrawals



Source: Solley *et al.*, 1988.

The total area in agricultural production in the United States and Puerto Rico is estimated to be approximately 3.6 billion ac (1.5 billion ha), of which approximately 605 million (245 million ha) are irrigated. Worldwide it is estimated that irrigation water demands exceed any other category of use by a factor of 10 (Pair *et al.*, 1983).

A significant portion of existing water reuse systems supply reclaimed water for agricultural irrigation. In Florida, agricultural irrigation accounts for approximately 34 percent of the total volume of reclaimed water used within the state (Florida Department of Environmental Regulation, 1990). In California, agricultural irrigation accounts for approximately 63 percent of the total volume of reclaimed water used within the state (California State Water Resources Control Board, 1990). Figure 27 shows the percentages of the types of crops irrigated with reclaimed water in California.

In California, Florida, and Texas, the following volumes of reclaimed water are being used for agricultural irrigation.

State	Agricultural Reuse mgd	Agricultural Reuse m^3/s
California	150	570×10^3
Florida	90	340×10^3
Texas	290*	$1,100 \times 10^{3}$*

* This is based on the design flow of the WWTP providing water and may exceed actual use.

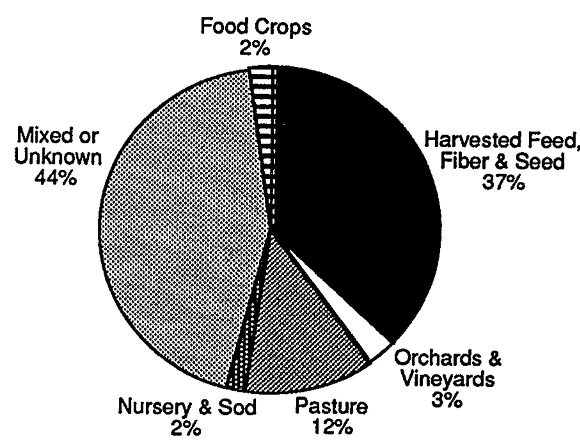
Given the high water demands for agricultural irrigation, the significant water conservation benefits of reuse in agriculture, and the opportunity to integrate agricultural reuse with other reuse applications, planning water reuse programs will often involve the investigation of agricultural irrigation.

This section discusses the considerations specific to water reuse programs for agricultural irrigation:

- Agricultural irrigation demands
- Reclaimed water quality for agricultural irrigation
- System design considerations

The technical issues common to all reuse programs are discussed in Chapter 2, and the reader is referred to the following subsections for this information: 2.4 - Treatment Requirements, 2.5 - Seasonal Storage Requirements, 2.6 - Supplemental Facilities (conveyance and distribution, operational storage, and alternative disposal).

Figure 27. Agricultural Reuse Categories by Percent in California



Source: California State Water Resources Control Board, 1990.

3.4.1 *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, and stage of plant growth, and other factors depending on the method of irrigation being used.

The supplier of reclaimed water must 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, the agricultural user is often unable to provide sufficient detail on irrigation demands for design purposes. The user's seasonal or even annual water use is seldom measured and recorded, even where water has been used for irrigation for a number of years. Expert guidance, however, is usually available through state colleges and universities and the local soil conservation service office.

Nevertheless, 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 data on an agricultural site's water use, evapotranspiration, percolation and runoff losses, and net irrigation must be estimated, often through the use of predictive equations. As discussed in Section 2.5 (Seasonal Storage), predictive equations may also be required to model periods of low demand for the purpose of sizing storage facilities.

Irrigation Requirement = Evapotranspiration - precipitation + surface runoff + percolation losses + conveyance and distribution losses

3.4.1.1 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. It has been suggested that the study and restudy of evapotranspiration is one of the most popular subjects in hydrology and irrigation (Jensen *et al.*, 1990).

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.

In water-critical regions, the use of weather stations to generate real-time (daily) estimates of evapotranspiration is becoming more common. The state of California has developed the California Irrigation Management Information System (CIMIS), which allows growers to obtain daily reference evapotranspiration information through a computer dial-up service. 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, allowing users to refine irrigation scheduling and conserve water.

Numerous equations and methods have been developed to define the evapotranspiration term. A variety of methods currently used to calculate evapotranspiration are briefly described below. The reader is referred to appropriate references for specific equations and more information on applying these methods.

a. *The Penman Equation (Jones et al., 1984; Withers and Vipond, 1980; Pair et al., 1983, Jensen et al., 1990)*

The Penman equation combines an energy balance with an experimentally derived aerodynamic equation as a means of calculating potential evapotranspiration. Because there is general agreement that the Penman or a modified form of the Penman equation provides the most reliable means of estimating evapotranspiration, the Penman equation is recommended when possible. However, it is often difficult to obtain the meteorological data required to calculate this equation. For example, dew point temperatures are not available in many locations. In addition, wind speed is normally not measured at 2 m above a grassed surface at most U.S. weather stations as required for this method. Even where the required data are available, the period of record may be insufficient to generate a data base sufficient for statistical analysis.

b. *Pan Evaporation Method (Pettygrove and Asano, 1985; Jones et al., 1984; Withers and Vipond, 1980; Pair et al., 1983)*

An open pan is currently the most widely used method of estimating evapotranspiration. In addition, there are numerous locations throughout the U.S. and the world where pan evaporation data are available for a long period of record.

The concept of the pan station is straightforward. A pan of standard dimensions is filled with water and exposed to the atmosphere. The resulting water loss through evaporation can be measured and, in turn, related to the consumptive use of a crop under similar conditions. The advantages of the pan method are simplicity and low cost. However, the user must exercise caution in the use of pan data. A number of different standard pans are now in use throughout the world, each differing in construction and each with a different pan coefficient. In addition, pans are relatively sensitive to location; a pan located within a large expanse of turf will have significantly lower potential evaporation than one surrounded by bare soil.

c. *Empirical Evaluations of Evapotranspiration (Jones et al., 1984; Withers and Vipond, 1980; Pair et al., 1983)*

Many empirical methods have been developed to estimate evapotranspiration. The advantages of these methods are that they require only commonly measured data, such as temperature, and most are relatively simple to calculate. However, the use of a simplified equation to evaluate the complex process of evapotranspiration has inherent limitations. When selecting an appropriate empirical method, the user should identify equations developed in a similar climate. If possible, the user should re-evaluate coefficients using local data. In general, empirical equations using only temperature as a means of calculating evapotranspiration are not adequate for arid and semiarid regions (Jensen *et al.*, 1990).

The Thornthwaite and Blaney-Criddle methods of estimating evapotranspiration are two of the most cited methods in the literature. 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.

3.4.1.2 Effective Precipitation, Percolation and Surface Water Runoff Losses

Traditionally, the design of land application systems has attempted to account for the movement of water into and out of the application site. This approach is oriented to maximizing hydraulic capacity and, in turn, minimizing the land required for a given disposal capacity. It is quite common to find crop selection for land application sites based on the crop's ability to tolerate extended periods of excessive soil moisture. Under disposal-oriented design, as specified in most state regulations, the application of effluent in a manner resulting in surface runoff is discouraged or prohibited. However, the designer typically provides for runoff of rainfall. In many cases, runoff losses are assumed to be a fixed percentage of total rainfall throughout the year based on Soil Conservation Service (SCS) runoff coefficients for a specific soil type and ground cover.

Percolation losses are generally based on site-specific investigation of the hydrogeologic conditions of the selected land application site. The EPA manual *Land Treatment of Municipal Wastewater* (EPA, 1981) recommends that the system percolation losses be estimated between 4 to 10 percent of the minimum soil permeability encountered on the site.

The allowable percolation loss from a land application site is not specifically regulated, but may be indirectly controlled by groundwater quality regulations. While the parameters related to maintenance of groundwater quality may vary from state to state, most areas specifically require nitrate levels of less than 10 mg/L, mainly to minimize the possibility of methemoglobinemia or "blue baby syndrome," which could result from consumption of groundwater containing elevated levels of nitrate. This water quality requirement is applicable to almost all land application systems using municipal wastewater effluents due to the nitrogen content of the reclaimed water.

The approach for the beneficial reuse of reclaimed water will, in most cases, vary significantly from land treatment. Specifically, the reclaimed water is treated as 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 would 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 (see Section 3.4.2).

In evaluating the need for supplemental irrigation, it is desirable to estimate that fraction of the precipitation which actually becomes available to the crop, called "effective rainfall." The amount of effective rainfall will be influenced by rainfall intensity, soil infiltration rates, soil water storage capacity, management of irrigation water, and rooting depth of the crop. As with methods of estimating evapotranspiration, a precise calculation of effective rainfall is not possible. The SCS has developed an empirical method (USDA, 1967) that provides a reasonable estimate of effective rainfall; however, site-specific information should be used if available.

Irrigation demand is that water required to meet the needs of the crop and overcome system losses. System losses will consist of percolation, surface water runoff, as well as 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 in a single system efficiency. The actual efficiency of a given system will be site specific and will vary widely depending on management practices followed. Irrigation efficiencies typically range from 35 to 90 percent (Pettygrove and Asano, 1985). A general range by type of irrigation system is as follows:

- Surface (flood) irrigation - 50 - 70 percent
- Sprinkler irrigation - 65 - 70 percent
- Drip/trickle irrigation - 85 - 90 percent

Combining the various losses, the net irrigation may also be written as:

Total Irrigation Demand = (ET - effective rainfall)/ system application efficiency

When using closed pipes to transmit reclaimed water, water system losses will be similar to those observed in potable distribution systems and, in most cases, should not represent a significant portion of the net demand. System losses may become significant when unlined, open channels are used to transmit water.

Since there are no hard and fast rules for selecting the most appropriate methods 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.

3.4.2 Reclaimed Water Quality

General treatment requirements to ensure a reliable reclaimed water suitable for the various reuse applications are presented in Section 2.4. There are also some constituents in reclaimed water that have special significance in agricultural irrigation.

The 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 these constituents encountered in the root zone or deposited on the foliage. Reclaimed water tends to have higher concentration 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 the type of storage facilities. In most cases, the reclaimed water is of acceptable quality if the municipal potable source is acceptable. Conditions which 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.

3.4.2.1 Salinity

Salinity is the single most important parameter in determining the suitability of a water for irrigation (Pettygrove and Asano, 1985). The tolerance of plants to salinity 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 buildup.

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 formula for leaching requirement is:

(U.S. Bureau of Reclamation, 1984)

$$LR = ECiw/ECdw \times 100$$

where: ECiw = electrical conductivity of irrigation water

ECdw = electrical conductivity of drainage water and is determined by the salt tolerance of the crop to be grown

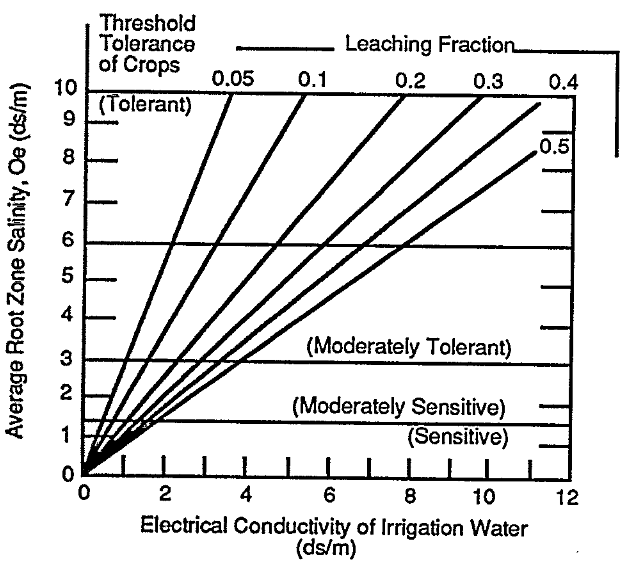
The extent of salt accumulation in the soil depends on the concentration of salts in the irrigation water and the rate at which it is removed by leaching. Salt accumulation can be especially detrimental during germination and when plants are young (seedlings), even at relatively low concentrations. Salinity is usually determined by measuring the electrical conductivity of the water, yet salinity may also be reported as TDS. Electrical conductivity of a water is a quick measure of its total dissolved salt concentration and is commonly expressed as ds/m or mmho/cm (Pettygrove and Asano, 1985). The TDS is commonly expressed as mg/L, a ratio of the weight of dissolved solids contained in one liter of solution.

The values for electrical conductivity (EC) and TDS are interchangeable within an accuracy of about +10 percent (Pettygrove and Asano, 1985). The equations used to convert EC to TDS is:

TDS (mg/L) x 0.00156 = EC (mmho/cm)

The EC is used as an expression of salinity in the irrigation water (ECiw), salinity in the saturated extract (ECe), and salinity in the soil solution (ECss). To determine the ECe, demineralized water is added to soil until the solid paste glistens and flows slightly. The soil paste is then filtered under suction and the solution is obtained and analyzed for electrical conductivity (Tanji, 1990). Crops are divided into the four major groups, shown in Figure 28, based on tolerance to irrigation salinity, leaching fraction, and the respective root zone salinity (ECe). Note that the leaching fraction is determined by measuring water infiltration and estimating evapotranspiration.

Figure 28. Assessing Crop Sensitivity to Salinity for Conventional Irrigation



Source: Tanji, 1990.

The following is a description of the irrigation water quality as it relates to salinity for each of the crop groups:

- Sensitive Crops - The water can be used for irrigation of most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices, except in soils of extremely low permeability.

- Moderately Sensitive Crops - The water can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

- Moderately Tolerant Crops - The water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and plants with good salt tolerance should be selected.

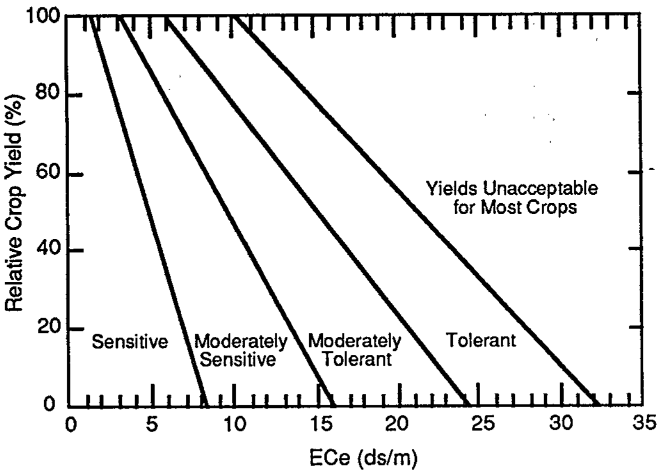
- Tolerant Crops - The water is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, draining must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected (Pair *et al.*, 1983).

Figure 29 shows the various crop divisions with a relationship of percent crop yield to the salinity of saturated soil extract taken from the root zone (ECe). Table 17 divides the types of crops into their respective groups based on salt tolerance at the root zone (ECe). In addition, a study in St. Petersburg, Florida, found that of the 205 species of landscape plants reviewed in a homeowner study, 55 were highly tolerant to reclaimed water, 108 were tolerant, 39 were found to need extra maintenance with reclaimed water, and only three species were not recommended (Parnell, 1987).

The concerns with salinity are its influence on: (1) the soil's osmotic potential, (2) specific ion toxicity, and (3) degradation of soil physical conditions that may occur. These conditions may result in reduced plant growth rates, reduced yields, and, in severe cases, total crop failure.

Salinity reduces the water uptake of plants by lowering the osmotic potential of the soil. This, in turn, causes the plant to use a large portion of its available energy on adjusting the salt concentration within its tissue to obtain adequate water, resulting in less energy available for plant growth. The problem is greater under hot and dry climatic conditions, because of greater plant water usage, and is even more severe when irrigation is inadequate.

Figure 29. Divisions for Classifying Crop Tolerance of Salinity



Source: Tanji, 1990.

The concentration of specific ions may cause one or more of these trace elements to accumulate in the soil and plant, and long-term buildup 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.

3.4.2.2 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. The concentration of sodium in water relative to calcium and magnesium is expressed as SAR and is calculated as follows:

$$SAR = \frac{Na}{\sqrt{[(Ca + Mg)/2]}}$$

where ion concentrations, Na, Ca and Mg are expressed in meq/L

For reclaimed water, it is recommended that the SAR be adjusted for alkalinity to include a more correct estimate of calcium in the soil water following irrigation, specifically adj R_{Na}. The adjusted value is calculated as:

$$adj\ R_{Na} = \frac{Na}{\sqrt{(Ca_x + Mg)/2}}$$

where the Ca_X value can be determined from Table 18.

Note that the calculated (adj R_{Na}) is to be substituted for the SAR value (Pettygrove and Asano, 1985).

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. Studies have also shown that in soils groups with a very high amount of organic matter or oxides show little loss of hydraulic conductivity when saturated with Na and equilibrated to very low levels of salinity (Tanji, 1990). 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 (Na) 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.

3.4.2.3 Trace Elements

Trace elements in reclaimed water normally occur in concentrations less than a few mg/L, with usual concentrations less than 100 µg/L (Pettygrove and Asano, 1985). Some are essential for plants and animals but all can become toxic at elevated concentrations or doses (Tanji, 1990).

A study in California (Engineering Science, 1987) was performed to determine if a higher concentration of heavy

Table 17. Crop Salt Tolerance

Sensitive	Moderately Sensitive	Moderately Tolerant	Tolerant
Bean	Broad Bean	Cowpea	Barley
Paddy Rice	Corn	Kenaf	Cotton
Sesame	Flax	Oats	Guar
Carrot	Millet	Safflower	Rye
Okra	Peanut	Sorghum	Sugar Beet
Onion	Sugarcane	Soybean	Triticale
Parsnip	Sunflower	Wheat	Semi-dwarf Wheat
Pea	Alfalfa	Barley (forage)	Durum Wheat
Strawberry	Bentgrass	Grass Canary	Alkali Grass
Almond	Angleton Bluestem	Hubam Clover	Nuttail Alkali
Apple	Smooth Brome	Sweet Clover	Bermuda Grass
Apricot	Buffelgrass	Tall Fescue	Kallar Grass
Avocado	Burnet	Meadow Fescue	Desert Salt Grass
Blackberry	Alsike Clover	Harding Grass	Wheat Grass
Boysenberry	Ladino Clover	Blue Panic Grass	Fairway Wheat
Cherimoya	Red Clover	Rape	Crested Wheat
Sweet Cherry	Strawberry Clover	Rescue Grass	Tall Wheat Grass
Sand Cherry	White Dutch Clover	Rhodes Grass	Altai Wild Rye
Currant	Corn (forage)	Italian Ryegrass	Russian Wild Rye
Gooseberry	Cowpea (forage)	Perennial Ryegrass	Asparagus
Grapefruit	Grass dallis	Sundan Grass	Guayule
Lemon	Meadow Foxtail	Narrowleaf Trefoil	Jojoba
Lime	Blue Grama	Broadleaf Trefoil	
Loquat	Love Grass	Wheat (forage)	
Mango	Cicer Milkvetch	Durum Wheat (forage)	
Orange	Tall Oat Grass	Standard Crested Wheat Grass	
Passion Fruit	Oats (forage)	Intermediate Wheat Grass	
Peach	Orchard Grass	Slender Wheat Grass	
Pear	Rye (forage)	Beardless Wild Rye	
Persimmon	Sesbania	Canadian Wild Rye	
Plum; Prune	Sirato	Artichoke	
Pummelo	Sphaerophysa	Red Beet	
Raspberry	Timothy	Zucchini Squash	
Rose Apple	Big Trefoil	Fig	
White Sapote	Common Vetch	Jujube	
Tangerine	Broccoli	Papaya	
	Brussel Sprouts	Pomegranate	
	Cabbage		
	Cauliflower		
	Celery		
	Sweet Corn		
	Cucumber		
	Eggplant		
	Kale		
	Kohlrabi		
	Lettuce		
	Muskmelon		
	Pepper		
	Potato		
	Pumpkin		
	Radish		
	Spinach		
	Scallop Squash		
	Sweet Potato		
	Tomato		
	Turnip		
	Watermelon		
	Castorbean		
	Grape		

Source: Tanji, 1990.

Table 18. Salinity of Applied Water (EC_w)

(mmho/cm or dS/m)

Ratio of HCO_3/Ca	0.1	0.2	0.3	0.5	0.7	1.0	2.0	3.0	4.0	5.0	6.0	8.0
0.05	13.20	13.61	13.92	14.40	14.79	15.26	15.91	16.43	17.28	17.97	19.07	19.94
0.10	8.31	8.57	8.77	9.07	9.31	9.62	10.02	10.35	10.89	11.32	12.01	12.56
0.15	6.34	6.54	6.69	6.92	7.11	7.34	7.65	7.90	8.31	8.64	9.17	9.58
0.20	5.24	5.40	5.52	5.71	5.87	6.06	6.31	6.52	6.86	7.13	7.57	7.91
0.25	4.51	4.65	4.76	4.92	5.06	5.22	5.44	5.62	5.91	6.15	6.52	6.82
0.30	4.00	4.12	4.21	4.36	4.48	4.62	4.82	4.98	5.24	5.44	5.77	6.04
0.35	3.61	3.72	3080	3.94	4.04	4.17	4.35	4.49	4.72	4.91	5.21	5.45
0.40	3.30	3.40	3.48	3.60	3.70	3.82	3.98	4.11	4.32	4.49	4.77	4.98
0.45	3.05	3.14	3.22	3.33	3.42	3.53	3.68	3.80	4.00	4.15	4.41	4.61
0.50	2.84	2.93	3.00	3.10	3.19	3.29	3.43	3.54	3.72	3.87	4.11	4.30
0.75	2.17	2.24	2.29	2.37	2.43	2.51	2.62	2.70	2.84	2.95	3.14	3.28
1.0	1.79	1.85	1.89	1.96	2.01	2.09	2.16	2.23	2.35	2.44	2.59	2.71
1.25	1.54	1.59	1.63	1.68	1.73	1.78	1.86	1.92	2.02	2.10	2.23	2.33
1.50	1.37	1.41	1.44	1.49	1.53	1.58	1.65	1.70	1.79	1.86	1.97	2.07
1.75	1.23	1.27	1.30	1.35	1.38	1.43	1.49	1.54	1.62	1.68	1.78	1.86
2.00	1.13	1.16	1.19	1.23	1.26	1.31	1.36	1.40	1.48	1.54	1.63	1.70
2.25	1.04	1.08	1.10	1.14	1.17	1.21	1.26	1.30	1.37	1.42	1.51	1.58
2.50	0.97	1.00	1.02	1.06	1.09	1.12	1.17	1.21	1.27	1.32	1.40	1.47
3.00	0.85	0.89	0.91	0.94	0.96	1.00	1.04	1.07	1.13	1.17	1.24	1.30
3.50	0.78	0.80	0.82	0.85	0.87	0.90	0.94	0.97	1.02	1.06	1.12	1.17
4.00	0.71	0.73	0.75	0.78	0.80	0.82	0.86	0.88	0.93	0.97	1.03	1.07
4.50	0.66	0.68	0.69	0.72	0.74	0.76	0.79	0.82	0.86	0.90	0.95	0.99
5.00	0.61	0.63	0.65	0.67	0.69	0.71	0.74	0.76	0.80	0.83	0.88	0.93
7.00	0.49	0.50	0.52	0.53	0.55	0.57	0.59	0.61	0.64	0.67	0.71	0.74
10.00	0.39	0.40	0.41	0.42	0.43	0.45	0.47	0.48	0.51	0.53	0.56	0.58
20.00	0.24	0.25	0.26	0.26	0.27	0.28	0.29	0.30	0.32	0.33	0.35	0.37

Source: Adapted from Suarez, 1981.

metals could be found in plots irrigated with reclaimed water vs. well water. After a 5-year period, it was determined that there were no increasing trends with the exception of copper, which rose for all water types, yet still well below the average of California soils. It was determined that concentrations were so low (below detection for the most part), that irrigation for much longer periods would lead to the same conclusion as the 5-year test with the exception of iron and zinc (two essential plant and animal micronutrients). It was found that iron was more concentrated in plots irrigated with well water and zinc was greater with the reclaimed water. However, at the levels found for either, the uptake by plants would be greater than the accumulation from irrigation input.

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.

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

Copper is not toxic to monogastric animals, but may be toxic to ruminants. However, their tolerance 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 in the small amounts they ingest. Most milk and beef products are also unaffected by livestock ingestion of cadmium because it is stored in the liver and kidneys of the animal rather than the fat or muscle tissues.

Table 19 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 with (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 (EPA, 1980b).

3.4.2.4 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.

3.4.2.5 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, they may also delay maturity and reduce crop quality and quantity. In addition, excessive nitrate in forages can cause an imbalance of nitrogen, potassium, and magnesium in the grazing animals and 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.

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. This is the case in Tallahassee, Florida, where a farmer leases city-owned land supplied with reclaimed water via a center-pivot irrigation system. Even though the irrigation rate exceeds the crops' consumptive needs, the dilute nature of the nitrogen (approximately 18 mg/L) requires supplemental fertilizers at certain times of the year (Allhands and Overman, 1989).

Soils in the western U.S. may contain enough potassium, while many sandy soils of the southern U.S. do not, yet in either case, the addition of potassium with reclaimed water has little effect on the crop. Phosphorus contained in reclaimed water is usually too low 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 does not appear to pose any problem to crops, but can be a problem in runoff to surface waters.

Numerous site specific studies have been conducted regarding the potential water quality concerns associated with reuse irrigation. A survey of agricultural systems operating in California found no indications that crop quality or quantity had deteriorated as a result of reclaimed water irrigation. In fact, several of the farmers using reclaimed water felt that crop production had been enhanced as a result of nutrients in the water (Boyle Engineering Corporation, 1981). Studies of the Tallahassee, Florida spray irrigation system noted that after 5 years of irrigation, steady state conditions with respect to ionic species on soils exchange site had not come to a steady state, but no adverse impacts on agricultural production were expected (Payne and Overman, 1987). These and other investigations suggest that reclaimed water will be suitable for most agricultural irrigation needs.

3.4.3 Other System Considerations

In addition to irrigation supply and demand and reclaimed water quality requirements, there are other

Table 19. Recommended Limits for Constituents in Reclaimed Water for Irrigation

TRACE HEAVY METALS

Constituent	Long-Term Use (mg/L)	Short-Term Use (mg/L)	Remarks
Aluminum	5.0	20	Can cause nonproductivity 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 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 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 molybdendum.
Lead	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium	2.5	2.5	Tolerated by most crops at 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 acid 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 added 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.

OTHER PARAMETERS

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	

Source: Adapted from EPA, 1973.

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. This requires that those investigating reclaimed water programs have a working knowledge of the appropriate regulations, crop requirements, and means of application. Important considerations include:

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

3.4.3.1 System Reliability
Two basic issues are involved in system reliability. First, as in any reuse project, when irrigation is implemented as a means of reducing or eliminating 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 the constituents in reclaimed water (see Sections 2.4 and 3.4.2) Reliability in quantity involves balancing supply with irrigation demand, largely accomplished by providing sufficient operational and seasonal storage facilities (see Sections 2.5 and 2.6.2).

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. In 1985 in Santa Rosa, California, the city exceeded its effluent discharge limits in part because the irrigation systems on the private farms were not able to distribute sufficient flows (Fox *et al.*, 1987).

In some cases, provisions may have to be made to supplement reclaimed water with another source to ensure that adequate supplies are available for peak demands. For example, to meet the occasional peak water demands associated with freeze protection of 27 citrus groves in the joint Orange County/Orlando, Florida Conserv II, water reuse program, 23 back-up irrigation wells were constructed, providing a peak well water flow of 51,000 gpm (3,220 L/s) (Cross *et al.*, 1992). The Walnut Valley Water District water reuse system in California also provides back-up wells to ensure demands can be met. As an interim solution until the wells went on line, two connections to the potable system were provided for emergency use (Cathcart and Biederman, 1984).

3.4.3.2 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 irrigation can take place and restrictions on the access to the irrigated site. Such use area controls may require modification of existing farm practices and limit the use of reclaimed water to areas where required buffer zones can 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.

3.4.3.3 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 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. In locations of karst topography, where reclaimed water may percolate into underground sources of drinking water, reuse may be limited and in some cases prohibited.

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.

3.4.3.4 Runoff Controls
Some irrigation practices, such 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 discharge to a surface water.

3.4.3.5 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, reclaimed water may extend an agricultural user's supply, allowing the user to expand production or plant a more valuable crop. Where irrigation is restricted as a water conservation measure in arid climates and during drought in other regions, reclaimed water can provide a dependable source for 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. Rates and fees for reuse systems are discussed in Chapter 6.

Agricultural users will also expect assurance that reclaimed water will be beneficial to their crops and capable of producing a wholesome and valuable product. In some cases, a pilot project may be in order.

In the early 1980s, the Irvine Ranch Water District in Orange County, California, investigated the use of reclaimed water for the irrigation of strawberries. Field studies indicated that over the course of the season, yields for test and control plots were similar. However, the elevated concentrations of sodium and chloride in the reclaimed water resulted in reduced yields early in the season. Early season berries were being sold as fresh fruit for approximately $8.60/tray. The late season berries typically were frozen and sold for approximately $3.60/tray. Even with equal yield for the total season, the shifting of berry production from early to late season posed a marketing problem for this application (Hyde and Young, 1984).

3.4.3.6 Irrigation Equipment

By and large, few changes in equipment are required to use reclaimed water for agricultural irrigation. There are, however, some considerations for certain irrigation systems.

As previously noted, surface irrigation systems (ridge and furrow, graded borders) normally result in the discharge of a portion of the irrigation water from the site. Where discharge is not permitted with reclaimed water, some method of tailwater 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 and the nozzle size. Studies in the Napa Sanitation District, California, indicated plugging of nozzles as small as 5/32-in (4-mm) diameter was not a serious problem with reclaimed water from an oxidation pond (Thornton *et al.*, 1984). In the Lubbock, Texas land treatment system, the use of a storage reservoir prior to irrigation greatly reduced nozzle clogging from trickling filter effluent. The quiescent reservoir allowed plastic fragments and other solid particles to settle out prior to irrigation. An unfortunate side effect of using the storage pond, however, was the loss of approximately 71 percent of the nitrogen value of the water (George *et al.*, 1984).

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, sprinkler irrigation of crops to be eaten raw is restricted by some regulatory agencies as it results in the direct contact of reclaimed water with the fruit.

Micro-irrigation systems apply water at slow rates frequently, on or beneath the soil surface. Water is applied as drops, minute streams, or miniature sprays through closely spaced emitters attached to water delivery lines or via miniature spray nozzles. The conduits on which the emitters or miniature sprinklers are mounted are usually on the soil surface within the diameter of the root zone. The conduits may be buried at shallow depths or attached to trees for certain applications such as orchards. An extremely efficient form of irrigation, micro-irrigation systems are usually used in areas where water is scarce or expensive; soils are sandy, rocky, or difficult to level; or where crops require a high degree of soil moisture control.

When reclaimed water is used in a micro-irrigation system, a good filtration system is required to prevent complete or partial clogging of emitters, and close, regular inspections of emitters are required to detect emitter clogging. In-line filters of a 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.

3.5 Habitat Restoration/Enhancement and Recreational Reuse

Uses of reclaimed water for recreational and environmental purposes range from the maintenance of landscape ponds, such as water hazards on golf course fairways, to full-scale development of water-based recreational sites for swimming, fishing, and boating. In between lies a gamut of possibilities that includes ornamental fountains, snowmaking, rearing of freshwater sport fish, and the creation of marshlands to serve as wildlife habitat and refuges. As with any form of reuse, the development of recreational and environmental water reuse projects will be a function of a water demands coupled with a cost-effective source of reclaimed water of suitable quality.

As discussed in Chapter 4, many states have regulations specifically addressing 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 is required for recreational water bodies where fishing, boating, and other non-body contact activities are permitted. And, 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. The primary purpose of the coagulation step is to reduce SS and, thereby, to improve the efficiency of virus removal by chlorination.

In California, approximately 7 percent of the total reuse within the state was associated with recreational and environmental reuse in 1987 (California State Water Resources Control Board, 1990). In Florida, approximately 9 percent of the reclaimed water currently produced is being used for environmental enhancements, all for wetlands restoration (Florida Department of Environmental Regulation, 1990).

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

- Creation or enhancement of wetlands habitat
- Recreational and aesthetic impoundments
- Stream augmentation
- Other recreational uses

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

3.5.1 Natural and Manmade Wetlands

Over the last 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. Approximately 109 million ac (44 million ha) of the original 215 million ac (87 million ha) of wetlands have been destroyed with an additional 370,000 to 555,000 (150,000 to 225,000 ha) destroyed each year (Hammer, 1989). 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 be a beneficial use (and therefore reuse) because the wetlands are maintained so that they may provide these valuable functions.

Reclaimed water has been applied to wetlands for three main objectives:

- To create, restore, and/or enhance wetlands systems;
- To provide additional treatment of reclaimed water prior to discharge to a receiving water body; and
- To provide a wet weather disposal alternative for a water reuse system (see Section 2.6.3).

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, manmade and restored wetlands can be designed and managed to maximize habitat diversity within the landscape.

The application of reclaimed water to wetlands is a good example of providing for compatible uses. Wetlands are often able to enhance the water quality of the reclaimed water without creating undesirable impacts to the wetlands system, thereby enhancing downstream natural water systems and providing concomitant aquifer recharge.

Water quality enhancement is provided by transformation and/or storage of specific components within the wetland. The maximum contact of reclaimed water within the wetland will ensure maximum nutrient assimilation. This is due to the nature of the assimilation process. If optimum conditions are maintained, nitrogen and BOD assimilation in wetlands will occur indefinitely, as they are primarily controlled by microbial processes. In contrast, phosphorus assimilation in wetlands is finite and is related to the adsorption capacity of the soil. The wetland will provide additional water quality enhancement to the high quality reclaimed water product.

In most reclaimed water to wetlands projects described in the literature, the primary intent is to provide additional treatment of effluent prior to discharge. However, this focus does not negate the need for design considerations that will maximize wildlife habitats, thereby resulting in an environmentally valuable system. Appropriate plant species should be selected based on the quality and quantity of reclaimed water applied to the wetland system. A salinity evaluation on any created wetlands should also be performed since highly saline wetlands often exhibit limited vegetative growth. Such design considerations will seek to balance the hydraulic and constituent loadings with the needs of the ecosystem. Protection of groundwater quality should also be considered.

Wetlands enhancement systems developed to provide wildlife habitats as well as treatment are illustrated by Arcata, California, and Orlando, Florida. In the Arcata program, one of the main goals of the project was the enhancement of the beneficial uses of the 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 wetland system, consisting of three 10-ac (4-ha) marshes, has attracted more than 200 species of birds, provided a fish hatchery for salmon, and was a direct contributor 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 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 mi (20 km) to the wetland that was created by diking approximately 1,200 ac (480 ha) of improved pasture. The system is further divided into smaller cells for flow and depth management.

The wetland consists of three major vegetative areas. The first area, approximately 420 ac (170 ha), is a shallow marsh consisting primarily of cattails and bulrush and with nutrient removal as the primary function. The second area consists of 380 ac (150 ha) of a variety of mixed marsh species utilized for nutrient removal and wildlife habitat. The final area, 400 ac (160 ha) of hardwood swamp, consists of a variety of tree species providing nutrient removal and wildlife habitat. The reclaimed water then flows through approximately 600 ac (240 ha) of natural wetland prior to discharge to the St. Johns River (Lothrop, n.d.)

A number of states provide regulations which specifically address the use of reclaimed water in wetlands systems, including Arizona, Florida, and South Dakota. 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 United States, are protected under EPA's NPDES Permit and Water Quality Standards programs. The quality of the 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 United States. As a result, the application of primary effluent discharge into constructed wetlands to meet secondary effluent standards has been utilized in some instances.

3.5.2 Recreational and Aesthetic Impoundments

For the purposes of this discussion, an impoundment is defined as a manmade water body. The use of reclaimed water to augment natural water bodies is discussed in Section 3.5.3. Impoundments may serve a variety of functions from aesthetic, non-contact uses, to boating and fishing, to 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. Phosphorous is generally the nutrient limited as a means of controlling algae in fresh water impoundments (Water Pollution Control Federation, 1989).

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 a storage facilities for irrigation water within the site.

In Las Colinas, Texas, the design for a 12,000-ac (4,800 ha) master planned development included a series of manmade lakes [19 lakes covering 270 ac (110 ha)] for aesthetic enhancement. Lake levels are maintained with reclaimed water supplemented by water from the Elm Fork of the Trinity River. Six fountain type aerators were installed to enhance and maintain water quality (Smith *et al.*, 1990)

In Santee, California, reclaimed water has been used to supply recreational lakes for boating and fishing since 1961. Five lakes are served with reclaimed water with a total surface area of approximately 30 ac (12 ha). High nutrient levels in the reclaimed water promote algae and aquatic weed growth in the first two lakes; however, algae and other plant control through chemicals and mechanical harvesting is practiced. The lakes have become a part of a widely used and popular recreational area for local residents (Water Pollution Control Federation, 1989).

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 utilized for fishing, boating and water skiing; however, swimming is restricted.

The Tillman Water Reclamation Plant in Los Angeles, California is providing 8 mgd (350 L/s) of reclaimed water to fill the 26-ac (11-ha) Sepulveda Wildlife Lake. The Sepulveda Lake was created to provide a way station for migratory birds that travel through the Los Angeles area. A walking path has also been provided along the lake for wildlife viewing. Once the lake is filled, the amount of reclaimed water provided to the lake is reduced to 5 mgd (219 L/s) (Office of Water Reclamation - City of Los Angeles, 1991).

3.5.3 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 watercourses. This may be necessary in locations where a significant volume of water is drawn for potable or other uses, significantly reducing the downstream volume of water in the river.

As with impoundments, the water quality requirements for stream augmentation will be based upon 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. To achieve aesthetic goals, studies in Kawasaki City, Japan, suggest that both phosphorus removal and high-level disinfection are required. However, to ensure that aquatic life is maintained, ozone is used in place of chlorine as a disinfectant (Kuribayashi, 1990).

In Japan, an appreciable amount of reclaimed water is being used for augmenting streams in urban areas and for creating ornamental streams and lakes (Murakami, 1989). Many streams and channels within urbanized Japanese cities dry up periodically as a result of changes in surrounding land use. Restoring these streams to productive water bodies has become important as people within the cities place more importance on a better environment. A typical project of this kind is illustrated by the restoration of the Nobidome and Tanagawa channels in metropolitan Tokyo. Originally constructed for water supply in the 17th century, these channels have lost all or most of their flow as a result of modern water transportation systems. The discharge of filtered secondary reclaimed water was begun in the early 1980s as a means of restoring these streams. Maintenance of the channels, primarily cleaning out trash and fallen leaves, is performed in cooperation with the local residents. The Nobidome receives approximately 4 mgd (175 L/s) and the Tanagawa approximately 3.5 mgd (153 L/s). Reaction from the surrounding urban population has been quite favorable (Murakami, 1989).

Several agencies in southern California are evaluating the process in which reclaimed water would be delivered to streams in order to maintain a constant high-quality flow of water for the enhancement of the aquatic and wildlife habitat as well as to maintain the aesthetic value of the streams. Reclaimed water delivered to these streams would also receive the benefit of additional treatment through natural processes (Crook, 1990).

3.5.4 Other Recreational Uses

Other recreational uses of reclaimed water that are beginning to gain recognition include the rearing of freshwater sport fish and snowmaking. Commercial fish production in reclaimed water impoundments is a widely used practice in Israel and China (Crook, 1990). Large-scale fish production with reclaimed water is currently being investigated in the United States and has the potential of providing a significant future use. Most recreational impoundments that utilize reclaimed water in the United States currently allow the use of fishing within the impoundment. When fish taken from an impoundment comprised entirely of reclaimed water are used for human consumption, the quality of the reclaimed water should be thoroughly assessed (chemical and microbiological quality) for possible bioaccumulation of toxic contaminants through the food chain.

The use of reclaimed water for snowmaking was originally studied as a means of storing effluent during winter when land application was not feasible. A study conducted at Steamboat Springs, Colorado, showed that snowmelt from reclaimed water has exhibited a substantial reduction in BOD and TSS (Smith, 1986). Reclaimed water for artificial snowmaking has been proposed as a method of supplementing snowmaking at ski resorts throughout New England. In Vermont, several experiments with using reclaimed water for snowmaking have been conducted; however at this time, no full-scale projects have been approved.

3.6 Groundwater Recharge

This section addresses planned groundwater recharge with 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 include: (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, or (5) to control or prevent ground subsidence.

Pumping of groundwater aquifers in coastal areas may result in seawater intrusion into the aquifers, making them unsuitable as sources of potable supply or for other uses where high salt levels are intolerable. A battery of injection wells and extraction wells can be used to create a hydraulic barrier to maintain intrusion control. Reclaimed water can be injected directly into a confined aquifer and subsequently extracted, if necessary, to maintain a seaward gradient and thus prevent inland subsurface seawater intrusion.

Infiltration and percolation of reclaimed water takes advantage of the subsoils' natural ability for biodegradation and filtration, thus providing additional *in situ* treatment of the wastewater 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, depending on the method of recharge, hydrogeological conditions, requirements of the downstream users, and other factors. In some cases, the reclaimed water and groundwater blend and become indistinguishable.

Groundwater recharge helps provide a loss of identity between reclaimed water and groundwater. This loss of identity has a positive psychological impact where reuse is contemplated and is an important factor in making reclaimed water acceptable for a wide variety of uses, including potable water supply augmentation.

Groundwater 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. Also, groundwater aquifers serve as a natural distribution system and may reduce the need for surface transmission facilities.

While there are obvious advantages associated with groundwater recharge, there are possible disadvantages to consider (Oaksford, 1985):

- Extensive land areas may be needed for spreading basins.
- Energy and injection wells for recharge may be prohibitively costly.

- Recharge may increase the danger of aquifer contamination. Aquifer remediation is difficult, expensive, and may take years to accomplish.
- Not all added water may be recoverable.
- 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.
- Sudden increases in water supply demand may not be met due to the slow movement of groundwater.
- Inadequate institutional arrangements or groundwater laws may not protect water rights and may present liability and other legal problems.

3.6.1 Methods of Groundwater Recharge

Recharge can be accomplished by riverbank or dune filtration, surface spreading, or direct injection.

3.6.1.1 Riverbank or Dune Filtration

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 a contaminated surface water, usually a river. The contaminated water is infiltrated into the groundwater zone through the riverbank, percolation from spreading basins, or percolation from drain fields of porous pipe. In the latter two 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 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), 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.

3.6.1.2 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 clay layers or other 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 bypass the soil during the initial stages of the flooding period;
- Sufficient clay contents to provide large capacities to adsorb trace elements and heavy metals and to provide surfaces on which microorganisms decompose organic constituents; and
- 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 (Pratt *et al.*, 1975). BOD and TOC in the reclaimed water will also be a carbon source.

Unfortunately, some of the above characteristics are mutually exclusive. 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 draft:

- Physical character and permeability of subsurface deposits;
- Depth to groundwater;
- Specific yield, thickness of the deposits, and position and allowable fluctuation of the water table;
- Transmissivity, hydraulic gradients, and pattern of pumping; and
- Structural and lithologic barriers to both vertical and lateral movement of groundwater.

Although reclaimed water typically receives secondary treatment and disinfection (and in some cases, advanced wastewater treatment by 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. 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 (Carlson *et al.*, 1982; Lance, *et al.*, 1980; Rice and Bouwer, 1984).

For surface spreading of the 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 an unsaturated (vadose) zone to take maximum advantage of treatment through the soil matrix. If infiltration is intended to improve water quality, as with rapid infiltration land treatment systems (EPA, 1981), the depth to the groundwater table should be deep enough to ensure continuous and effective removal of chemical and microbiological constituents.

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.

a. 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 O&M costs. Disadvantages are large areal requirements, evaporation losses, and clogging.

b. Ridge and Furrow

Water is placed in narrow, flat-bottomed ditches. Ridge and furrows are 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 stream beds 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 washouts and possible legal restrictions related to such construction practices.

d. Infiltration Basins

Infiltration basins are the most widely used method of groundwater recharge. Basins afford high loading rates and 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.

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 over 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 done by operating *in situ* test pits or ponds. Hydraulic loading rates for rapid infiltration basins vary from 65 to 500 ft (20 to 150 m)/yr, but are usually less than 300 ft (90 m)/yr (Bouwer, 1988).

Though management techniques are site specific and vary accordingly, some common principles are practiced in most systems. A wetting and drying cycle with periodic cleaning of the bottom is used to prevent clogging by accumulated SS, maintain a high rate of infiltration, maintain microbial populations to consume organic matter and help reduce levels of microbiological constituents in the reclaimed water, and promote nitrification and denitrification processes for nitrogen removal. The loading rates are usually higher when nitrogen removal is not a concern.

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 and is determined on a case-by-case basis from field testing. 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

Table 20. Summary of Facilities and Management Practices for Percolation Recharge

Location	Load Rate (MG/ac/yr)	Perc. Rate (ft/d)	Load Schedule	Soil Type	Spreading Area Maintenance
Camp Pendelton, CA	N/A	8	As water becomes available	Coarse sand	Berm redevelopment, remove surface solids every other year
Hemet, CA	29	2.5	Fill 1 day (2.5-ft depth), drain 2 days, dry 1 day	Medium & coarse sand	Periodic rototilling of basins
Oceanside, CA	47	4.5	Fill to 3-ft depth, drain & dry, refill	Coarse sand	Basins scarified periodically
Phoeniz, AZ	137	2.5	Fill 10 days, dry 14 days	Loamy sand surface, coarse sand & gravel	Closely maintain flooding schedule, periodic scarifying
San Clemente, CA	140	5-10	Continuous	Coarse sand & gravel	None
St. Croix, Virgin Is.	36	1-2	Fill 18 days, dry 30 days	Silt, sand & clay	—
Whittier, CA	46	5-10	Fill 7 days (4-ft. depth), drain 7 days, dry 7 days	Sandy loam	Basins scarified periodically

Source: EPA, 1977.

reclaimed water within the basins minimizes algal growth. 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. Table 20 summarizes facilities and management practices for surface spreading operations at some sites in the U.S.

3.6.1.3 Soil-Aquifer Treatment Systems

Where hydrogeologic conditions permit groundwater recharge with surface infiltration facilities, considerable improvement in water quality may be obtained by movement of the wastewater through the soil, unsaturated zone, and aquifer. Table 21 provides an example of improvement in the quality of secondary effluent in a groundwater recharge soil-aquifer treatment (SAT) system. These data are the results of a demonstration project in the Salt River bed west of Phoenix, Arizona (Bouwer and Rice, 1984). The cost of SAT has been shown to be less than 40 percent of the cost of equivalent above-ground treatment (Bouwer, 1991).

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 30. 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.

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 (Bouwer, 1991), secondary treatment may not be necessary where the wastewater is subjected to SAT and subsequently reused for nonpotable purposes. The higher organic content of primary effluent may enhance nitrogen removal by denitrification in the SAT system (Lance *et al.*, 1980) and may enhance removal of synthetic organic compounds by stimulating greater microbiological activity in the soil (McCarty *et al*, 1984). A disadvantage of using primary effluent is that infiltration basin hydraulic loading rates may be lower than if higher quality effluent is used. This would require more frequent cleaning of the basins and increase the cost of the SAT, but not necessarily the total system cost.

Other methods of pretreatment prior to SAT may include lagoons or stabilization ponds, overland flow, or "natural" methods such as wetlands treatment. However, some of these low cost treatment methods may create infiltration

Table 21. 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, 1984.

problems if the water contains significant amounts of algae. The algae can form a filter cake or clogging layer on the bottom of the infiltration basins. To help alleviate this problem, the SAT infiltration basins should be shallow enough to avoid compaction of the clogging layer and to promote rapid turnover of the water in the basins (Bouwer and Rice, 1989).

3.6.1.4 Direct Injection

Direct injection involves the pumping of 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 "bubble," from which water can be extracted for reuse. Direct injection is also an effective method for creating barriers against saltwater intrusion in coastal areas.

Direct injection requires water of higher quality than surface spreading because of the absence of soil matrix treatment afforded by surface spreading and the need to maintain the hydraulic capacity of the confined aquifer. 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. Using these processes, or various subsets in appropriate combinations, it is possible to satisfy all present water quality requirements for reuse.

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 (Todd, 1980).

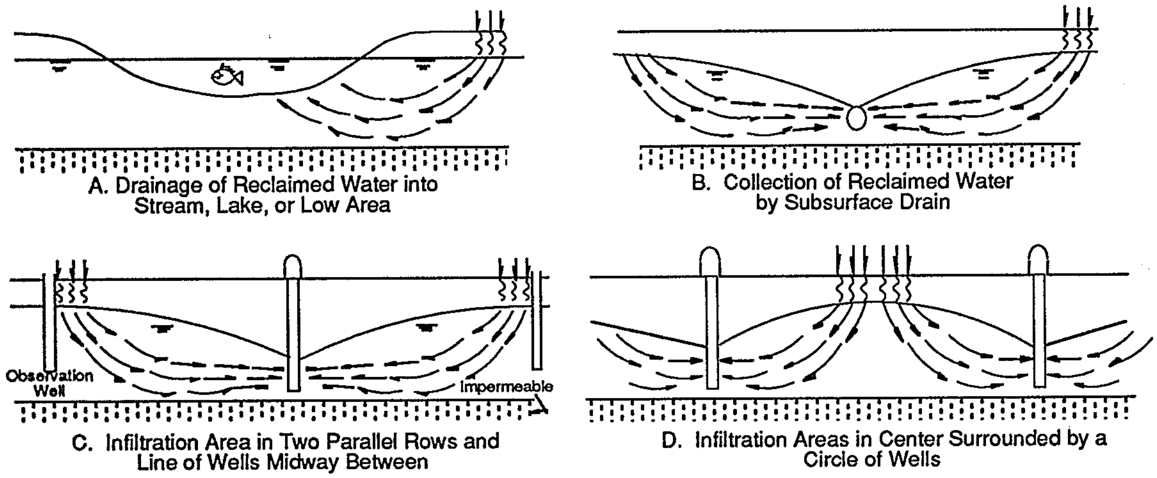
Ideally, an injection well will recharge water at the same rate as it can yield water by pumping. However, conditions are rarely ideal. Though clogging can easily by remedied in a surface spreading system by scraping, discing, drying and other methods, remediation in a direct injection system can be 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 SS, 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.

There are many criteria specific to the quality of the reclaimed water, the groundwater, and the aquifer material that have to be taken into consideration prior to construction and operation. These include possible chemical reactions between the reclaimed water and the groundwater, iron precipitation, ionic reactions, biochemical changes, temperature differences, and viscosity changes (O'Hare, 1986). Most clogging problems are avoided by proper pretreatment and proper operation.

3.6.2 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

Figure 30. Schematic of Soil-Aquifer Treatment Systems



Source: Bouwer, 1991.

to processes such as biodegradation by microorganisms, adsorption, filtration, ion exchange, volatilization, dilution, chemical oxidation and reduction, chemical precipitation and complex formation, and photochemical reactions (in spreading basins) (Roberts, 1980; EPA, 1989). For surface spreading operations, most of the removals of both chemical and microbiological constituents occur in the top 6 ft (2 m) of the vadose zone at the spreading site.

3.6.2.1 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. 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, impingent on, 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 SS concentration, soil characteristics, and hydraulic loading (Chang and Page, 1979). 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. In a groundwater recharge system, the impact of microbial activity on the attenuation of inorganic constituents is thought to be insignificant (Chang and Page, 1979). 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 removals in excess of 90 percent have been achieved by precipitation and adsorption in the underground (Sontheimer, 1980; Idelovitch, *et al.*, 1980), although the ability of the soil to remove these and other constituents may decrease over time. Heavy metal removal varies widely for the different elements, ranging from 0 to more than 90 percent, depending on speciation of the influent metals.

Trace metals which normally occur in solution as anions (e.g., silver, chromium, fluoride, molybdenum, and selenium) are strongly retained by soil (Chang and Page, 1979; John, 1972). Boron, which is mainly in the form of undissociated boric acid in soil solutions, is rather weakly adsorbed and, given sufficient amounts of leaching water, most of the adsorbed boron is desorbed (Rhoades *et al.*, 1979). There are indications that once heavy metals are adsorbed, they are not readily desorbed, although desorption depends, in part, on buffer capacity, salt concentrations, and reduction-oxidation potentially (Sontheimer, 1980).

For surface spreading operations where an aerobic zone is maintained, ammonia is effectively converted to nitrates, but subsequent denitrification is dependent, in part, on anaerobic conditions during the flooding cycle and is often partial and fluctuating unless the system is carefully managed.

3.6.2.2 Dissolved Organic Constituents

Dissolved organic constituents are subject to biodegradation and adsorption during recharge. Biodegradation mainly occurs by microorganisms attached to the media surface. 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, but biodegradation may be less rapid and perhaps less extensive (Roberts, 1980). The biodegradation of easily degradable organics occurs a short distance (few meters) from the point of recharge.

The end products of complete degradation under aerobic conditions include carbon dioxide, sulfate, nitrate, phosphate, and water, and 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. The degradation of organic contaminants may be partial and result in a residual organic product that cannot be further degraded at an appreciable rate.

Adsorption of organic constituents retards their movement (they can desorb and move chromatographically in the underground) and attenuates concentration fluctuations. Attenuation is a measure of the damping of organic constituent concentration fluctuations. The degree of attenuation increases with increasing adsorption strength, increasing distance from the recharge point, and increasing frequency of input fluctuation (Roberts, 1980). Recharged water may be free of many chemicals when it first appears at an extraction well, but the chemicals may begin to appear much later. Thus, chemical retardation needs to be evaluated when determining the effectiveness of contaminant removal in a recharge system (Bouwer, 1991).

Adsorption of uncharged organic compounds is believed to be related to the hydrophobic nature of compounds; highly chlorinated hydrocarbons are strongly adsorbed onto soils and, under typical recharge conditions, may be retained for many years (Roberts, 1980). Data reported by Sontheimer (1972) for riverbank infiltration along the Rhine River indicate that organic removal efficiency in bank filtration decreased as the relative amount of chlorine in the molecule increased. Studies involving sand dune filtration in the Netherlands indicated that the haloforms and organic nitrogen compounds were readily removed during passage through the dunes (Piet and Zoeteman, 1980).

In one study involving rapid infiltration of secondary effluent, nonhalogenated aliphatic and aromatic hydrocarbons and the priority pollutants ethylbenzene, napthalene, phenanthene, and diethylphthalate exhibited a concentration decrease between 50 and 99 percent during soil percolation, but many of the compounds could still be detected in the underlying groundwater (Bouwer, *et al.*, 1984). Smaller reduction in concentrations of the halogenated organic compounds and organic substances represented by total organic halogen were observed with soil passage compared to the specific nonhalogenated organic compounds found in the basin water. Another study indicated that nonvolatile organic halogens in injected reclaimed water were not retarded during passage through the ground, but that 50 percent were removed, presumably due to microbial degradation (Reinhard, 1984). Table 22 indicates the variability in different constituent removals after 2.5 m (8 ft) of percolation at a spreading basin.

3.6.2.3 Microorganisms

The survival or retention of pathogenic microorganisms in the subsurface **is** dependent on several factors, including climate, soil composition, antagonism by soil microflora, flow rate, and type of microorganism. At low temperatures (below 4°C [39°F]) some microorganisms can survive for months or years. The die-off rate is approximately doubled with each 10°C 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 enhances their transport (Wellings *et al.*, 1975).

The nature of the soil affects survival and retention. For example, rapid infiltration sites at which 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 (EPA, 1981). Other soil properties, such as pH, cation concentration, moisture holding capacity, and organic

Table 22. Results of Test Basin Sampling Program at Whittier Narrows, California

Constituent	Average Concentration At Surface	Average Concentration At 8 ft (2.5 m)	Linear Trend	Significance[a]
Total hardness ($mg\ CaCO_3/L$)	202	373	Increasing	<0.001
Total dissolved solids (mg/L)	516	703	Increasing	<0.001
Ammonia (mg/L)	14.6	0.25	Decreasing	<0.001
Nitrate (mg/L)	0.91	8.52	Increasing	0.009
Nitrite (mg/L)	0.86	0.02	Decreasing	<0.001
COD (mg/L)	29.3	12.3	Decreasing	<0.001
TOC (mg/L)	10.15	3.43	Decreasing	<0.001
Methylene chloride (µg/L)	16.9	1.9	Decreasing	0.026
Chloroform (µg/L)	5.2	2.5	Decreasing	0.008
Trichloroethylene (µg/L)	2.7	3.8	Increasing	NS[b]
Tetrachloroethylene (µg/L)	2.3	1.0	Decreasing	0.019

[a]Level of significance based on two-tailed *t*-test.
[b]Not significant ($p>0.05$)

Source: Nellor *et al.*, 1985.

matter affect the survival of bacteria and viruses in the soil (Gerba and Lance, 1980). Resistance of microorganisms to environmental factors depends on the species and strains present.

Drying of 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 (Gerba, Wallis, and Melnick, 1975). 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. Factors that may influence virus movement in groundwater are given in Table 23. Viruses have been isolated by a number of investigators examining a variety of recharge operations, after various migration distances. These are summarized in Table 24. 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.

3.6.3 Health and Regulatory Considerations

The constraints on recharge are conditioned by the use to which the abstracted water will be put, and include health concerns, economic feasibility, physical limitations, legal restrictions, water quality constraints, and reclaimed water availability. Of these constraints, the health concerns are the most important as they pervade almost all recharge projects. Where there is to be ingestion of the reclaimed water, 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 2.4 Health Assessment and Section 3.7 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 for groundwater recharge. In light of these uncertainties, some states have set stringent water quality requirements and require high levels of treatment—in some cases organics removal processes—where recharge affects potable aquifers.

3.7 Augmentation of Potable Supplies

Table 23. 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.

Table 24. Isolation of Viruses Beneath Land Treatment Sites

Site Location	Site Type[a]	Maximum Distance of Virus Migration (m): Depth	Horizontal
St. Petersburg, FL	S	6.0	—
Gainesville, FL	S	3.0	7
Lubbock, TX	S	30.5	—
Kerrville, TX	S	1.4	—
Muskegon, MI	S	10.0	—
San Angelo, TX	S	27.5	—
East Meadow, NY	R	11.4	3.0
Holbrook, NY	R	6.1	45.7
Sayville, NY	R	2.4	3
12 Pines, NY	R	6.4	—
North Masapequa, NY	R	9.1	—
Babylon, NY	R	22.8	408
Ft. Devens, MA	R	28.9	183
Vineland, NJ	R	16.8	250
Lake George, NY	R	45.7	400
Phoenix, AZ	R	18.3	3
Dan Region, Israel	R	31-67	60-270

[a]S = Slow-rate infiltration, R = Rapid infiltration.
Source: Adapted from Gerba and Goyal, 1985.

Water is a renewable resource. It is cleansed and reused continually, powered by solar energy in the hydrological cycle. The distillate produced, rainfall, is pure, until it picks up contaminants as it falls through the atmosphere and flows over and through the ground and in rivers and lakes polluted by urban, industrial, and agricultural discharges.

A principle that has guided 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 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..."

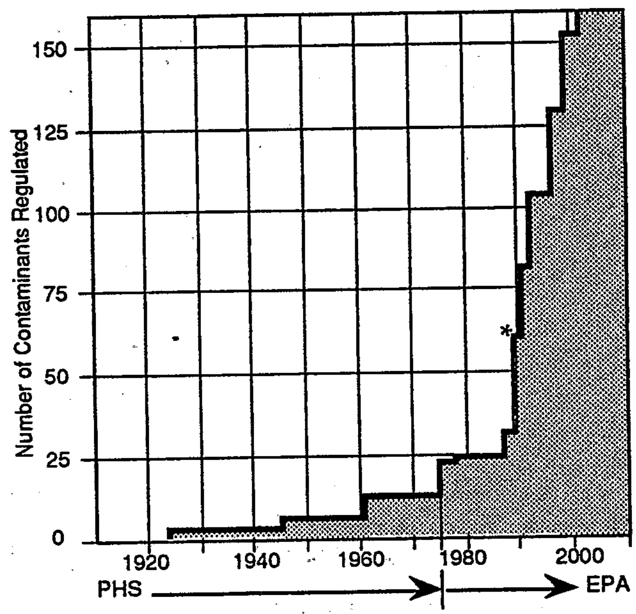
This section discusses indirect potable reuse, where treated wastewater is discharged into a water course or underground and withdrawn downstream or downgradient at a later time for potable purposes, and direct potable reuse, where the reclamation plant effluent is piped into the potable water system. Both such sources of potable water are, on their face, less desirable than using a higher quality source for drinking.

3.7.1 Water Quality Objectives for Potable Reuse

Whereas the water quality requirements for nonpotable urban reuse are quite tractable and treatment requirements are not likely to change significantly in the future, drinking water quality standards will become more rigorous in the future, requiring more and more treatment for potable reuse. The number of contaminants regulated, by the Public Health Service until 1974 and subsequently by the EPA, has grown from a handful in 1925 to a target of more than 100 as shown in Figure 31. Not only are the numbers of contaminants to be monitored increasing, but, for many of them, the maximum contaminant limits (MCLs) are decreasing. For example, the MCL for lead was reduced in 1992 from 50 ug/L to an action level of 15 ug/L. The health effects for many of the individual regulated contaminants are not well established.

It is estimated that only about 10 percent by weight of the organic compounds in drinking water have been identified (National Research Council, 1980) and the health effects of only a few of the individual identified compounds have been determined (National Research Council, 1980). The health effects of mixtures of two or more of the hundreds of compounds in any single source of drinking water drawn from wastewater will not be easily characterized. Health effects studies for reuse are applicable only to the specific situation, as the contaminant mix varies from city to city. Also, for any one city, it is likely that the contaminants will change over the years.

Figure 31. Number of Drinking Water Contaminants Regulated by the U.S. Government



*From this date, requirements of Safe Drinking Water Act and its amendments

Some organic compounds, particularly chlorinated species, are known or suspected carcinogens. Many epidemiological studies have been conducted to assess the potential health effects associated with drinking water derived from sources containing significant amounts of wastewater. The results have generally been inconclusive, although they provided sufficient evidence for maintaining a hypothesis that there may be a health risk (National Research Council, 1980). One study, conducted by the National Cancer Institute, indicated an increased incidence of bladder cancer in people who drank chlorinated surface water as compared to those who drank unchlorinated groundwater (Cantor *et al.*, 1987). Recognizing the limitations of epidemiological studies because of the many compounding variables, these studies — and the earlier research on drinking water taken from the Mississippi River that led to initial passage of the Safe Drinking Water Act — do provide a basis for concern where water that may contain significant levels of organic constituents is subsequently chlorinated and distributed for potable use. In general, the poorer the raw water quality, the more chlorine is required and the greater is the resulting risk.

Quality standards have been established for many inorganic constituents and treatment and analytical technology has demonstrated our capability to identify, quantify, and control these substances. Similarly, available technology is capable of eliminating pathogenic agents from contaminated waters. However, unanswered questions remain with organic constituents, due mainly to their potential large number and unresolved health risk potential resulting from long-term exposure to extremely low considerations.

3.7.2 Indirect Potable Water Reuse

Many cities have elected in the past to take water from large rivers that receive substantial wastewater discharges because of the assurance that conventional filtration and disinfection will eliminate the pathogens responsible for water-borne infectious disease. These supplies were generally less costly and were 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. Nevertheless, most cities do provide water of acceptable quality that meets current drinking water regulations.

More recent indirect potable reuse projects are exemplified by the Upper Occoquan Sewage Authority (UOSA) treatment facilities in northern Virginia, which discharge reclaimed water into the Bull Run just above Occoquan Reservoir, a source of water supply for Fairfax County, Virginia, and the Clayton County, Georgia, project where wastewater, following secondary treatment, undergoes land treatment, with the return subsurface flow reaching a stream used as a source of potable water. The UOSA plant provides AWT (Robbins and Ehalt, 1985) 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.

While UOSA now provides a significant portion of the water in the system, varying from an average of about 10 percent of the total flow to as much as 40 percent in low flow periods, most surface 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 the reclaimed water is almost always the responsibility of a water supply agency that is not at all related politically, administratively or even geographically, except for being downstream, to the wastewater disposal agency.

While direct potable reuse is not likely to be adopted soon, indirect potable reuse via surface waters has been, and will continue to be, practiced widely. Issues evolving from these practices are the substance of extensive studies of water pollution control and water treatment, resulting in a large number of publications and regulations that do not require elucidation in this document. Indirect potable reuse via groundwater recharge is being practiced to a lesser extent.

3.7.3 Groundwater Recharge for Potable Reuse

As mentioned in Section 3.6.1., Methods of Groundwater Recharge, groundwater recharge via riverbank or sand dune filtration, surface spreading, or injection has long been used to augment potable aquifers. Riverbank or dune filtration of untreated surface water is distinctly different from recharge of highly treated wastewater, but the health concerns associated with this practice are similar to those for potable reuse generally. Riverbank or dune filtration includes infiltrating river water into the groundwater zones through the riverbank, percolation from spreading basins, or percolation from drain fields or porous pipe. In the latter two 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 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), 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.

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 in response to uncertainties about the health consequences of recharge for potable use raised by a California Consulting Panel in 1975-76.

In 1978, the Sanitation Districts of Los Angeles County initiated a 5-year, $1.4 million, study of the Montebello Forebay Groundwater Recharge Project at Whittier Narrows that had been replenishing groundwater with reclaimed water since 1962. Three water reclamation plants provide water for the spreading operation. The plants provide secondary treatment (activated sludge), dual-media filtration (Whittier Narrows and San Jose Creek) or activated carbon filtration (Pomona), disinfection with chlorine, and dechlorination. By 1978, the amount of reclaimed water spread averaged about 9 billion gal/yr (34×10^3 m^3/yr) or 16 percent of the total inflow to the groundwater basin with no more than about 8 billion gal ($42 \times 10^6 \times m^3$) 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).

Historical impacts on groundwater quality and human health and the relative impacts of the different replenishment sources-reclaimed water, stormwater runoff, and imported surface water-on groundwater quality were assessed after conducting a wide range of research tasks, including:

- Water quality characterizations of groundwater, reclaimed water, and other recharge sources in terms of their microbiological and inorganic chemical content;
- Toxicological and chemical studies of groundwater, reclaimed water and other recharge sources to isolate and identify health-significant organic constituents;
- Percolation studies to evaluate the efficacy of soil in attenuating inorganic and organic chemicals in reclaimed water;
- Hydrogeological studies to determine the movement of reclaimed water through groundwater and the relative contribution of reclaimed water to municipal water supplies; and,
- Epidemiological studies of populations ingesting reclaimed water to determine if their health characteristics differ significantly from a demographically similar control population.

The study's results indicated that the risks associated with the three sources of recharge water were not significantly different and that the historical proportion of reclaimed water used for replenishment had no measurable impact on either groundwater quality or human health (Nellor, *et al.*, 1984). The health effects study did not demonstrate any measurable adverse effects on the area's groundwater or the health of the population ingesting the water. The cancer-related epidemiological study findings are somewhat weakened by the fact that the minimal observed latency period for human cancers that have been linked to chemical agents is about 15 years, and may be much longer. Because of the relatively short time period that groundwater containing reclaimed water has been consumed, it is unlikely that examination of cancer mortality rates would have detected an effect of exposure to reclaimed water resulting from the groundwater recharge operation, even if an effect were present (State of California, 1987).

Groundwater recharge has inherent disadvantages not present with indirect surface water reuse. If water of poor quality is discharged to a river, the river can be expected to be cleansed when the pollution is stopped. If poor quality water is charged into an aquifer and found later to be troublesome, cleansing the aquifer will be costly and difficult.

3.7.4 Direct Potable Water Reuse

Pipe-to-pipe water reclamation and direct potable reuse is currently practiced in only one city in the world, Windhoek, Namibia, and there only intermittently. 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, which 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 and certainly better than what is produced by many purveyors of drinking water elsewhere in the country who use run-of-river sources. Table 25 illustrates the high quality of the product water produced by the demonstration plant, to the extent revealed by the parameters monitored. Health

Table 25. Test Results, Denver Potable Water Reuse Demonstration Project (Geometric Mean Values, Jan. 9 to Dec. 31, 1989)

Parameter (mg/l unless indicated)	MCL	RO	UF
General			
Total Alkalinity	—	3	166
Hardness	—	6	108
TSS	—	*	*
TDS	500	18	352
Specific Conductance (umhos/cm)	—	67	648
pH	6.5 - 8.5	6.6	7.8
DO	—	8.3	6.9
Temperature - °C	—	21	21
Turbidity - NTU	1.0	0.06	0.2
TOC	—	*	0.7
Color	15	*	*
Particle Size > 128 µm (count/50 ml)	—	*	*
Particle Size 64-128 µm (count/50 ml)	—	*	*
Particle Size 32-64 µm (count/50 ml)	—	1.2	18
Particle Size 16-32 µm (count/50 ml)	—	58	100
Particle Size 8-16 µm (count/50 ml)	—	147	448
Particle Size 4-8 µm (count/50 ml)	—	219	1290
Asbestos - million fibers/l	7	*	*
MBAS	0.5	*	*
TOX	—	8	23
Radiological			
Gross Alpha - pCi/l	15	*	*
Gross Beta - pCi/l	50	*	6
Radium 228 - pCi/l	5	*	*
Radium 226 - pCi/l	5	*	*
Tritium - pCi/l	20,000	*	37
Radon - pCi/l	—	*	*
Plutonium - pCi/l	—	*	*
Microbiological			
m-HPC (count/ml)	—	*	350
Total Coliform (count/100 ml)	1	*	*
Fecal Strep (count/100 ml)	—	*	*
Fecal Coliform (count/100 ml)	—	*	*
Shigella	—	*	*
Salmonella	—	*	*
Clostridium	—	*	*
Campylobacter	—	*	*
Coliphage B (pfu/100 ml)	—	*	*
Coliphage C (pfu/100 ml)	—	*	*
Giardia (cysts/l)	—	*	*
Endamoeba coli (cysts/l)	—	*	*
Nematodes (count/l)	—	*	*
Algae (count/ml)	—	*	*
Enteric Virus	—	*	*
Entamoeba histolytica (cysts/l)	—	*	*
Cryptosporidium (oocysts/l)	—	*	*
Inorganic			
Aluminum	—	*	*
Arsenic	0.05	*	*
Boron	—	0.2	0.3
Bromide	—	*	*
Cadmium	0.01	*	*
Calcium	—	1	38
Chloride	250	19	96
Chromium	0.05	*	*
Copper	1	0.009	0.01
Cyanide	0.2	*	0.03
Fluoride	2	*	0.78
Iron	0.3	0.02	0.07
Potassium	—	0.7	9.1
Magnesium	—	0.1	1.8
Manganese	0.05	*	*
Mercury	0.002	*	*
Molybdenum	—	*	0.004
TKN	—	5	19
Ammonia-N	—	5	19
Nitrate-N	10	0.1	0.3
Nitrite-N	1	*	*
Nickel	0.1	*	*
Inorganic (continued)			
Total Phosphate-P	—	0.02	0.05
Selenium	0.01	*	*
Silica	—	2	8.8
Strontium	—	*	0.13
Sulfate	250	1	58
Lead	0.05	*	*
Uranium	—	*	*
Zinc	5	0.006	0.016
Sodium	—	4.8	78
Lithium	—	*	0.014
Titanium	—	*	0.035
Barium	1.0	*	*
Silver	0.05	*	*
Rubidium	—	*	0.003
Vanadium	—	*	*
Iodine	—	*	0.002
Antimony	—	*	*
Thallium	0.002	*	*

Test Method	Number of Tests UF	Number of Tests RO	Comments
EPA 502.2	47	53	No compounds detected
Grob Closed Loop Stripping GC/MS (EPA 8270)	44	48	No compounds detected
Carbamate Pesticides (EPA - 531)	2	2	No compounds detected
Pesticides (EPA 508) + (EPA 608)	5	5	No compounds detected
Herbicides (EPA 515.1)	5	5	No compounds detected
Polychlorinated Biphenyls (EPA 504)	3	3	No compounds detected
Polynuclear Aromatic Hydrocarbons (EPA 610)	3	3	No compounds detected
Base Neutral & Acid Extractables (EPA 625)	3	4	No compounds detected
Haloacetic Acids**	3	4	No compounds detected
Pentane Extractable Disinfection Byproducts**	3	4	No compounds detected
Aldehydes**	2	2	UF contained: 7 µg/l acetaldehyde and 13 µg/l formaldehyde RO contained: no aldehydes

NOTES:

MCL = EPA Maximum Contaminant Level for drinking water at time of testing.

RO = Reuse product treated by processes in Figure 32 including reverse osmosis.

UF = Reuse product treated by processes in Figure 32 including ultrafiltration.

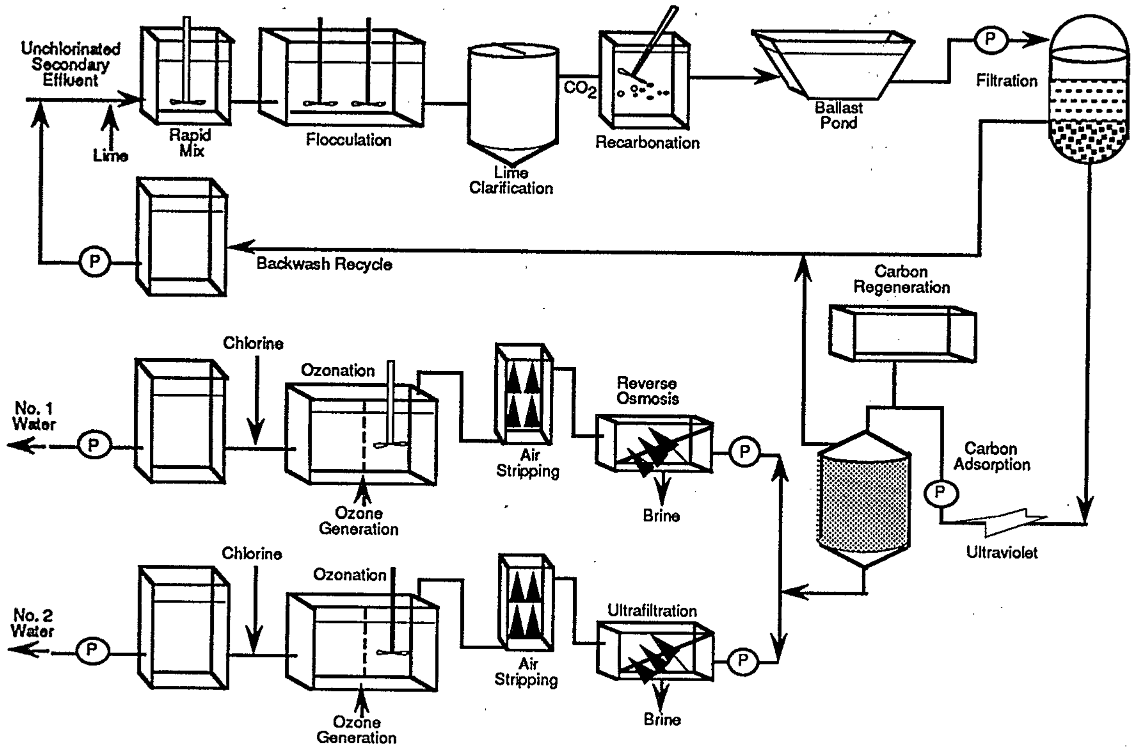
— = No MCL established at time of testing.

* = More than 50% of data below detection limit.

** = Montgomery Laboratory Methods (Pasadena, California).

Source: Hamaan *et al.*, 1992.

Figure 32. Denver Potable Reuse Demonstration Treatment Processes



Source: Adapted from Lauer, 1991.

effects and toxicity studies were also carried out, but the results are not yet available. Field work was completed in 1990, but there are no immediate plans to implement direct or indirect potable reuse in Denver.

Representative of the treatment train required for direct potable reuse is that developed in Denver. It includes, after secondary treatment, the following processes, as shown in Figure 32:

- High-pH lime clarification,
- Recarbonation,
- Multimedia filtration,
- Ultraviolet disinfection (as an option),
- Activated carbon adsorption,
- Reverse osmosis or ultrafiltration (as alternative options),
- Air stripping,
- Ozonation, and
- Chlorination

Most of these unit processes are well understood and 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.

Despite the generally excellent results achieved in Denver, there are no immediate plans to implement potable reuse there. The implementation of direct, pipe-to-pipe, potable reuse is not likely to be adopted in the foreseeable future in the U.S. or elsewhere for several reasons:

- Many attitude surveys show that the public will accept and endorse many types of nonpotable reuse while being reluctant to accept potable reuse. In general, the public's reluctance to support reuse increases as the degree of human contact with the reclaimed water increases. Section 7.3 includes a discussion of public perceptions about reuse.
- Indirect potable reuse is more acceptable to the public than direct potable reuse because the water is perceived to be "laundered" as it moves in a river, lake, or aquifer. Whittier Narrows and El

Paso are examples. Indirect reuse, by virtue of the residence time in the water course, reservoir or aquifer, often provides additional treatment and 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 substitution of reclaimed water for potable quality water now used for nonpotable purposes would release more of the high quality water service for potable purposes.

3.8 Case Studies

3.8.1 Pioneering Urban Reuse for Water Conservation: St. Petersburg, Florida

The City of St. Petersburg, Florida, is recognized as a pioneer in urban water reuse. Faced with the alternatives of ceasing effluent discharges to Tampa Bay or upgrading to advanced wastewater treatment, the city council adopted a policy of "zero discharge" in 1977, and in 1978 St. Petersburg began distributing reclaimed water for nonpotable uses via an urban dual distribution system.

Today, St. Petersburg operates one of the largest urban reuse systems in the world, providing reclaimed water to more than 7,000 residential homes and businesses. In 1991, the city provided approximately 21 mgd (920 L/s) of reclaimed water for irrigation of individual homes, condominiums, parks, school grounds, and golf courses; cooling tower make-up; and supplemental fire protection.

Four wastewater treatment plants, with a total combined capacity of 68.4 mgd (3,000 L/s), provide activated sludge secondary treatment, followed by alum coagulation, filtration, and disinfection.

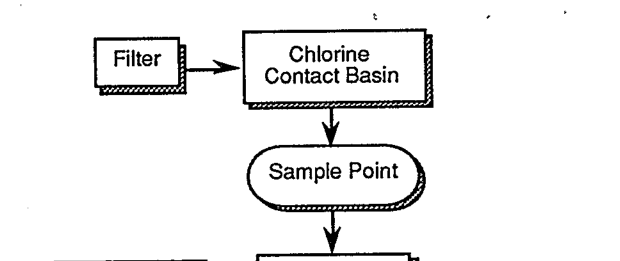
The dual distribution system comprises an extensive network of more than 260 mi (420 km) of pipe ranging in diameter from 2 to 48 in (5 to 122 cm). The system incorporates five city-owned and operated, and four privately-owned and operated booster pump stations. Operational storage is provided in covered storage tanks at the treatment facilities; however, no seasonal storage is provided. Instead, 10 deep wells inject excess reclaimed water into a saltwater aquifer approximately 1,000 ft (300 m) below the land surface. On a yearly average, approximately 60 percent of the reclaimed water produced is injected into the deep wells.

Criteria for delivery of reclaimed water to the system include chlorine residual, turbidity, SS, and chloride concentrations. Reclaimed water is rejected for reuse and diverted to the deep wells if the chlorine residual is less than 4.0 mg/L, turbidity exceeds 2.5 nephelometric turbidity units (NTU), SS exceed 5 mg/L rejected water, or chloride concentrations exceed 600 mg/L.

While the initial impetus for the reuse system was pollution abatement, its greatest benefit has been water conservation. By providing reclaimed water for urban irrigation and other nonpotable uses, St. Petersburg has been able to meet the community's rising potable water demands without increasing supplies, despite a 10 percent population growth. Since procuring additional potable supplies from an inland source would be prohibitively expensive, water reuse has also made economic sense for St. Petersburg.

Source: Johnson, 1990; CDM 1987.

City of St. Petersburg Reclaimed Water Delivery Criteria



Source: Johnson, 1990.

3.8.2 *Meeting Cooling Water Demands with Reclaimed Water: Palo Verde Nuclear Generating Station, Arizona*

The Palo Verde Nuclear Generating Station (PVNGS) is the largest nuclear power plant in the nation, with a generating capacity of 3,810 MW. The plant is located in the desert, approximately 55 mi (89 km) west of Phoenix, Arizona. The facility utilizes reclaimed water for cooling purposes, and has zero discharge. The sources of the cooling water for PVNGS are two wastewater treatment plants in Phoenix and Tolleson, which provide secondary treatment. The reclaimed water receives additional treatment at the power plant to meet water quality requirements.

PVNGS initially investigated alternative cooling systems in conjunction with the available sources of cooling water in the surrounding area. PVNGS first investigated once-through cooling and found that the high demand could not be met by any water bodies in the surrounding area. PVNGS then decided to utilize cooling towers which would only require an outside source to provide enough water lost through evaporation and for blowdown water to control salt content. This make-up demand of approximately 37,000 gpm (2,330 L/s), based on 75 percent annual average station capacity factor, still posed obstacles in locating a source of water that could meet this delivery rate and the quality requirements for coolant water.

The Colorado River, located 100 mi (160 km) to the west, was the first choice; however, the competition for the water from several states eliminated that alternative. Groundwater was also eliminated as an alternative due to quantity and quality concerns. It was then determined that of the 150 mgd (6,575 L/s) of secondary quality effluent being produced by the 91st Avenue WWTP in Phoenix, only 35 mgd (1,530 L/s) was committed to other users and the remaining 115 mgd (5,000 L/s) was being discharged to the normally dry Salt River. In addition, the Tolleson WWTP, located only 1 mile from the 91st Avenue plant, produced 17.5 mgd (767 L/s) of effluent that was also being discharged into the Salt River.

The combined available flow from the two plants, 132.5 mgd (5,800 L/s), was determined to more than adequately meet the PVNGS flow demand and was selected as the cooling water source. The transmission system from the WWTPs to PVNGS consists of 28 mi (45 km) of gravity pipeline, ranging from 114 in (290 cm) to 96 in (244 cm) in diameter, and 8 mi (13 km) of 66-in (168 cm) diameter pressurized force main.

Two 467-ac (189-ha) evaporation ponds were constructed to dispose of liquid waste from blowdown. The number of cycles of concentration was determined to be 15 without any scale formation, so long as the reclaimed water from the WWTP was further treated prior to use. A 90-mgd (3,940 L/s) tertiary wastewater reclamation facility (WRF) was constructed at PVNGS. The treatment process includes trickling filtration, cold lime/soda ash softening, and gravity filters.

The trickling filtration reduces influent ammonia, which causes metal corrosion, from 18-25 mg/L (As N) to less than 5 mg/L. The filters provided a second benefit of reducing alkalinity, thereby lowering the lime softening demand. Cold lime/soda ash softening reduces scaling and corrosive components such as calcium, magnesium, silica and phosphate. Lastly, gravity filters deliver a filtered effluent of less than 10 mg/L TSS.

3.8.3 *Agricultural Reuse in Tallahassee, Florida*

The Tallahassee agricultural reuse system is a cooperative operation in which the city owns and maintains the irrigation system, while the farm is leased to commercial enterprise. During 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 utilize reclaimed water for agricultural purposes. Spray irrigation of reclaimed water from the City's secondary wastewater treatment plant was initiated in 1966.

Detailed studies of this system in 1971 showed that the system was successful in producing crops for agricultural use. The study 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 ac (50 ha) of land used for hay production. Based upon success of the early studies and experience, a new sprayfield was constructed in 1980 southeast of Tallahassee.

The Southeast Sprayfield has been expanded twice since 1980 to a total area of approximately 1,750 ac (700 ha). The permitted application rate of the site is 3.16 in (8 cm)/week, for a total capacity of 21.5 mgd (942 L/s).

Sandy soils account for the high application rate. The soil composition is about 95 percent sand, with a clay layer at a depth of approximately 33 ft (10 m). The sprayfield has gently rolling topography with surface elevations ranging from 20 to 70 ft (6 to 21 m) above sea level.

Secondary treatment is provided the city's Thomas P. Smith wastewater renovation plant. The reclaimed water produced by this 17.5-mgd (767 L/s) activated sludge plant meets 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 mi (13.7 km) from the treatment plant to the sprayfield and distributed via 13 center-pivot irrigation units.

The 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.

Sources: Payne *et al.*, 1989; Overman and Leseman, 1982.

3.8.4 *Seasonal Water Reuse Promotes Water Quality Protection: Sonoma County, California*

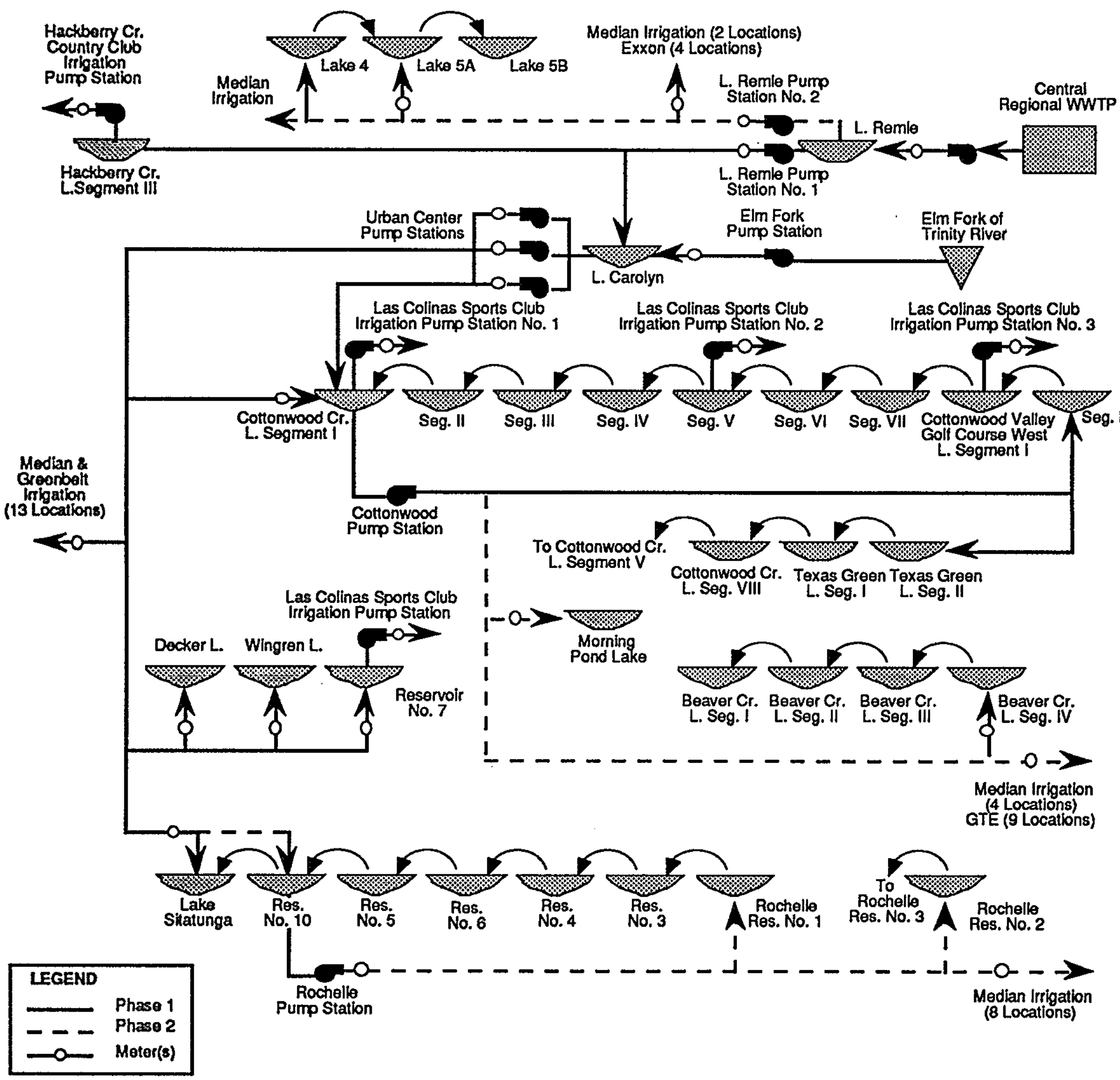
Faced with a "no discharge" requirement in accordance with the San Francisco Bay Regional Water Quality Control Board's 1982 Basin Plan, the Sonoma Valley County Sanitation District investigated the diversion of approximately 3 mgd (131 L/s) of effluent during the dry weather months of May through October. The receiving water, Schell Slough, is a tidal estuary less than 150 ft (46 m) wide and less than 10 ft (3 m) deep at high tide. The slough is particularly sensitive to water quality impacts during the dry season, from May to October, when fresh water flows in the slough cease and the water body becomes a dead end slough flushed only by limited tidal action. Dry weather dye studies indicated limited flushing in the dry season. Based on these studies, the "no discharge" directive for the district was modified to prohibit discharge only from May to October 31 of each year, with discharge allowed during the rainy season.

Instead of discharging to the slough during the dry season, local vineyards are irrigated with reclaimed water. While the nutrient content of reclaimed water is often viewed as a benefit, in this application there was a concern that the nitrogen would produce excessive foliage growth at the expense of grape production. As a condition of use, the farmers required denitrification of the reclaimed water. Nitrogen removal is achieved by denitrification on an overland flow field. Cheese whey is added to the reclaimed water prior to overland flow as a substitute for growth of the denitrification microorganisms. A backup means of avoiding discharge to Schell Slough between May and October has been developed for periods of high wastewater flows and/or low irrigation demands. Excess reclaimed water is spray irrigated and flows through a wetlands into Huderman slough. Huderman Slough has greater dilution flows than Schell Slough in dry weather, resulting in reduced impacts when and if a discharge is required.

3.8.5 *Combining Reclaimed Water and River Water for Irrigation and Lake Augmentation: Las Colinas, Texas*

Advanced secondary treated effluent and raw water from the Elm Fork of the Trinity River are used to irrigate golf courses, medians and greenbelt areas, and to maintain water levels at the Las Colinas development in Irving, Texas. Las Colinas is a 12,000-ac (4,800 ha) master planned development that features exclusive residential areas, high-rise offices, luxury hotels, and four championship golf courses. The drought-proof supply of reclaimed water and river water, known as the Raw Water Supply Project (RWSP), delivers irrigation water to 550 ac (220 ha) of landscaped areas and provides water to 19 lakes to make up evaporative losses from their 270-ac (110 ha) total surface area.

Schematic of the Las Colinas Raw Water Supply Project



The RWSP was initiated in July 1987. The reclaimed water originates from the 115-mgd (5,040 L/s) Central Regional wastewater treatment plant (CRWWTP). Reclaimed water is available year-round but is limited to the pumping system's capacity of 16.4 mgd (719 L/s). Reclaimed water is pumped 11 mi (18 km) through a 30-in (76-cm) diameter pipeline to Lake Remle. A portion of the water is then pumped to a storage lake for irrigation at one country club, and a portion is pumped to Lake Carolyn where it is mixed with river water. A pump station on the Elm Fork can deliver up to 4.6 mgd (202 L/s) of river water through a 16-in (41-cm) diameter pipeline to Lake Carolyn. All water from the Elm Fork and the CRWWTP blends with water in at least one lake before distribution to 23 discharge points. The lakes are designed to allow water to spill from lake to lake within the development thereby controlling water surface elevations and enhancing circulation. A schematic of the distribution system is presented below.

Treatment processes at the CRWWTP consist of primary clarification, equalization, activated sludge, secondary clarification, filtration, activated carbon (as needed), and disinfection by chlorination. The reclaimed water discharged into Lake Remle has consistently met discharge permit requirements of no more than 10 mg/L BOD and 15 mg/L TSS. In addition, water quality samples are collected from the Elm Fork and at selected lakes to assess the water's irrigation, aesthetic, and recreational quality.

The parameters monitored include BOD, TSS, fecal coliform, dissolved oxygen, Secchi depth, pH, sodium adsorption ratio (SAR), salinity, ortho-phosphorus, and algae. Mixing the reclaimed water with river water in lakes reduces the SAR value of the reclaimed water from 3.85 to less than 2.0 in Lake Carolyn. A SAR value of 3.0 was established as an acceptable limit to irrigate golf courses at Las Colinas. The concentration of ortho-phosphorus has increased at sampling locations in Lake Remle and Lake Carolyn since the RWSP began. However, accelerated eutrophication of lakes has not been noticed, and the lake maintenance program for aquatic weeds and algae was not altered.

Six fountain aerators were installed in lakes to increase their assimilative capacity and to improve lake appearance. In general, water quality in the Las Colinas lakes remains acceptable subsequent to delivery of reclaimed water. The success of the program is attributed to the excellent quality of the reclaimed water; the significant dilution which occurs as the reclaimed water, river water and natural drainage blend during progression through the system; and the flexibility to manage the system by blending waters and promoting circulation through the lakes, as required, to maintain water quality.

Sources: Water Pollution Control Federation, 1989; Smith *et al.*, 1990.

3.8.6 *Integrating Wetlands Application with Urban Reuse: Hilton Head Island, South Carolina*

Hilton Head Island, located off the southeastern shore of South Carolina, is plagued by poor soil conditions and saltwater intrusion. The island is resort-oriented with several golf courses and a booming population. Because of the soil conditions and the increasing population, wastewater treatment and effluent disposal have become an increasing concern.

In 1982, a wastewater management plan was developed with the goal of maximizing water reuse on the island. In 1983, the Hilton Head Island Utility Committee was created to coordinate the efforts of the various agencies involved in implementing the plan. The island-wide plan called for upgrading all wastewater treatment plants to tertiary treatment in order to minimize nutrient concentrations in the reclaimed water and allow for discharge when reuse demand is not sufficient. The treatment levels can remain at the advanced secondary treatment levels for golf course irrigation. In addition to managing and coordinating the island-wide wastewater treatment and reuse program, the Hilton Head Island Utility Committee also developed guidelines for reuse. These guidelines contain information regarding the approved uses of reclaimed water, design criteria, and administrative and hook-up procedures.

Golf courses have been irrigated with reclaimed water on Hilton Head Island since 1973, when the Sea Pines and Forest Beach Public Service Districts began irrigating the Club Course at Sea Pines Plantation. In 1985, the Sea Pines Public Service District upgraded and expanded the existing wastewater treatment plant to 5 mgd (219 L/s).

The reclaimed water transmission system was also to be upgraded and expanded in two phases. The Phase I expansion includes service to approximately 150 ac (60 ha) of commercial and multi-family residences in addition to the existing and new golf course irrigation. The entire system, once completed, will include approximately 13 linear mi (20 km) of new reuse piping.

To serve the expanded irrigation system, a new 10-mgd (438 L/s) effluent pumping station has been constructed, but is not yet fully operational. In addition, a 5-million gal (19-million L) storage tank has been constructed.

Because the demand for reclaimed water decreases during the rainy season, an alternative disposal system is required. Several alternatives were studied, with the most environmentally sound being the use of existing wetlands on the island.

The use of reclaimed water to supplement wetlands systems is ideal. The demand for reuse among the connected customers decreases in the wet winter months and increases in the summer. Due to the natural cycling, wetlands typically are drier in the summer and wet in the winter. This is the exact opposite of the reuse demand and makes a perfect complement to the irrigation system.

Boggy Gut wetland in the Sea Pines Forest Preserve was selected for a 3-year pilot study beginning in 1983. The study called for an increase in the discharge from 0.3 mgd (13 L/s) to 1.0 mgd (44 L/s) over the entire study period. No observable detrimental impacts on groundwater were noted, and the pilot study was deemed a success. It has since become fully operational.

The Sea Pines Public Service District Wetlands Program has been expanded to include the White Ibis Marsh, which recently began to receive reclaimed water. The conceptual plan is to enhance the performance of both wetland cells by stopping service to one cell every 5 years and allowing the built up organics to oxidize. Service will once again be returned to the renewed cell and the same process repeated for the next cell.

The second project of interest is the Hilton Head Plantation treatment plant and reuse system, located in the northern portion of the island. The AWT plant serves a private residential area, with golf course irrigation as the primary means of reuse. The wet weather back-up to the system is discharge to two wetlands: the Whooping Crane Conservancy and the Cypress Conservancy.

Prior to wet weather discharge, both of these wetlands areas had been drying due to changes in water flow patterns resulting from development in the area. The Nature Conservancy worked with the Hilton Head Plantation in an effort to mutually benefit both institutions. Hilton Head Plantation was granted a wet weather discharge back-up to the golf course irrigation system, and the Whooping Crane and Cypress conservancies were given much needed water to help restore their natural flow patterns.

Since wet weather discharge has begun to these two wetlands areas, there has been a revival of wildlife. Wading birds have increased in the conservancies, and they are once again in their rookery states.

Both of these projects on Hilton Head Island are using reclaimed water for recreational benefit by golf course irrigation and are providing enhancement to area wetlands by wet weather discharge.

Source: Hirsekorn and Ellison, 1987.

3.8.7 *Groundwater Replenishment with Reclaimed Water: Los Angeles County, California*

In south-central Los Angeles County, replenishment of groundwater basins is accomplished by artificial recharge of aquifers in the Montebello Forebay area. Waters used for recharge via surface spreading include local storm runoff, imported water from the Colorado River and state project, and reclaimed water. The latter has been used as a source of replenishment water since 1962. At that time, approximately 12,000 ac-ft/yr (15 x 10^6 m^3/yr) of disinfected, activated sludge secondary effluent from the Sanitation Districts of Los Angeles County Whittier Narrows water reclamation plant (WRP) was spread in the Montebello Forebay area of the Central groundwater basin, which has an estimated usable storage capacity of 780,000 ac-ft (960 x 10^6 m^3). In 1973, the San Jose Creek WRP was placed in service and also supplied secondary effluent for recharge. In addition, effluent from the Pomona WRP that is not reused for other purposes is discharged into San Jose Creek, a tributary of the San Gabriel River, and ultimately becomes a source for recharge in the Montebello Forebay.

In 1978, all three reclamation plants were upgraded to provide secondary treatment, dual-media filtration (Whittier Narrows and San Jose Creek WRPs) or activated carbon filtration (Pomona WRP), and chlorination/ dechlorination. In 1990, 50,000 ac-ft (62 x 10^6 m^3/yr.)of reclaimed water was recharged, or approximately 30 percent of the total inflow to the Montebello Forebay.

The replenishment program is operated by the Los Angeles County Department of Public Works (DPW), while overall management of the groundwater basin is administered by the Central and West Basin Water Replenishment District. DPW has constructed two spreading areas designed to increase the indigenous percolation capacity. The Rio Hondo spreading basins have a total of 427 ac (173 ha) available for spreading, and the San Gabriel River spreading grounds have 224 ac (91 ha). The Rio Hondo and San Gabriel River spreading grounds are subdivided into individual basins that range in size from 4 to 20 ac (1.5 to 8 ha).

Under normal operating conditions, batteries of the basins are rotated through a 21-day cycle consisting of:

- ❑ A 7-day flooding period during which the basins are filled to maintain a constant 1.2-m (4-ft) depth;
- ❑ A 7-day draining period during which the flow to the basins is terminated and the basins are allowed to drain; and
- ❑ A 7-day drying period during which the basins are allowed to thoroughly dry out.

This wetting/drying operation serves several purposes, including maintenance of aerobic conditions in the upper soil strata and vector control in the basins.

The reclaimed water produced by each reclamation plant complies with primary drinking water standards and meets total coliform and turbidity requirements of less than 2.2/100 mL and 2 NTU, respectively. Reclaimed water and groundwater quality data are given in the following table.

1988-1989 Results of Reclaimed Water Analyses for the Montebello Forebay Groundwater Recharge Project[a]

Constituent	San Jose WRP[b]	Whittier Narrows WRP	Pomona WRP	Discharge Limits
Arsenic (mg/L)	0.005	0.004	<0.004	0.05
Aluminum (mg/L)	<0.06	<0.10	<0.08	1.0
Barium (mg/L)	0.06	0.04	0.04	1.0
Cadmium (mg/L)	ND[c]	ND	ND	0.01
Chromium (mg/L)	<0.02	<0.05	<0.03	0.05
Lead (mg/L)	ND	ND	<0.05	0.05
Manganese (mg/L)	<0.02	<0.01	<0.01	0.05
Mercury (mg/L)	<0.0003	ND	<0.0001	0.002
Selenium (mg/L)	<0.001	0.007	<0.004	0.01
Silver (mg/L)	<0.005	ND	<0.005	0.05
Lindane (ug/L)	0.05	0.07	<0.03	4
Endrin(ug/L)	ND	ND	ND	0.2
Toxapene (ug/L)	ND	ND	ND	5
Methoxyclor (ug/L)	ND	ND	ND	100
2,4-D(ug/L)	ND	ND	ND	100
2,3,5-TP (ug/L)	<0.11	ND	ND	10
SS (mg/L)	<3	<2	<1	15
BOD (mg/L)	7	4	4	20
Turbidity (TU)	1.6	.1.6	1.0	2
Total Coliform (#/100 mL)	<1	<1	<1	2.2
TDS (mg/L)	598	523	552	700
Nitrite + Nitrate (mg/L)	1.55	2.19	0.69	10
Chloride (mg/L)	123	83	121	250
Sulfate (mg/L)	108	105	82	250
Fluoride (mg/L)	0.57	0.74	0.50	1.6

a Average of samples collected from October 1988 through September 1989. Sampling frequency varied from daily to bimonthly depending on constituent.
b WRP - Water reclamation plant
c ND - Not detected.

Source: Sanitation Districts of Los Angeles County, 1989.

3.8.8 Aquifer Recharge Using Injection of Reclaimed Water: El Paso, Texas

El Paso, Texas has injected reclaimed wastewater from the Fred Hervey water reclamation plant into the Hueco Bolson aquifer since June 1985. The Hueco Bolson aquifer is an unconfined aquifer that supplies about 65 percent of the water supply needs of El Paso. The reclaimed water is transported from the treatment plant 1 mile (1.6 km) to a 3-mile (4.8 km) long series of 10 injection wells. Each well is 16-in (41 cm) diameter and is screened from about 350 ft (107 m) deep to a completed depth of 800 ft (244 m) below ground.

The Hueco Bolson aquifer recharge was selected as a demonstration study for the High Plains Reuse Project. The 4-year study, slated to be completed by October 1992, is sponsored by the U.S. Bureau of Reclamation, El Paso Water Utility, and the U.S. Geological Survey. The study investigates the impacts of using reclaimed water to recharge a water supply aquifer and evaluates effectiveness and reliability of treatment processes in the plant.

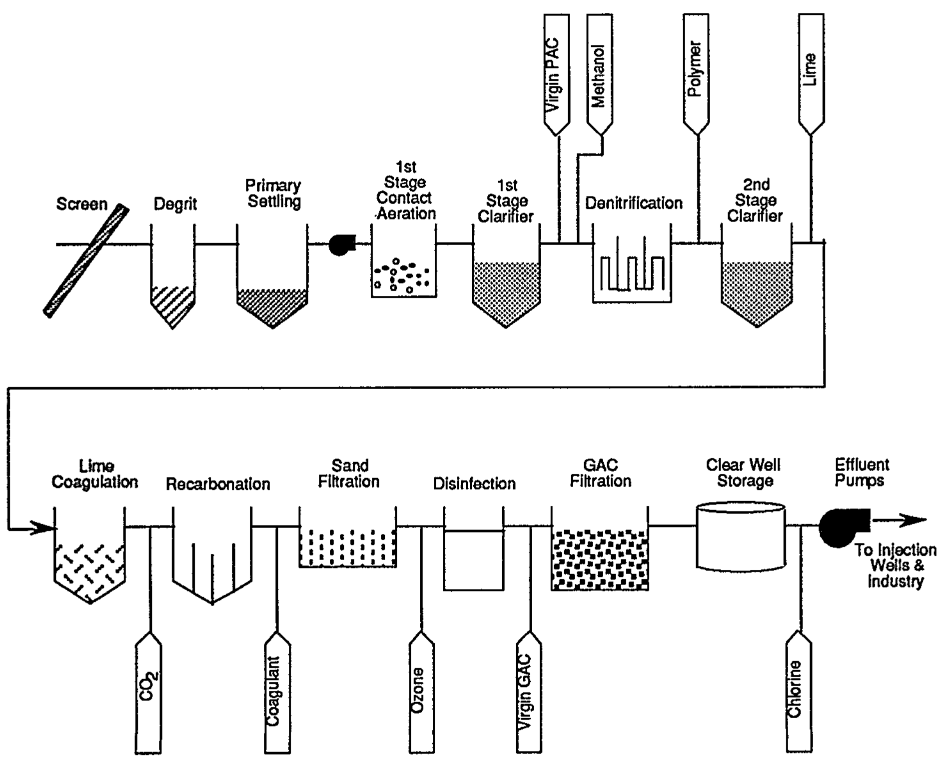
As part of the study, a groundwater flow and solute transport model was used to calculate the residence time of injected reclaimed water in the aquifer before it is pumped out at production wells located from 0.25 mi (0.4 km) to 4.5 mi (7.2 km) distant from the injection wells. The model results indicate that the representative residence time is approximately 5 to 15 years.

The reclaimed water must meet drinking water standards before it is injected to the aquifer. The effluent maintains a free chlorine residual of about 0.3 mg/L as it leaves the treatment train. The chlorine residual is needed to prevent bacterial growth in the storage tank before the reclaimed water is injected. The concentrations of trihalomethanes (THMs) in the effluent is less than 50 ug/L (microgram per liter). Groundwater samples collected from monitor wells near the injection site have had elevated concentrations of THMs, but always less than 30 ug/L.

The demonstration study includes a full evaluation of the reliability of the water reclamation plant and identification of the role played by each treatment step in achieving the drinking water quality objectives established for the effluent. The plant reliability review involves analyses of priority pollutants and THMs in water samples taken from the treatment train, THM-precursor analysis at the granular activated carbon and ozonation treatment stages, and evaluations of biotoxicity and pathogen removal.

The Fred Hervey Water Reclamation Plant has a maximum capacity of about 12 mgd (526 L/s). Its 10-step treatment train begins with primary treatment to allow

Liquid Treatment Train for Groundwater Recharge, El Paso, Texas



screening, degritting, sedimentation and flow equalization. The primary effluent enters a two-stage biophysical process which combines activated sludge with powdered activated carbon adsorption (PACT™ system). This step of the treatment is designed for organic removal, nitrification and denitrification. Methanol is added to the second stage to provide a carbon source for the denitrifiers. Waste secondary sludge and spent carbon are processed in a wet air regeneration (oxidation) unit which destroys the sludge and regenerates the carbon for reuse in the PACT system. The wastewater effluent advances to a lime treatment step to remove phosphorus and heavy metals, to kill viruses, and to soften the effluent. Turbidity removal is provided by sand filters and disinfection is provided by ozonation. The final product water is passed through a granular activated carbon filter to provide final polishing before release to storage.

Between 1985 and 1990, approximately 7.5 billion gal (28 x 10^6 m^3) of reclaimed water have been injected to recharge the Hueco Bolson aquifers. The current price of treating and injecting the water is about $2.00/gal (up from $1.55/1,000 gal in 1986).

Before the aquifer recharge project was initiated, water levels in the Hueco Bolson aquifer declined at a rate of 2 to 6 ft (0.6 to 1.8 m)/yr because groundwater was withdrawn 20 times faster than the aquifer's natural rate of recharge. Groundwater model results indicate that groundwater levels in 1990 are 8 to 10 ft (2.4 to 3.0 m) higher than what they would have been without the aquifer recharge project.

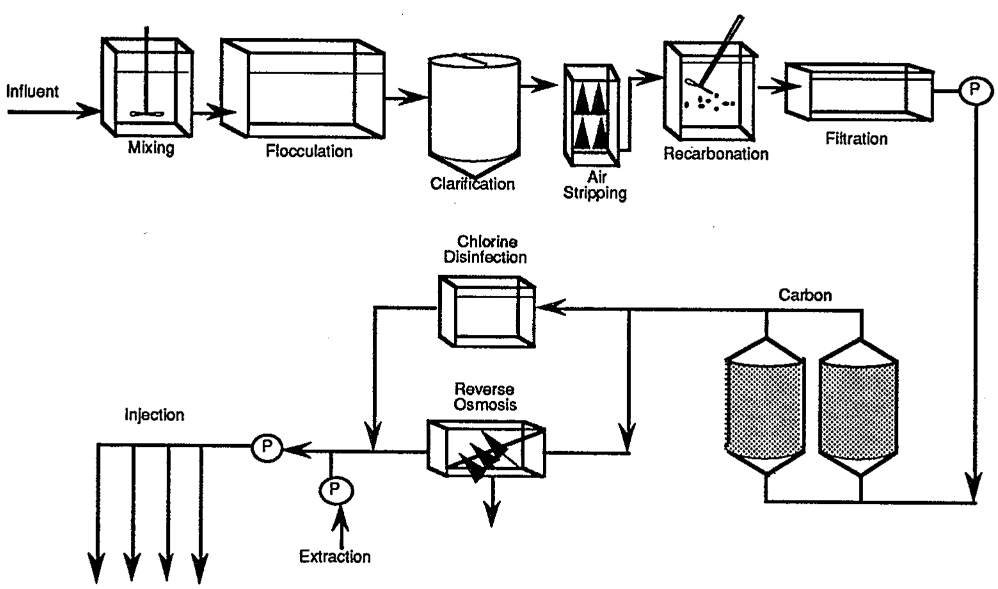
Sources: Knorr, 1985, Knorr *et al.*, 1987.

3.8.9 Water Factory 21 Direct Injection Project: Orange County, California

A project involving groundwater recharge by the injection of reclaimed water is operated by the Orange County Water District (OCWD) in Fountain Valley, California. OCWD first began pilot studies in 1965 to determine the feasibility of using tertiary wastewater treatment in a hydraulic barrier system to prevent saltwater encroachment into potable water supply aquifers. Construction of a tertiary treatment facility, known as Water Factory 21, was started in 1972, and injection operations began in 1976.

Water Factory 21 has a design capacity of 15 mgd (657 L/s) and treats activated sludge secondary effluent from the adjacent Orange County Sanitation District's (OCSD) wastewater treatment plant by the following unit operations: lime clarification for removal of SS, heavy metals, and dissolved minerals; air stripping (not currently in service) for removal of ammonia and volatile organic

Water Factory 21 Treatment Processes



Source: Adapted from Water Pollution Control Federation, 1989.

compounds; recarbonation for pH control; mixed-media filtration for removal of SS; granular activated carbon adsorption for removal of dissolved organics; reverse osmosis (RO) for demineralization; and chlorination for biological control and disinfection.

Due to a total dissolved solids limitation of 500 mg/L prior to injection, RO is used to demineralize up to 5 mgd (219 L/s) of the reclaimed water used for injection. The feedwater to the RO plant is effluent from the mixed-media filters. Effluent from the carbon adsorption process is disinfected and blended with RO-treated water. Activated carbon is regenerated onsite. Solids from the settling basins are incinerated in a multiple-hearth furnace from which lime is recovered and reused in the chemical clarifier. Brine from the RO plant is pumped to OCSD's facilities for ocean disposal.

Reclaimed water produced at Water Factory 21 is injected into a series of 23 multi-casing wells, providing 81 individual injection points into four aquifers to form a seawater intrusion barrier known as the Talbert injection barrier (Argo and Cline, 1985). The injection wells are located approximately 3.5 mi (5.6 km) inland from the Pacific Ocean. There are seven extraction wells (not currently being used) located between the injection wells and the coast. Before injection, the product water is blended 2:1 with well water from a deep aquifer not subject to contamination. Depending on basin conditions, the injected water flows toward the ocean forming a seawater barrier, flows inland to augment the potable groundwater supply, or flows in both directions.

Water Factory 21 reliably produces high-quality water. No coliform organisms were detected in any of 179 samples of the reclaimed water during 1988. A virus monitoring program conducted from 1975 to 1982 demonstrated to the satisfaction of the state and county health agencies that Water Factory 21 produces reclaimed water that is essentially free of measurable levels of viruses (McCarty et. al., 1982). The average turbidity of filter effluent was 0.22 FTU and did not exceed 1.0 FTU during 1988.

The average COD and TOC concentrations for 1988 were 8 mg/L and 2.6 mg/L, respectively. The effectiveness of Water Factory 21's treatment processes for the removal of inorganic and organic constituents is shown in the following tables.

Water Factory 21 Injection Water Quality

Constituent	Discharge Limits	Injection Water*
Concentration in mg/L		
Sodium	115	82
Sulfate	125	56
Chloride	120	84
TDS	500	306
Hardness	180	60
pH (units)	6.5-8.5	7.0
Ammonia Nitrogen	—	4-7
Nitrate Nitrogen	—	0.4
Total Nitrogen	10	5.8
Boron	.05	0.4
Cyanide	0.2	<0.01
Fluoride	1.0	0.5
MBAs	0.5	0.5
Concentration in ug/L		
Arsenic	50	<5.0
Barium	1,000	18
Cadmium	10	0.6
Chromium	50	<1.0
Cobalt	200	<1.0
Copper	1,000	4.7
Iron	300	33
Lead	50	<1.0
Manganese	50	4.3
Mercury	2	<0.5
Selenium	10	<5.0
Silver	50	3.3

*After blending 2:1 with deep well water.

Source: Wesner, 1989.

Water Compounds Detected in Water Factory 21 Injection Water[a]

Constituent	Injection Water [b] (ug/L)
Methylene Chloride	1.0
Chloroform	5.4
Dibromochloromethane	1.1
Chlorobenzene	TR[c]
Bromodichloromethane	3.7
Bromoform	0.8
1,1,1-Trichlorethane	TR

a Fifty-three specific volatile organic compounds were reported as undetected in the sample.
b After blending 2:1 with deep well water.
c TR = Trace. Concentration was below reportable detection limit.

Source: Orange County Water District, 1989.

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5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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CHAPTER 4

Water Reuse Regulations and Guidelines in the U.S.

Most reuse programs operate within a framework of regulations that must be addressed in the earliest stages of planning. A thorough understanding of all applicable regulations is required to plan the most effective design and operation of a water reuse program and to streamline implementation.

Currently, there are no federal regulations directly governing water reuse practices in the United States. Water reuse regulations have, however, been developed by many of the states. These regulations vary considerably from state to state. Some states, such as Arizona, California, Florida, and Texas, have developed regulations that strongly encourage water reuse as a water resources conservation strategy. These states have developed comprehensive regulations specifying water quality requirements, treatment processes, or both for the full spectrum of reuse applications. The objective in these states is to derive the maximum resource benefits of the reclaimed water while protecting the environment and public health. Some states have developed water reuse regulations with the primary intent of providing a disposal alternative to discharge to surface waters, without considering the management of reclaimed water as a resource.

This section provides an inventory of the various state water reuse regulations throughout the U.S. and introduces recommended guidelines that may aid in the development of more comprehensive state or even federal standards for water reuse. Water reuse outside the U.S. is discussed in Chapter 8.

4.1 Inventory of Existing State Regulations

The following inventory of state reuse regulations is based on a survey of all states conducted specifically for this document. Regulatory agencies in all 50 states were contacted by mail in September 1990 and asked to provide information concerning their current regulations governing water reuse. After follow-up contact, all 50 states responded to the request for information. All of the information presented in this section is considered current as of March 1992.

Also as part of the survey, all states were asked to provide an inventory of their existing reuse projects. The results indicated there are approximately 1,900 reuse projects currently operating throughout 34 states. This represents a significant increase since the survey conducted in 1979 as part of the original 1980 Guidelines (EPA, 1980b), when only 540 reuse projects were reported throughout 24 states.

Only California and Florida compile comprehensive inventories of reuse projects by types of reuse application. These inventories are available from the California Water Resources Control Board in Sacramento and the Florida Department of Environmental Regulation in Tallahassee, respectively.

The U.S. Geological Survey compiles an estimate of national reclaimed water use every 5 years in their publication *Estimated Use of Water in the United States.* The 1990 inventory estimated that approximately 900 mgd of the effluent discharged in the U.S. was used for beneficial purposes.

Most states do not have regulations that cover all potential uses of reclaimed water. Arizona, California, Florida, Texas, Oregon, Colorado, Nevada, and Hawaii have extensive regulations or guidelines that prescribe requirements for a wide range of end uses of the reclaimed water. Other states have regulations or guidelines which focus upon land treatment of wastewater effluent, emphasizing additional treatment or effluent disposal rather than beneficial reuse, even though the effluent may be used for irrigation of agricultural sites, golf courses, or public access lands.

Based on the inventory, current regulations may be divided into the following reuse categories:

- Unrestricted urban reuse - irrigation of areas in which public access is not restricted, such as parks, playgrounds, school yards, and residences; toilet flushing, air conditioning, fire protection, construction, ornamental fountains, and aesthetic impoundments.

- Restricted urban reuse - irrigation of areas in which public access can be controlled, such as golf courses, cemeteries, and highway medians.

- Agricultural reuse on food crops - irrigation of food crops which are intended for direct human consumption, often further classified as to whether the food crop is to be processed or consumed raw.

- Agricultural reuse on non-food crops - irrigation of fodder, fiber, and seed crops, pasture land, commercial nurseries, and sod farms.

- Unrestricted recreational reuse - an impoundment of water in which no limitations are imposed on body-contact water recreation activities.

- Restricted recreational reuse - an impoundment of reclaimed water in which recreation is limited to fishing, boating, and other non-contact recreational activities.

- Environmental reuse - reclaimed water used to create artificial wetlands, enhance natural wetlands, and to sustain stream flows.

- Industrial reuse - reclaimed water used in industrial facilities primarily for cooling system make-up water, boiler-feed water, process water, and general washdown.

Table 26 provides an overview of the current water reuse regulations and guidelines by state and by reuse category. The table identifies those states that have regulations, those with guidelines and those states which currently do not have either. Regulations refer to actual rules that have been enacted and are enforceable by governmental agencies. Guidelines, on the other hand, are not enforceable but can be used in the development of a reuse program.

As of March 1992, 18 states had adopted regulations regarding the reuse of reclaimed water, 18 states had guidelines or design standards, and 14 states had no regulations or guidelines. In states with no specific regulations or guidelines on water reclamation and reuse, programs may still be permitted on a case-by-case basis.

The majority of current state regulations and guidelines pertain to the use of reclaimed water for urban and agricultural irrigation. At the time of the survey, the only states that had specific regulations or guidelines regarding the use of reclaimed water for purposes other than irrigation were Arizona, California, Florida, Hawaii, Nevada, Oregon, Colorado, South Dakota, Texas, and Utah.

Table 27 shows the number of states with regulations or guidelines for each type of reuse. The category of unrestricted urban reuse has been subdivided to indicate the number of states that have regulations pertaining to urban reuse not involving irrigation. Florida, Texas, and Hawaii are the only states that have regulations pertaining to the use of reclaimed water for toilet flushing. Florida, Texas, and Hawaii all require a high degree of treatment prior to use for toilet flushing. In addition, Texas requires that the reclaimed water be dyed blue prior to distribution for use as toilet flush water, while Florida requires that reclaimed water may only be used for toilet flush water where residents do not have access to the plumbing system for repairs or modifications.

Florida and Hawaii are currently the only states with regulations pertaining to the use of reclaimed water for fire protection, while Nevada, Florida, Hawaii, and Oregon have regulations for the use of reclaimed water for construction purposes. The use of reclaimed water for landscape or aesthetic impoundments is regulated in the states of California, Florida, Hawaii, Oregon, Texas, Colorado, and Nevada. Hawaii is currently the only state with regulations or guidelines pertaining to the use of reclaimed water for street cleaning.

At this time, Arizona, California, Colorado, Hawaii, Nevada, Oregon, and Texas have regulations or guidelines pertaining to recreational reuse, while Arizona, Florida, and South Dakota have regulations or guidelines pertaining to environmental reuse utilizing natural or artificial wetlands. Reclaimed water used for industrial purposes is currently regulated in Arizona, Hawaii, Nevada, Oregon, Texas and Utah.

Summaries of each state's regulatory or guideline requirements for each type of reuse are given in Appendix A in Tables A-1 through A-8. The regulations pertaining to each type of reuse are divided into the following categories:

- Reclaimed water quality and treatment requirements

Table 26. Summary of State Reuse Regulations and Guidelines

STATE	Regulations	Guidelines	No Regulations or Guidelines (2)	Unrestricted Urban Reuse	Restricted Urban Reuse	Agricultural Reuse Food Crops	Agricultural Reuse Non-Food Crops	Unrestricted Recreational Reuse	Restricted Recreational Reuse	Environmental Reuse	Industrial Reuse
Alabama		•					•				
Alaska			•								
Arizona	•			•	•	•	•	•	•	•	•
Arkansas		•		•	•	•	•				
California	•			•	•	•	•	•	•		
Colorado		•		•	•	•	•	•	•		
Connecticut			•								
Delaware		•		•	•		•				
Florida	•			•	•	•	•			•	
Georgia		•		•	•		•				
Hawaii		• (1)		•	•	•	•		•		•
Idaho	•			•	•	•	•				
Illinois	• (1)			•	•		•				
Indiana	•					•	•				
Iowa			•								
Kansas		•		•	•	•	•				
Kentucky			•								
Louisiana			•								
Maine			•								
Maryland		•			•		•				
Massachusetts			•								
Michigan	•					•	•				
Minnesota			•								
Mississippi			•								
Missouri	•				•		•				
Montana		•		•	•	•	•				
Nebraska		•			•		•				
Nevada		• (1)		•	•	•	•	•	•		•
New Hampshire			•								
New Jersey	•						•				
New Mexico		•		•	•	•	•				
New York		•					•				
North Carolina	•				•						
North Dakota		•					•				
Ohio			•								
Oklahoma		•			•		•				
Oregon	•			•	•	•	•	•	•		•
Pennsylvania			•								
Rhode Island			•								
South Carolina		•		•	•		•				
South Dakota		•		•	•		•			•	
Tennessee	•			•	•		•				
Texas	•			•	•	•	•		•		•
Utah	•			•	•	•	•				•
Vermont	•						•				
Virginia			•								
Washington		•		•	•	•	•				
West Virginia	•					•	•				
Wisconsin	•						•				
Wyoming	•			•	•	•	•				

(1) Draft or Proposed
(2) Specific regulations on reuse have not been adopted; however, reclamation may be approved on a case-by-case basis.

Table 27. **Number of States with Regulations or Guidelines for Each Type of Reuse Application**

Type of Reuse	Number of States
Unrestricted Urban	22
Irrigation	22
Toilet Flushing	3
Fire Protection	2
Construction	4
Landscape Impoundment	7
Street Cleaning	1
Restricted Urban	27
Agricultural (Food Crops)	19
Agricultural (Non-Food Crops)	35
Unrestricted Recreational	5
Restricted Recreational	7
Environmental (Wetlands)	3
Industrial	6

- Reclaimed water monitoring requirements
- Treatment facility reliability
- Storage requirements
- Application rates
- Groundwater monitoring
- Setback distances (buffer zone)

4.1.1 Reclaimed Water Quality and Treatment Requirements

Requirements for water quality and treatment receive the most attention in state reuse regulations. States which have water reuse regulations or guidelines have set standards for reclaimed water quality and/or specified minimum treatment requirements. Generally, where unrestricted public exposure is likely in the reuse application, wastewater must be treated to the highest degree prior to its application. Where exposure is not likely, however, a lower level of treatment is usually accepted.

The most common parameters for which water quality limits are imposed are biochemical oxygen demand (BOD), total suspended solids (TSS), and total or fecal coliform counts. Total and fecal coliform counts are generally used as indicators to determine the degree of disinfection. A limit on turbidity is usually specified to monitor the performance of the treatment facility.

4.1.1.1 Unrestricted Urban Reuse

Unrestricted urban reuse involves the use of reclaimed water where public exposure is likely in the reuse application, thereby necessitating the highest degree of treatment. Review of existing regulations, however, reveals a wide variation in treatment and water quality requirements for unrestricted urban reuse. For example, Utah requires advanced treatment with BOD not to exceed 10 mg/L and TSS not to exceed 5 mg/L. In addition, total coliform is not to exceed 3/100 mL at any time. South Dakota, on the other hand, requires only secondary treatment with disinfection with the median total coliform count not to exceed 200/100 mL.

In general, all states with regulations require a minimum of secondary or biological treatment prior to unrestricted urban reuse, with most requiring disinfection. However, many states require additional levels of treatment. The states of Idaho, California, and Colorado require oxidation, coagulation, clarification, filtration, and disinfection prior to unrestricted urban reuse. Other states, such as Arizona and Texas, do not specify the type of treatment processes required, but only set limits on the reclaimed water quality.

Where specified, limits on BOD range from 5 mg/L to 30 mg/L. Texas requires that BOD not exceed 5 mg/L (monthly average) except when reclaimed water is used for landscape impoundments, in which case BOD is limited to 10 mg/L. Georgia, on the other hand, requires that BOD not exceed 30 mg/L prior to unrestricted urban reuse. Limits on TSS vary from 5 mg/L to 30 mg/L. Both Utah and Florida require that TSS not exceed 5 mg/L, with Florida requiring that the TSS limit be achieved prior to disinfection and not be exceeded in any one sample. Georgia requires that TSS not exceed 30 mg/L. For those states that do not specify limitations on BOD or TSS, a particular level of treatment is usually specified.

Average fecal and total coliform limits for those states that limit coliforms range from non-detectable to 200/100 mL. Higher single sample fecal and total coliform limits are noted in several state regulations. Florida requires that 75 percent of the fecal coliform samples taken over a 30-day period be below detectable levels, with no single sample in excess of 25/100 mL. Conversely, South Dakota requires a medial total coliform count not to exceed 200/100 mL. Utah requires that no single sample exceed a total coliform count of 3/100 mL for unrestricted urban reuse, while Texas and Arizona require that no single fecal coliform count exceed 75/100 mL.

Where specified, limits on turbidity range from 2 to 5 NTU. For example, Oregon requires that the turbidity not exceed 2 NTU (24-hour mean) and California requires the turbidity not exceed 2 NTU. Arizona requires that turbidity not exceed 5 NTU. Florida requires continuous on-line monitoring of turbidity; however, no limit is specified.

At this time, Arizona and Hawaii are the only states that have set limits on certain pathogenic organisms for unrestricted urban reuse. In Arizona, the pathogens include enteric viruses and *Ascaris lumbricoides* (roundworm) eggs. Arizona's allowable limit for the enteric virus is 125 plaque forming units (pfu)/40 L and none detectable for *Ascaris lumbricoides*. In Hawaii, the pathogens are enteric viruses and the allowable limit is less than 1 pfu/40 L. South Carolina requires that viruses be monitored but does not specify the type of viruses to be monitored or any limits.

4.1.1.2 Restricted Urban Reuse

Restricted urban reuse involves the use of reclaimed water where public exposure to the reclaimed water is controlled; therefore, treatment requirements may not be as strict as in unrestricted urban reuse. Review of existing regulations, again, reveals a wide variation in treatment and water quality requirements for restricted urban reuse. Only 12 of 22 states that regulate both categories adjust requirements downward for this category. Five states do not permit unrestricted urban reuse, but only allow restricted urban reuse. For example, Utah requires advanced treatment with BOD not to exceed 10 mg/L and TSS not to exceed 5 mg/L. In addition, total coliform is not to exceed 3/100 mL at any time. New Mexico, on the other hand, requires that the reclaimed water be adequately treated and disinfected with the fecal coliform count not to exceed 1,000/100 mL.

In general, most states with regulations require a minimum of secondary or biological treatment followed by disinfection prior to restricted urban reuse. Again, many states require additional levels of treatment, with California, Idaho, and Colorado requiring disinfection and biological oxidation prior to restricted urban reuse. South Carolina requires secondary treatment with disinfection, chemical addition, and filtration, except for golf course irrigation where filtration and chemical addition are not required. As in unrestricted urban reuse, Arizona does not specify the type of treatment processes required, but only sets limits on the reclaimed water quality.

Where specified, limits on BOD range from 5 mg/L to 30 mg/L. South Carolina requires that BOD not exceed 5 mg/L (monthly average), while Delaware, Hawaii, Maryland, Georgia, and Texas require that BOD not exceed 30 mg/L prior to restricted urban reuse. Limits on TSS vary from 5 mg/L to 90 mg/L. Utah, Florida, South Carolina, and North Carolina require that TSS not exceed 5 mg/L, while Maryland requires that TSS not exceed 90 mg/L. As in unrestricted urban reuse, for those states that do not specify limitations on BOD or TSS, a particular level of treatment is usually specified.

Average fecal coliform limits for those states that limit fecal coliforms range from non-detectable to 1,000/100 mL, with some states allowing higher single sample fecal coliform limits. As in unrestricted urban reuse, Florida requires that 75 percent of the fecal coliform samples taken over a 30-day period be below detectable levels, with no single sample in excess of 25/100 mL. New Mexico, on the other hand, requires the fecal coliform count not to exceed 1,000/100 mL. North Carolina requires that the maximum fecal coliform level not exceed 1/100 mL, while Arizona requires that no single fecal coliform count exceed 1,000/100 mL.

Nevada is the only state that has set a limit on turbidity for restricted urban reuse, requiring that no single sample exceed a turbidity of 5 NTU.

4.1.1.3 Agricultural Reuse - Food Crops

The use of reclaimed water for irrigation of food crops is prohibited in some states, while others allow irrigation of food crops with reclaimed water only if the crop is to be processed and not eaten raw. Most states require a high level of treatment when reclaimed water is used for edible crops, especially those which are consumed raw. As in other reuse applications, however, existing regulations on treatment and water quality requirements vary from state to state and depend largely on the type of irrigation employed and the type of food crop being irrigated. For example, for foods consumed raw, Colorado requires that the reclaimed water be disinfected and biologically oxidized when surface irrigation is used, with the mean total coliform count not to exceed 2.2/100 mL. When spray irrigation is utilized, Colorado requires that the reclaimed water be disinfected, oxidized, coagulated, clarified, and filtered, with the mean total coliform count not to exceed 2.2/100 mL. For processed foods, Colorado requires only disinfection and oxidation regardless of the type of irrigation, with the total coliform count not to exceed 23/100 mL.

Treatment requirements range from primary treatment in Arkansas for irrigation of processed food crops, to biological oxidation, coagulation, clarification, filtration, and disinfection in California, Colorado, and Idaho.

Where specified, limits on BOD range from 20 mg/L to 30 mg/L. Florida requires that the annual average CBOD not exceed 20 mg/L after secondary treatment with filtration and high level disinfection, while Texas requires that the BOD not exceed 30 mg/L (monthly average) when the reclaimed water is treated using a pond system. In Texas, spray irrigation is not permitted on foods to be consumed raw. Limits on TSS vary from 5 mg/L to 25 mg/L. Florida requires that TSS not exceed 5 mg/L in any one sample prior to disinfection, while Utah requires that the TSS not exceed 25 mg/L (monthly average). In Florida, direct contact of reclaimed water on edible crops that are not processed is prohibited, while Utah only considers the irrigation of particular food crops on a case-by-case basis and does not allow the use of spray irrigation.

Average fecal and total coliform limits for those states that limit coliforms range from non-detectable to 2,000/100 mL. Florida requires that 75 percent of the fecal coliform samples taken over a 30-day period be below detectable levels, with no single sample in excess of 25/100 mL. Conversely, Utah requires a median total coliform count of 2,000/100 mL. Again, some states allow higher single sample coliform counts. California and Oregon require that no single sample exceed a total coliform count of 23/100 mL, while Arizona requires that no single fecal coliform count exceed 2,500/100 mL for irrigation of food crops that are to be processed.

Where specified, limits on turbidity range from 1 to 3 NTU. For example, Arizona requires that the turbidity not exceed 1 NTU for reclaimed water irrigated on food crops to be consumed raw, while Texas requires that turbidity not exceed 3 NTU.

At this time, Arizona and Hawaii are the only states that have set limits on certain pathogenic organisms for agricultural reuse of nonfood crops. In Arizona, the pathogens include: enteric viruses, Entamoeba histolytica, Giardia *lamblia*, and *Ascaris lumbricoides*. The limits on these pathogenic organisms apply to irrigation of unprocessed food crops. The allowable limit for all of these organisms in Arizona, with the exception of enteric viruses, is none detectable. The allowable limit for enteric viruses is 1 pfu/40 L. In Hawaii, when reclaimed water is used to irrigate root food crops or food crops with the above-ground edible portion that touches the ground, the pathogens that have set limits include: enteric viruses, viable oocysts, *Cryptosporidium*, and cysts of *Giardia* and *Entamoeba*. Hawaii's guidelines state that these organisms, with the exception of enteric viruses, should be non-detectable. The allowable limit for enteric viruses is 1 pfu/40 L.

4.1.1.4 Agricultural Reuse - Nonfood Crops

The use of reclaimed water for agricultural irrigation of nonfood crops presents the least opportunity of human exposure to the water, resulting in less stringent treatment and water quality requirements than other forms of reuse. Treatment requirements range from primary treatment in Arkansas, California, and New Mexico, to secondary treatment with disinfection in the majority of the states with regulations. Arkansas, California and New Mexico also require disinfection when irrigating pastures for milking animals.

Where specified, limits on BOD range from 20 mg/L to 75 mg/L. Florida requires that the annual *average* CBOD not exceed 20 mg/L after secondary treatment and basic disinfection. Texas also requires that BOD not exceed 20 mg/L when using a treatment system other than a pond system. Delaware and Georgia require that the BOD not exceed 75 mg/L during peak flow conditions and 50 mg/L during average flow conditions. Limits on TSS vary from 10 mg/L to 90 mg/L. Florida requires that the annual average TSS not exceed 20 mg/L except when a subsurface application is used, in which case the single sample TSS limit is 10 mg/L. Maryland, on the other hand, requires that TSS not exceed 90 mg/L.

Average fecal and total coliform limits for those states that limit coliforms range from 2.2/100 mL to 2,000/100 mL. Nevada requires that the median fecal coliform count not exceed 2.2/100 mL for spray irrigation sites with no buffer zone. California, Hawaii, and Oregon all require that the median total coliform count not exceed 23/100 mL. Conversely, Utah requires that the total coliform count not exceed 2,000/100 mL. Some states allow higher single sample coliform counts. Nevada requires that no single sample exceed a fecal coliform count of 23/100 mL for spray irrigation sites with no buffer zone, while Arizona requires that no single fecal coliform count exceed 4,000/100 mL.

At this time no states have any required limits on turbidity for reclaimed water used for agricultural reuse on nonfood crops.

As for pathogenic organisms, Arizona calls for no detectable common large tapeworms when reclaimed water is used for irrigation of pastures.

4.1.1.5 Unrestricted Recreational Reuse

As with unrestricted urban reuse, unrestricted recreational reuse involves the use of reclaimed water where public exposure is likely, thereby necessitating the highest degree of treatment. Only five states (Arizona, Colorado, California, Nevada, and Oregon) have regulations pertaining to unrestricted recreational reuse. Nevada requires secondary treatment with disinfection, while California and Colorado require disinfection, biological oxidation, coagulation, clarification, and filtration. None of these five states have set limits on BOD or TSS; however, California, Oregon, and Colorado all require that the median total coliform count not exceed

2.2/100 mL, with no single sample to exceed 23/100 mL. Nevada requires that the median fecal coliform count not exceed 2.2/100 mL, with no single sample to exceed 23/100 mL, while Arizona requires that the median fecal coliform count not exceed 200/100 mL, with no single sample to exceed 800/100 mL.

Limits on turbidity range from 1 NTU in Arizona to 2 NTU in California, Nevada, and Oregon. Colorado has no limit on turbidity.

At this time, Arizona is the only state which has set limits on certain pathogenic organisms for unrestricted recreational reuse. The pathogens include: enteric virus, Entamoeba histolytica, Giardia lamblia, and *Ascaris lumbricoides*. The allowable limit for all of these organisms, with the exception of enteric virus, is none detectable. The allowable limit for the enteric virus is 1 pfu/40 L.

4.1.1.6 Restricted Recreational Reuse

State regulations regarding treatment and water quality requirements for restricted recreational reuse are generally less stringent than for unrestricted recreational reuse since the public exposure to the reclaimed water is less likely. Only seven states (Arizona, Colorado, California, Hawaii, Nevada, Oregon, and Texas) have regulations pertaining to restricted recreational reuse. With the exception of Arizona, all of the states with regulations basically require secondary treatment with disinfection. Arizona does not specify treatment process requirements.

Texas is the only state with a limit on BOD, which is set at 10 mg/L. None of the seven states has set limits on TSS. California, Oregon, and Colorado require that the median total coliform count not exceed 2.2/100 mL. Oregon also requires that no single total coliform sample exceed 23/100 mL. Nevada requires that the median fecal coliform count not exceed 2.2/100 mL, with no single sample exceeding 23/100 mL, while Texas requires that the fecal coliform count not exceed 75/100 mL. Hawaii requires that the mean total coliform count not exceed 23/100 mL, with no two consecutive samples exceeding 240/100 mL. Arizona, on the other hand, requires the median fecal coliform count not to exceed 1,000/100 mL, with no single sample exceeding 4,000/100 mL.

Limits on turbidity range from 3 NTU in Nevada and Texas to 5 NTU in Arizona. Colorado, California, and Oregon have no limits on turbidity.

At this time, Arizona is the only state which has set limits on certain pathogenic organisms for restricted recreational reuse. The pathogens include enteric viruses and *Ascaris lumbricoides*. The allowable limit for enteric viruses is 125/40 L and none detectable for *Ascaris lumbricoides*.

4.1.1.7 Environmental - Wetlands

Review of existing reuse regulations show only three states (Arizona, Florida and South Dakota) with regulations pertaining to the use of reclaimed water for creation of artificial wetlands and/or the enhancement of natural wetlands.

South Dakota, whose regulations apply only to creation of artificial wetlands, require pretreatment with stabilization ponds prior to delivery to artificial wetlands. Florida has comprehensive and complex rules governing the discharge of reclaimed water to wetlands. Treatment and disinfection levels are established for different types of wetlands, different types of uses, and the degree of public access. Most wetland systems in Florida are used for additional treatment and only wetland restoration projects are considered reuse. Arizona does not specify the level of treatment required, but requires that the pH remain between 6.5 - 8.6, the dissolved oxygen in the receiving water not drop below 6 mg/L, and the mean fecal coliform count not exceed 1,000/100 mL, with no single sample exceeding 4,000/100 mL. Arizona also requires that the temperature of the reclaimed water shall not interfere with aquatic life and wildlife in the wetland system.

4.1.1.8 Industrial Reuse

Based on review of the existing reuse regulations, five states (Hawaii, Nevada, Oregon, Texas, and Utah) have regulations pertaining to industrial reuse of reclaimed water.

Nevada requires a minimum of secondary treatment and disinfection, with the mean fecal coliform count not to exceed 200/100 mL and no single sample exceeding 400/100 mL. Oregon requires biological treatment and disinfection, with the median total coliform count not to exceed 23/100 mL and no two consecutive samples exceeding 240/100 mL. Texas requires that the BOD not exceed 30 mg/L with treatment using a pond system and 20 mg/L with treatment other than a pond system. Texas also requires that the fecal coliform count not exceed 200/100 mL. Elsewhere, Utah requires advanced treatment, with the BOD not exceeding 10 mg/L at any time, TSS not exceeding 5 mg/L at any time, and the total coliform count not exceeding 3/100 mL at any time.

In addition to a total coliform count not to exceed 23/100 mL for a single sample, the state of Hawaii has set limits for enteric viruses when reclaimed water is used for industrial cooling water. The allowable limit for enteric viruses is 1 pfu/40 L. Hawaii also requires that reclaimed water used for industrial cooling be treated with biocide or other disinfection agent to prevent viability of *Legionella* and *Klebsiella.*

4.1.2 Reclaimed Water Monitoring Requirements

Reclaimed water monitoring requirements vary greatly from state to state and again depend on the type of reuse. For unrestricted urban reuse, Arizona requires sampling for fecal coliform daily, while for agricultural reuse of non-food crops sampling for fecal coliform is only required once a month. Arizona also requires that turbidity be monitored on a continuous basis when a limit on turbidity is specified.

California, Florida, and Washington also require the continuous on-line monitoring of turbidity. Oregon, on the other hand, requires that turbidity be monitored hourly for unrestricted urban and recreational reuse as well as agricultural reuse on food crops and sampling for total coliform be conducted either once a day or once a week, depending on the type of reuse application.

Washington requires continuous on-line turbidity monitoring for agricultural reuse on food crops, while California requires that total coliform samples be taken on a daily basis and turbidity be monitored on a continuous basis for unrestricted urban and recreational reuse, as well as agricultural reuse on food crops. For unrestricted and restricted urban reuse, as well as agricultural reuse on food crops, Florida requires the continuous on-line monitoring of turbidity and chlorine residual. Even though no limits on turbidity are specified in Florida, continuous monitoring serves as an on-line surrogate for SS. In addition, Florida requires that the TSS limit must be achieved prior to disinfection and that fecal coliform samples be taken daily for treatment facilities with capacities greater than 0.5 mgd (22 L/s). Florida also requires an annual analysis of primary and secondary drinking water standards for reclaimed water used in irrigation. Other states determine monitoring requirements on a case-by-case basis depending on the type of reuse.

4.1.3 Treatment Facility Reliability

Some states have adopted facility reliability regulations or guidelines in place of, or in addition to, water quality requirements. Generally, requirements consist of alarms warning of power failure or failure of essential unit processes, automatic stand-by power sources, emergency storage, and the provision that each treatment process be equipped with multiple units or a back-up unit.

Articles 8, 9, and 10 of California's Title 22 regulations provide design and operational considerations covering alarms, power supply, emergency storage and disposal, treatment processes, and chemical supply, storage and feed facilities. For treatment processes, a variety of reliability features are acceptable in California. For example, for biological treatment, it is required that all biological treatment processes be provided with one of the following:

- ❑ Alarm (failure and power loss) and multiple units capable of producing biologically oxidized wastewater with one unit not in operation.
- ❑ Alarm (failure and power loss) and short-term (24-hour) storage or disposal provisions and stand-by replacement equipment.
- ❑ Alarm (failure and power loss) and long-term (20 days) storage or disposal provisions.

Florida requires Class I reliability of its treatment facilities when reclaimed water is used for irrigation of food crops and restricted and unrestricted urban reuse. Class I reliability requires multiple treatment units or back-up units and a secondary power source. In addition, a minimum of 1 day of reject storage is required to store reclaimed water of unacceptable quality for additional treatment. Florida also requires staffing at the water reclamation facility 24 hours/day, 7 days/week or 6 hours/day, 7 days/week as long as reclaimed water is delivered to the reuse system only during periods when a qualified operator is present; however, operator presence can be reduced to 6 hours/day if additional reliability features are provided.

Florida has also established minimum system sizes for treatment facilities to aid in assuring the continuous production of high-quality reclaimed water. Minimum system size for unrestricted and restricted urban reuse is 0.1 mgd (4 L/s), with the exception of residential lawn irrigation, which is 0.5 mgd (22 L/s). A minimum system size of 0.5 mgd (22 L/s) is also required for edible crop irrigation, with the exception of citrus irrigation under restricted access conditions, which is 0.1 mgd (4 L/s).

In South Carolina, operator presence is required 24 hr/d, 7 days/week and a minimum system size of 1.0 mgd (44 L/s) is required. In addition, South Carolina requires a back-up effluent disposal system for inclement weather or unusual operating conditions.

Other states which have regulations or guidelines regarding treatment facility reliability include Hawaii, North Carolina, Oregon, and Washington. Washington's guidelines pertaining to treatment facility reliability are similar to California's regulations. Both Oregon and North Carolina require that multiple treatment units be provided for all essential treatment processes and a secondary or back-up power source be supplied.

4.1.4 *Minimum Storage Requirements*

Current regulations regarding storage requirements are primarily based upon the need to limit or prevent surface water discharge and are not related to storage required to meet diurnal or seasonal variations in supply and demand. Storage requirements vary from state to state and are generally dependent upon geographic location and site conditions. For example, Arizona requires a minimum storage volume equal to 5 days of the average design flow, while South Dakota requires a minimum storage volume of 210 days of the average design flow. The large difference is primarily due to the high number of non-irrigation days due to freezing temperatures in the northern states.

Most states that specify storage requirements do not differentiate between operational and seasonal storage, with the exception of Georgia and Delaware, which require that both operational and wet weather storage be considered. The majority of states that have storage requirements in their regulations require that a water balance be performed on the reuse system, taking into account all inputs and outputs of water to the system based on a specified rainfall recurrence interval. For example, in addition to the minimum storage requirement of 60 days, Maryland also requires that a water balance be performed based on a 1-in-10 year rainfall recurrence interval to determine if additional storage is required beyond the minimum requirement of 60 days.

Texas, on the other hand, requires that a water balance be performed based on average rainfall conditions, while Illinois requires that a water balance be performed based on a 1-in-20 year rainfall recurrence interval to determine if storage beyond the minimum requirement of 150 days is needed.

4.1.5 *Application Rates*

When regulations specify application or hydraulic loading rates, the regulations generally pertain to land application systems that are used primarily for additional wastewater treatment for disposal rather than reuse. When systems are developed chiefly for the purpose of land treatment and/or disposal, the objective is often to dispose of as much effluent on as little land as possible; thus, application rates are often far greater than irrigation demands and limits are set for the maximum hydraulic loading. On the other hand, when the reclaimed water is managed as a valuable resource, the objective is to apply the water according to irrigation needs rather than maximum hydraulic loading, and application limits are rarely specified.

Many states do not have any specific requirements regarding reclaimed water application rates, as these are generally based on site conditions; however, some states require that the hydraulic loading rate not exceed 2.0 to 2.5 in (51-64 mm)/week. Nebraska's guidelines suggest that hydraulic loading rates not exceed 4.0 in (102 mm)/ week.

In addition to hydraulic loading rates, some states also have limits on nitrogen loading. For example, Georgia and Delaware both require that the effluent percolating from the reuse system have a nitrate-nitrogen concentration of 10 mg/L or less, while Missouri and Nebraska both require that the nitrogen loading not exceed the nitrogen uptake of the crop.

4.1.6 *Groundwater Monitoring*

Groundwater monitoring programs associated with irrigation of reclaimed water are required by Arkansas, Delaware, Florida, Georgia, Illinois, Maryland, Missouri, South Carolina, Washington, Wisconsin, West Virginia, New Jersey, Hawaii, Tennessee, and Montana. In general, these groundwater monitoring programs require that one well be placed hydraulically upgradient of the reuse site to assess background and incoming groundwater conditions within the aquifer in question and two wells be placed hydraulically downgradient of the reuse sites. Groundwater monitoring programs associated with reclaimed water irrigation generally focus on water quality in the surficial aquifer. Groundwater monitoring programs associated with reclaimed water irrigation generally focus on water quality in the surficial aquifer. Florida generally requires a minimum of three monitoring wells at each reuse site. Some states also require that a well be placed within each reuse site. South Carolina's guidelines suggest that a minimum of 9 wells be placed in golf courses (18-holes) that irrigate with reclaimed water. Sampling parameters and frequency of sampling are generally considered on a case-by-case basis.

4.1.7 *Setback Distances for Irrigation*

Many states have established setback distances or buffer zones between reuse irrigation sites and various facilities such as potable water supply wells, property lines, residential areas, and roadways. Setback distances vary depending on the quality of reclaimed water and the method of application. For example, Illinois requires a 50-ft (15 m) setback from the edge of the wetted perimeter of the reuse site to a residential lot for a non-spray application system, but requires a 150-ft (45-m) setback for a spray irrigation system. For restricted and unrestricted urban reuse and irrigation of food crops, Florida requires a 75-ft (23-m) setback to potable water supply wells; but for agricultural reuse on non-food crops, Florida requires a 500-ft (150-m) setback to potable water supply wells and a 100-ft (30-m) setback to property lines. Florida will allow reduced setback distances for agricultural reuse on non-food crops if additional facility reliability and treatment are provided. Colorado recommends a 500-ft (150-m) setback distance to domestic supply wells and a 100-ft (30-m) setback to any irrigation well regardless of the quality of the reclaimed water.

Oregon and Nevada do not require setback distances when reclaimed water is used for unrestricted urban reuse or irrigation of food crops due to the high degree of treatment required; however, setback distances are required for irrigation of non-food crops and restricted urban reuse. In Nevada, the quality requirements for reclaimed water are based not only on the type of reuse, but also on the setback distance. For example, for restricted urban reuse and a 100-ft (30-m) buffer zone, Nevada requires that the reclaimed water have a mean fecal coliform count of no more than 23/100 mL and a turbidity of no more than 5 NTU. However, with no buffer zone, the reclaimed water must have a mean fecal coliform count of no more than 2.2/100 mL and a turbidity of no more than 3 NTU.

4.2 Suggested Guidelines for Water Reuse

Table 28 presents suggested wastewater treatment processes, reclaimed water quality, monitoring, and setback distances for various types of water reuse. Suggested guidelines are presented for the following categories:

- Urban Reuse
- Restricted Access Area Irrigation
- Agricultural Reuse - Food Crops
  - Food crops not commercially processed
  - Commercially processed food crops and surface irrigation of orchards and vineyards
- Agricultural Reuse - Non Food Crops
  - Pasture for milking animals and fodder, fiber, and seed crops
- Recreational Impoundments
- Landscape Impoundments
- Construction Uses
- Industrial Reuse
- Environmental Reuse
- Groundwater Recharge
  - Spreading or injection into nonpotable aquifer
- Indirect Potable Reuse
  - Spreading into potable aquifer
  - Injection into potable aquifer
  - Augmentation of surface supplies

These guidelines apply to domestic wastewater from municipal or other wastewater treatment facilities having a limited input of industrial waste. The suggested guidelines are predicated principally on water reclamation and reuse information from the U.S. and are intended to apply to reclamation and reuse facilities in the U.S. Local conditions may limit the applicability of these guidelines in some countries (see Chapter 8). It is explicitly stated that the direct application of these suggested guidelines will not be used by AID as strict criteria for funding.

The suggested treatment processes, reclaimed water quality, monitoring frequency, and setback distances are based on:

- Water reuse experience in the U.S. and elsewhere;
- Research and pilot plant or demonstration study data;
- Technical material from the literature;
- Various states' reuse regulations, policies, or guidelines (see Appendix A);
- Attainability; and
- Sound engineering practice.

These guidelines are not intended to be used as definitive water reclamation and reuse criteria. They are intended to provide reasonable guidance for water reuse opportunities, particularly in states that have not developed their own criteria or guidelines.

Adverse health consequences associated with the reuse of raw or improperly treated wastewater are well documented (Lund, 1980; Feachem *et al.*, 1983, Shuval *et al.*, 1986). As a consequence, water reuse standards and guidelines are principally directed at public health

Table 28. Suggested Guidelines for Water Reuse [1] (Page 1 of 6)

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Urban Reuse All types of landscape irrigation, (e.g., golf courses, parks, cemeteries) —also vehicle washing, toilet flushing, use in fire protection systems and commercial air conditioners, and other uses with similar access or exposure to the water	• Secondary [4] • Filtration [5] • Disinfection [6]	• pH = 6 - 9 • ≤ 10 mg/l BOD [7] • ≤ 2 NTU [8] • No detectable fecal coli/100 ml [9,10] • 1 mg/l Cl_2 residual (min.) [11]	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous	• 50 ft (15 m) to potable water supply wells	• See Table 19 for other recommended limits. • At controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water, a lower level of treatment, e.g., secondary treatment and disinfection to achieve ≤ 14 fecal coli/100 ml, may be appropriate. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens. [12] • Reclaimed water should be clear, odorless, and contain no substances that are toxic upon ingestion. • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • A chlorine residual of 0.5 mg/l or greater in the distribution system is recommended to reduce odors, slime, and bacterial regrowth. • See Section 2.4.3. for recommended treatment reliability.
Restricted Access Area Irrigation Sod farms, silviculture sites, and other areas where public access is prohibited, restricted, or infrequent	• Secondary [4] • Disinfection [6]	• pH = 6 - 9 • ≤ 30 mg/l BOD [7] • ≤ 30 mg/l SS • ≤ 200 fecal coli/100 ml [9,13,14] • 1 mg/l Cl_2 residual (min.) [11]	• pH - weekly • BOD - weekly • SS - daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public (if spray irrigation)	• See Table 19 for other recommended limits. • If spray irrigation, SS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. • See Section 2.4.3 for recommended treatment reliability.
Agricultural Reuse - Food Crops Not Commercially Processed [15] Surface or spray irrigation of any food crop, including crops eaten raw.	• Secondary [4] • Filtration [5] • Disinfection [6]	• pH = 6 - 9 • ≤ 10 mg/l BOD [7] • ≤ 2 NTU [8] • No detectable fecal coli/100 ml [9,10] • 1 mg/l Cl_2 residual (min.) [11]	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous	• 50 ft (15 m) to potable water supply wells	• See Table 19 for other recommended limits. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens. [12] • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • High nutrient levels may adversely affect some crops during certain growth stages. • See Section 2.4.3 for recommended treatment reliability.

Table 28. Suggested Guidelines for Water Reuse [1] (Page 2 of 6)

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Agricultural Reuse - Food Crops Commercially Processed; [15] *Surface Irrigation of Orchards and Vineyards*	• Secondary [4] • Disinfection [6]	• pH = 6 - 9 • ≤ 30 mg/l BOD [7] • ≤ 30 mg/l SS • ≤ 200 fecal coli/100 ml [9,13,14] • 1 mg/l Cl_2 residual (min.) [11]	• pH - weekly • BOD - weekly • SS - daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public	• See Table 19 for other recommended limits. • If spray irrigation, SS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. • High nutrient levels may adversely affect some crops during certain growth stages. • See Section 2.4.3 for recommended treatment reliability.
Agricultural Reuse - Non-Food Crops Pasture for milking animals; fodder, fiber and seed crops	• Secondary [4] • Disinfection [6]	• pH = 6 - 9 • ≤ 30 mg/l BOD [7] • ≤ 30 mg/l SS • ≤ 200 fecal coli/100 ml [9,13,14] • 1 mg/l Cl_2 residual (min.) [11]	• pH - weekly • BOD - weekly • SS - daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public (if spray irrigation)	• See Table 19 for other recommended limits. • If spray irrigation, SS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. • High nutrient levels may adversely affect some crops during certain growth periods. • Milking animals should be prohibited from grazing for 15 days after irrigation ceases. A higher level of disinfection, e.g., to achieve ≤14 fecal coli/100 ml, should be provided if this waiting period is not adhered to. • See Section 2.4.3 for recommended treatment reliability.
Recreational Impoundments Incidental contact (e.g., fishing and boating) and full body contact with reclaimed water allowed	• Secondary [4] • Filtration [5] • Disinfection [6]	• pH = 6 - 9 • ≤ 10 mg/l BOD [7] • ≤2 NTU [8] • No detectable fecal coli/100 ml [9,10] • 1 mg/l Cl_2 residual (min.) [11]	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous	• 500 ft (150 m) to potable water supply wells (minimum) if bottom not sealed	• Dechlorination may be necessary to protect aquatic species of flora and fauna. • Reclaimed water should be non-irritating to skin and eyes. • Reclaimed water should be clear, odorless, and contain no substances that are toxic upon ingestion. • Nutrient removal may be necessary to avoid algae growth in impoundments. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens. [12] • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • Fish caught in impoundments can be consumed. • See Section 2.4.3 for recommended treatment reliability.

Table 28. Suggested Guidelines for Water Reuse[1] (Page 3 of 6)

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Landscape Impoundments Aesthetic impoundment where public contact with reclaimed water is not allowed	• Secondary[4] • Disinfection[6]	• $\leq$ 30 mg/l BOD[7] • $\leq$ 30 mg/l SS • $\leq$ 200 fecal coli/100 ml[9,13,14] • 1 mg/l Cl_2 residual (min.)[11]	• pH - weekly • SS - daily • Coliform - daily • Cl_2 residual - continuous	• 500 ft (150 m) to potable water supply wells (minimum) if bottom not sealed	• Nutrient removal processes may be necessary to avoid algae growth in impoundments. • Dechlorination may be necessary to protect aquatic species of flora and fauna. • See Section 2.4.3 for recommended treatment reliability.
Construction Uses Soil compaction, dust control, washing aggregate, making concrete	• Secondary[4] • Disinfection[6]	• $\leq$ 30 mg/l BOD • $\leq$ 30 mg/l SS • $\leq$ 200 fecal coli/100 ml[9,13,14] • 1 mg/l Cl_2 residual (min.)[11]	• BOD - weekly • SS - daily • Coliform - daily • Cl_2 residual - continuous		• Worker contact with reclaimed water should be minimized. • A higher level of disinfection, e.g., to achieve $\leq$ 14 fecal coli/100 ml, should be provided where frequent worker contact with reclaimed water is likely. • See Section 2.4.3 for recommended treatment reliability.
Industrial Reuse Once-through cooling	• Secondary[4]	• pH = 6 - 9 • $\leq$ 30 mg/l BOD[7] • $\leq$ 30 mg/l SS • $\leq$ 200 fecal coli/100 ml[9,13,14] • 1 mg/l Cl_2 residual (min.)[11]	• pH - daily • BOD - weekly • SS - weekly • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to areas accessible to the public	• Windblown spray should not reach areas accessible to users or the public.
Recirculating cooling towers	• Secondary[4] • Disinfection[6] (chemical coagulation and filtration[5] may be needed)	• Variable, depends on recirculation ratio (see Section 3.3.1)		• 300 ft (90 m) to areas accessible to the public. May be reduced if high level of disinfection is provided.	• Windblown spray should not reach areas accessible to the public. • See Table 13 for additional recommended limits. • Additional treatment by user is usually provided to prevent scaling, corrosion, biological growths, fouling and foaming. • See Section 2.4.3 for recommended treatment reliability.
Other Industrial Uses	← Depends on site specific use (See Sections 3.3.2 and 3.3.3) →				
Environmental Reuse Wetlands, marshes, wildlife habitat, stream augmentation	• Variable • Secondary[4] and disinfection[6] (min.)	Variable, but not to exceed: • $\leq$ 30 mg/l BOD[7] • $\leq$ 30 mg/l SS • $\leq$ 200 fecal coli/100 ml[9,13,14]	• BOD - weekly • SS - daily • Coliform - daily • Cl_2 residual - continuous		• Dechlorination may be necessary to protect aquatic species of flora and fauna. • Possible effects on groundwater should be evaluated. • Receiving water quality requirements may necessitate additional treatment. • The temperature of the reclaimed water should not adversely affect ecosystem. • See Section 2.4.3 for recommended treatment reliability.

Table 28. Suggested Guidelines for Water Reuse[1] (Page 4 of 6)

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Distance to Point of Withdrawal	Comments
Groundwater Recharge By spreading or injection into nonpotable aquifers	• Site specific and use dependent • Primary (min.) for spreading • Secondary[4] (min.) for injection	• Site specific and use dependent	• Depends on treatment and use	• Site specific	• Facility should be designed to ensure that no reclaimed water reaches potable water supply aquifers. • See Section 3.6 for more information. • For injection projects, filtration and disinfection may be needed to prevent clogging. • See Section 2.4.3 for recommended treatment reliability.
Indirect Potable Reuse Groundwater recharge by spreading into potable aquifers	• Site specific • Secondary [4] and disinfection [6] (min.) May also need filtration [5] and/or advanced wastewater treatment [16]	• Site specific • Meet drinking water standards after percolation through vadose zone	Includes, but not limited to, the following: • pH - daily • Coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other[17] - depends on constituent	• 2000 ft (600 m) to extraction wells. May vary depending on treatment provided and site-specific conditions.	• The depth to groundwater (i.e., thickness of the vadose zone) should be at least 6 feet (2m) at the maximum groundwater mounding point. • The reclaimed water should be retained underground for at least 1 year prior to withdrawal. • Recommended treatment is site-specific and depends on factors such as type of soil, percolation rate, thickness of vadose zone, native groundwater quality, and dilution. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • See Sections 3.6 and 3.7 for more information. • The reclaimed water should not contain measurable levels of pathogens after percolation through the vadose zone.[12] • See Section 2.4.3. for recommended treatment reliability.
Groundwater recharge by injection into potable aquifers	• Secondary [4] • Filtration [5] • Disinfection [6] • Advanced wastewater treatment [16]	Includes, but not limited to, the following: • pH = 6.5 - 8.5 • $\leq$ 2 NTU [8] • No detectable fecal coli/100 ml [9,10] • 1 mg/l Cl_2 residual (min.) [11] • Meet drinking water standards	Includes, but not limited to, the following: • pH - daily • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other[17] depends on constituent	• 2000 ft (600m) to extraction wells. May vary depending on site-specific conditions.	• The reclaimed water should be retained underground for at least 1 year prior to withdrawal. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • Recommended quality limits should be met at the point of injection. • The reclaimed water should not contain measurable levels of pathogens at the point of injection.[12] • See Sections 3.6 and 3.7 for more information. • A higher chlorine residual and/or a longer contact time may be necessary to assure virus inactivation. • See Section 2.4.3. for recommended treatment reliability.

Table 28. Suggested Guidelines for Water Reuse[1] (Page 5 of 6)

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Distance to Point of Withdrawal	Comments
Indirect Potable Reuse Augmentation of surface supplies	• Secondary [4] • Filtration [5] • Disinfection [6] • Advanced wastewater treatment[16]	Includes, but not limited to, the following: • pH = 6.5 - 8.5 • ≤ 2 NTU[8] • No detectable fecal coli/100 ml[9,10] • 1 mg/l Cl_2 residual (min.)[11] • Meet drinking water standards	Includes, but not limited to, the following: • pH - daily • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other[17] - depends on constituent	• Site specific	• Recommended level of treatment is site-specific and depends on factors such as receiving water quality, time and distance to point of withdrawal, dilution and subsequent treatment prior to distribution for potable uses. • The reclaimed water should not contain measurable levels of pathogens. [12] • See Section 3.7 for more information. • A higher chlorine residual and/or a longer contact time may be necessary to assure virus inactivation. • See Section 2.4.3 for recommended treatment reliability.

Table 28. **Suggested Guidelines for Water Reuse**[1] (Page 6 of 6)

Footnotes

1 These guidelines are based on water reclamation and reuse practices in the U.S., and they are especially directed at states that have not developed their own regulations or guidelines. While the guidelines should be useful in many areas outside the U.S., local conditions may limit the applicability of the guidelines in some countries (see Chapter 8). It is explicitly stated that the direct application of these suggested guidelines will not be used by AID as strict criteria for funding.

2 Unless otherwise noted, recommended quality limits apply to the reclaimed water at the point of discharge from the treatment facility.

3 Setback distances are recommended to protect potable water supply sources from contamination and to protect humans from unreasonable health risks due to exposure to reclaimed water.

4 Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contactors, and many stabilization pond systems. Secondary treatment should produce effluent in which both the BOD and SS do not exceed 30 mg/l.

5 Filtration means the passing of wastewater through natural undisturbed soils or filter media such as sand and/or anthracite.

6 Disinfection means the destruction, inactivation, or removal of pathogenic microorganisms by chemical, physical, or biological means. Disinfection may be accomplished by chlorination, ozonation, other chemical disinfectants, UV radiation, membrane processes, or other processes.

7 As determined from the 5-day BOD test.

8 The recommended turbidity limit should be met prior to disinfection. The average turbidity should be based on a 24-hour time period. The turbidity should not exceed 5 NTU at any time. If SS is used in lieu of turbidity, the average SS should not exceed 5 mg/l.

9 Unless otherwise noted, recommended coliform limits are median values determined from the bacteriological results of the last 7 days for which analyses have been completed. Either the membrane filter or fermentation tube technique may be used.

10 The number of fecal coliform organisms should not exceed 14/100 ml in any sample.

11 Total chlorine residual after a minimum contact time of 30 minutes.

12 It is advisable to fully characterize the microbiological quality of the reclaimed water prior to implementation of a reuse program.

13 The number of fecal coliform organisms should not exceed 800/100 ml in any sample.

14 Some stabilization pond systems may be able to meet this coliform limit without disinfection.

15 Commercially processed food crops are those that, prior to sale to the public or others, have undergone chemical or physical processing sufficient to destroy pathogens.

16 Advanced wastewater treatment processes include chemical clarification, carbon adsorption, reverse osmosis and other membrane processes, air stripping, ultrafiltration, and ion exchange.

17 Monitoring should include inorganic and organic compounds, or classes of compounds, that are known or suspected to be toxic, carcinogenic, teratogenic, or mutagenic and are not included in the drinking water standards.

protection and generally are based on the control of pathogenic organisms. These guidelines address health protection via suggested wastewater treatment unit processes, reclaimed water quality limits, and other controls (setback distances, etc.).

Both treatment processes and water quality limits are recommended for the following reasons:

- Water quality criteria that include the use of surrogate parameters may not adequately characterize reclaimed water quality;

- A combination of treatment and quality requirements known to produce reclaimed water of acceptable quality obviate the need to monitor the finished water for certain constituents, e.g., some health-significant chemical constituents or pathogenic microorganisms;

- Expensive, time-consuming, and, in some cases, questionable monitoring for pathogenic organisms, such as viruses, is eliminated without compromising health protection; and

- Treatment reliability is enhanced.

It would be impractical to monitor reclaimed water for all of the chemical constituents and pathogenic organisms of concern, and surrogate parameters are universally accepted. In the U.S., total and fecal coliforms are the most commonly used indicator organisms in reclaimed water. The total coliform analysis includes enumeration of organisms of both fecal and nonfecal origin, while the fecal coliform analysis is specific for coliform organisms of fecal origin. Therefore, fecal coliforms are better indicators of fecal contamination than total coliforms, and these guidelines use fecal coliform as the indicator organism. Either the multiple-tube fermentation technique or the membrane filter technique may be used to quantify the coliform levels in the reclaimed water.

These guidelines do not include suggested parasite or virus limits. Parasites have not been shown to be a problem at water reuse operations in the U.S. at the treatment and quality limits recommended in these guidelines. Viruses are of concern in reclaimed water, but virus limits are not recommended in these guidelines for the following reasons:

- A significant body of information exists indicating that viruses are reduced or inactivated to low or immeasurable levels via appropriate wastewater treatment, including filtration and disinfection (Sanitation Districts of Los Angeles County, 1977; Engineering-Science, 1987; Crook, 1989);

- The identification and enumeration of viruses in wastewater are hampered by relatively low virus recovery rates, the complexity and high cost of laboratory procedures, and the limited number of facilities having the personnel and equipment necessary to perform the analyses;

- The laboratory culturing procedure to determine the presence or absence of viruses in a water sample takes about 14 days, and another 14 days are required to identify the viruses;

- There is no consensus among virus experts regarding the health significance of low levels of viruses in reclaimed water; and

- There have been no documented cases of viral disease resulting from the reuse of wastewater at any of the water reuse operations in the U.S.

The removal of suspended matter is related to the virus issue. It is known that many pathogens are particulate-associated and that particulate matter can shield both bacteria and viruses from disinfectants. Also, organic matter consumes chlorine, thus making less of the disinfectant available for disinfection. There is general agreement that particulate matter should be reduced to low levels, e.g., 2 NTU or 5 mg/L SS, prior to disinfection to ensure reliable destruction of pathogenic microorganisms during the disinfection process. Suspended solids measurements are typically performed daily on a composite sample and only reflect an average value. Continuously monitored turbidity is superior to daily SS measurements as an aid to treatment operation.

The need to remove organic matter is related to the type of reuse. Some of the adverse effects associated with organic substances are that they are aesthetically displeasing (may be malodorous and impart color), provide food for microorganisms, adversely affect disinfection processes, and consume oxygen. The recommended BOD limit is intended to indicate that the organic matter has been stabilized, is nonputrescible, and has been lowered to levels commensurate with anticipated types of reuse. SS limits are suggested as a measure of organic and inorganic particulate matter in reclaimed water that has received secondary treatment. The recommended BOD and SS limits are readily achievable at well operated water reclamation plants.

The suggested setback distances are somewhat subjective. They are intended to protect drinking water supplies from contamination and, where appropriate, to protect humans from exposure to the reclaimed water. While studies indicate the health risk associated with aerosols from spray irrigation sites using reclaimed water is low (EPA, 1980), the general practice is to limit, through design or operational controls, exposure to aerosols and windblown spray produced from reclaimed water that is not highly disinfected.

Unplanned or incidental indirect potable reuse occurs in many states in the U.S., while planned or intentional indirect potable reuse via groundwater recharge or augmentation of surface supplies is a less-widely accepted practice. Whereas the water quality requirements for nonpotable water uses are tractable and not likely to change significantly in the future, the number of water quality constituents to be monitored in drinking water (and, hence, reclaimed water intended for potable reuse) will increase and quality requirements will become more restrictive. Consequently, it would not be prudent to suggest a complete list of reclaimed water quality limits for all constituents of concern. Some general and specific information is provided in the guidelines to indicate the extensive treatment, water quality, and other requirements that are likely to be imposed where indirect potable reuse is contemplated.

4.3 References

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CHAPTER 5

Legal and Institutional Issues

This chapter provides a general discussion to identify major legal and institutional issues associated with assessing the feasibility of water reuse. Specific parts of this chapter might not apply in every state, but should still support an overall understanding of primary legal and institutional issues. Existing state regulations and guidelines governing reuse are reviewed in Chapter 4.

Discussed in this section are:

- Legal issues at federal, state, and local levels;
- Organizations typically involved in water reuse;
- General steps to follow throughout implementation of a reuse project; and
- Case studies illustrated legal issues related to reuse.

In the simplest terms, the legal and institutional issues relate to what may and may not be done and, in the case of the former, how it may be done. These issues arise in the context of federal, state and local statutes, regulations, case law and agency policies, and the institutions that promulgate and enforce them. The available body of statutory and case law directly addressing the area of water reuse is generally not well developed or well settled at the present time. As a result, the assessment of potential legal and institutional issues for a given water reuse project should give due regard to the risks inherent in this area.

5.1 Identifying Legal Issues

A critical aspect of any legal and institutional analysis of the feasibility of a water reuse project, and perhaps the most difficult, is the identification of potential issues affecting implementation of the project. Major sources of law that could raise issues or provide guidance in this area include:

- Federal Statutes - The federal statutes directly concerned with water reuse are currently limited. However, federal statutes governing interstate and international water rights may warrant careful review.
- Federal Case Law - Although existing court opinions at the federal level are not abundant on the subject of water reuse, available case law in the areas of federal water rights and applicable constitutional provisions may need to be considered.
- State Statutes - State legislation generally can have a major impact on many aspects of water reuse. Such legislation and administrative agency regulations can be particularly important in the areas of water rights, enabling authority for local governmental units (cities, towns, villages, counties, districts, regional agencies, and interjurisdictional arrangements), water service area franchise rights, public health, and environmental quality.
- State Case Law - Although many states may currently have no reported court opinions directly addressing the topic of water reuse, it may be necessary to look to other states for nonbinding guidance in this area, and there may be important cases within the subject state that indirectly impact implementation of the project.
- Local Ordinances - To the extent that a water reuse program or project does not exist in a given local jurisdiction, it is unlikely that water reuse ordinances would be currently in effect. However, implementation of a new water reuse project normally would require the adoption of a new ordinance and possibly the amendment of existing ordinances.

5.2 Federal Legal Issues

There are limited federal laws or regulations concerned directly with wastewater reclamation and water reuse. Currently, when the United States government sets aside or reserves land, it has the right to adequate water from sources on or adjacent to the property to meet the required needs of the land. Referred to as federal reserved water rights, the quantity of water reserved by the government need not be established or used at the time of the land acquisition. These rights to water are not lost due to non-use or abandonment and can be used for purposes other than that which it was originally intended, as long as consumption does not increase. These rights may be set aside by executive order, statute, treaty, or agreement (Weinberg, 1990).

Water may also be appropriated by the federal government in order to carry out purposes established by Congress on non-reserved lands. The government may be using lands in accordance with the direction of Congress but not hold these lands as reservations. Like the federal reserved rights, this right to water for unreserved lands may not cause harm to other users of the water and the appropriation may not take priority over already existing appropriations. There is some question as to whether there is sufficient legal basis for claiming water under the non-reserved rights. Congress does, however, appear to have the power to authorize the use of unappropriated water for federal purposes on federal land, whether such land is reserved or unreserved (Weinberg and Allan, 1990).

Although there have been many court decisions relating to the water rights of Indian reservations and other federal lands, there still a great deal of uncertainty as to how those decisions should be interpreted. If there is any potential of conflict with the federal reserved water rights, either from an Indian reservation or other federal reserve, a very careful legal interpretation of such water rights should be obtained.

5.3 State Legal Issues

A review of existing and any proposed legislation relating to water rights, health, environmental quality and utility regulation for the state should be done during the initial development and planning phase of the reuse system. New legislation at the state level can affect reuse opportunities; thus, as new legislation is enacted and as proposed legislation is filed, it should be carefully studied.

A determination should be made regarding what is regulated, facilitated or prohibited by the state law, by whom, and by what process. The state statutes deserve careful review and can provide a good source of information in determining legal steps to take in order to help secure a successful reuse program. Relevant case law should also be carefully reviewed, and can be helpful where state statutes are silent or ambiguous. Such judicial decisions can also provide assistance in identifying potential issues that may not yet have been resolved. Normally such court opinions will provide some insight into the judicial reasoning underlying a given decision and often will identify a need for new state legislation or for changes in the administrative practices of state agencies.

5.3.1 State Water Rights

It generally can be assumed that water rights are an especially important issue. The water rights system in a given state can actually promote reuse measures, or it can pose an obstacle to reuse.

It generally can be assumed that water rights will be an issue in water-poor areas and/or if reclaimed water will be utilized in a consumptive fashion. These, ironically, are both conditions under which water reuse might be most attractive.

A water right is a right to use water. It is not a right of ownership. The state generally retains ownership of so-called natural or public water within its boundaries, and state statutes, regulations and case law govern the allocation and administration of the rights of private parties and governmental entities to use such water. A "water right" allows water to be diverted at one or more particular points and a portion of the water to be used for one or more particular purposes. A basic doctrine in water-rights law is that harm cannot be rendered upon others who have a claim to the water.

There are two main systems of water rights - the appropriative doctrine and the riparian doctrine.

5.3.1.1 Appropriative Rights System

The appropriative rights system is found in most western states and in areas that are water-poor (California has both appropriative and riparian rights). It is a system by which the right to use water is appropriated — that is, it is assigned or delegated to the consumer. The basic notion is: first in time, first in right. In other words, the right derives from beneficial use on a first-come, first-served basis and not from the property's proximity to the water source. The first party to use the water has the most senior claim to that water. The senior users have a continued right to the water, and a late user generally cannot diminish the quantity or quality of the water to the senior user. This assures the senior users of adequate water under almost any rainfall conditions, and the later users having some moderate assurance to the water. The last to obtain water rights may be limited to water only during times when it is available (wet season). The right is for a specific quantity of water, but the appropriator may not divert more water than can be used. If the appropriated water is not used, it will be lost. The system does, however, allow for the storage of water on either a temporary or seasonal basis (Viessman and Hammer, 1985).

Generally, appropriative water rights are acquired pursuant to statutory law; thus, typically, there are comprehensive water codes which govern the acquisition and control of the water rights. The acquisition of the water right is usually accompanied by an application to state officials responsible for water rights and granted with a permit or license. The appropriative rights doctrine allows for obtaining water by putting it to beneficial use in accordance with procedures set forth in state statutes and judicial decisions. This right has been supported by statutes and high court decisions as well as constitutional provisions (Viessman and Hammer, 1985).

The appropriative water rights system is generally used for groundwater throughout the United States. Water percolating through the ground is controlled by three different appropriative methods: absolute ownership, reasonable use rule, or specific use rule. Absolute ownership occurs when the water located directly beneath a property is considered to belong to the property owner to use in any amount regardless of the effect on the water table of the adjacent land, as long as it is not for a malicious use. The reasonable use rule limits the withdrawal to the quantity necessary for reasonable and beneficial use in connection with the land located above the water. Water cannot be wasted or exported. The specific use rule occurs when the use of the water has been restricted to one use.

During times of excess water supply, storage alternatives may be considered as part of the reuse project so water may be used at a later date. A determination of the ownership or rights to use of reclaimed water which has been stored in an aquifer, for example, will need to be made before consideration is given to this alternative. Ownership claims may be made by those who have previously been withdrawing the groundwater, since the reclaimed water has been commingled with the existing groundwater (Water Pollution Control Federation, 1989).

5.3.1.2 Riparian Rights System

The riparian water rights system is found primarily in the east and in water-abundant areas. The right is based on the proximity to water. "The owner of land containing a natural stream or abutting a stream is entitled to receive the full natural flow of the stream without change in quality or quantity" (Viessman and Hammer, 1985).

A riparian user is not entitled to make any use of the water that substantially depletes the stream flow or that significantly degrades the quality of the stream. Such riparian use can only be for a legal and beneficial purpose. The right of one riparian owner is generally correlative with the rights of the other riparian owners, with each land owner being assured some water when available.

Water used under a riparian right can be used only on the riparian land and is acquired by the purchase of the land. The water withdrawn for the riparian property cannot be extended to another property. However, unlike the appropriative doctrine, under riparian right, the right to the unused water can be held indefinitely and without forfeiture. This limits the ability of the water authority to quantify the amount of water that has a hold against it and can lead to water being allocated in excess of that available. This doctrine does not allow for storage of water.

In the United States versus the Rio Grande Dam and Irrigation Company, the United State Supreme Court has determined that each state has the right to change the rules of common law referring to the rights of the riparian owner to the continuous natural flow of the stream and to permit appropriation of waters for such purposes as it deems wise (Viessman and Hammer, 1985).

5.3.1.3 Water Rights as Related to Reuse

In the western U.S., many users of reclaimed water have found that reclaimed water can offer a more reliable source of water, rather than obtaining appropriated water rights from the state's water board. This is particularly true when the water appropriation would be designated a low-priority right and would be withdrawn in times of water shortages. Because of the difficulty associated with obtaining an uninterrupted supply of water in the West, water reuse becomes an attractive alternative for procuring water. Water rights issues can constrain reclamation/reuse projects by imposing restrictions and requirements regarding the use and return of that water.

The impact of the water rights issue on a water reuse program can be serious and may require professional legal counsel experienced in this area. The following generalizations are offered:

- Injury to Others - If the water reuse program could substantially reduce natural flows in a local watercourse, there may be obstacles associated with water rights.

- Water Sources - Water-rights law for streams and rivers is relatively clear and well-defined, but is less so for other surface water sources and even less so for groundwater. An even more careful review of the water rights laws will be necessary if contemplating a program that will affect groundwater.

- Reducing Withdrawals - A water reuse program that reduces withdrawals from the water supply will probably pose no third-party conflict with water-rights issues, but the impact of such reductions on water rights of the project proponent should be evaluated.

- Reducing Discharge - Some uses of reclaimed water can reduce or eliminate the discharge of water to the watercourse from which water is withdrawn. Examples of such uses include evaporative cooling, infiltration/percolation through irrigation, or diversion to a different stream or watershed. Multiple uses of water is generally acceptable under the law, but reducing watercourse flows through reuse can pose problems. Therefore, although a discharger of wastewater treatment plant effluent is not generally bound to continue the discharge, reduction or elimination of its effluent due to reuse could face legal challenge and could result in serious economic and environmental losses downstream.

- Changes in Point-of-Discharge or Place-of-Use - In appropriative states, the statutes might contain laws designed to protect the area of the origin of the water, to limit the places of use, or to require the same point of discharge. In riparian states, the place of use can be an issue; potential users located outside the watershed from which the water was originally drawn (or, for that matter, outside the jurisdiction abutting the watercourse) might have no claim to the water.

- Hierarchy of Use - Generally with water reuse, the concept of "reasonable-use" and "beneficial use" should not present an obstacle, particularly if such recycling is economically justified. Nevertheless, a hierarchy of use still exists in both riparian and appropriative law, and in times of water shortage, it is possible that a more important use could make claim to reclaimed water that, for example, is being used for industrial process water.

5.3.2 State Liability Laws

Generally, when a person fails to take reasonable precautions with a product to protect users and others from foreseeable injuries, the person may be considered negligent and liable for the damage caused by use of the product. A party tends to be considered negligent if they violate certain statutes or regulations. Most states have well-defined liability laws relating to defects in design and manufacture of products. Legal precedents exist for considering distributed potable water a product that is subject to these laws (Zeitzew, 1979). The municipal officials planning to implement a program of water reuse must take direction in assuring safety and reliability in the reclaimed water system.

Understanding the potential for product and other theories of liability can minimize exposure by providing clear direction on accepted uses for reclaimed water and stating the hazards of its use and misuse. Exposure to liability may be decreased by including information within contract documents regarding the possibility of danger to crops, potential for property damage, and correct usage procedures for the reclaimed water.

Liability suits can also arise from not delivering the reclaimed water in the quantity or quality promised. This may be considered breach of contract or of warranty, either expressed or implied. This potential for liability will need to be considered when determining the treatment levels, reliability, distribution system, public information procedures, and insurance coverage for a reuse project (Richardson, 1985).

5.3.3 State Franchise Law

A franchise is generally an exclusive right or license granted to a private individual or corporation to market goods or services in a particular area. Franchises are often granted when economies-of-scale and capital investment levels disfavor competition, such as in the instance of electric or water utilities. A problem that could apply to water reuse would be where reuse conflicts with a service that is exclusively the right of some other entity. Some other water-supplying entity might have the exclusive right to sell water in its service area. A municipal wastewater treatment agency attempting to institute reuse in an area receiving water service from a private water supply corporation could find itself in direct conflict with the corporation's right to be the exclusive provider of water.

The scope of such franchise rights, like that of water rights, varies from state to state. In each case, the potential infringement upon franchise rights should be carefully considered.

5.3.4 *State Case Law*

Case law should be assessed carefully where potential conflicts might exist or where previous conflicts have been resolved in the courts.

5.4 Local Legal Issues

Steps to minimize liability in implementing a reuse program include developing an informed awareness of issues that can accompany use of reclaimed water; selecting highly qualified design and operations personnel; monitoring reclaimed water quality, including monitoring of known hazardous substances not yet regulated by state statute; and developing and maintaining contingency plans and emergency backup procedures to assure system reliability (Zeitzew, 1979).

5.4.1 *Reuse Ordinance*

It may be necessary to develop a clear and concise municipal ordinance to address issues and requirements of the reuse system. In addition to delegating which municipal entity is responsible for the reuse program, at a minimum a reuse ordinance should contain each of the items summarized below. However, in each case, the adequacy of state enabling authority must be considered as well.

- ❑ Requirements for Connection - Define when property owners will be required to connect to the reuse system. Examples include the requirement for turf grass facilities (parks, golf courses, cemeteries, schools, etc.) to connect when the system becomes available, requirements for new developments to connect prior to being inhabited, and requirements for all properties to connect as the reuse system becomes available.

- ❑ Cross-Connection Control Measures - Clearly state the protective measures to be taken to avoid cross connection of the reclaimed water lines with potable water lines in the reuse ordinance. This may include the requirement for backflow preventers and use of color-coded pipes for the reclaimed and potable water.

- ❑ Inspection Policy - System inspection procedures and requirements should state which department(s) is responsible for inspection, under what conditions inspection may be required, and the consequences if users refuse to allow inspection (i.e., disconnection of service). Inspection is recommended to determine if there are any illegal hook-ups, violations of ordinances, or cross connections.

- ❑ Irrigation System Limitations - The reuse ordinance might specify the type of irrigation system to be used in order to receive reclaimed water. This could include the requirement that the system be a permanent below ground system, or that a single hose connection to a hose bibb be allowed for hand watering. It might also include limitations to the size and type of pipe to be used in the irrigation systems. The requirements for a timer for the irrigation system may also be included.

- ❑ Penalties for Violation of the Ordinance - In the event the ordinance is violated, penalties should be specified at a level adequate to deter violation. These may include disconnection of service and a fee for reconnection. Fines and jail time are provided for in some ordinances (Mesa, Arizona and Brevard County, Florida) for major infractions.

- ❑ Fees and Rates for Receiving Reclaimed Water - Any fees charged for reclaimed water connection and the rates associated with service should be addressed in an ordinance. Reclaimed water rate ordinances are generally separate from those regulations that control reclaimed water use. Chapter 6 provides a discussion of the development of the financial aspects of water reuse fees and rates.

- ❑ System Reliability - In addition to the elements presented above, it is often helpful to establish the system reliability as part of a reclaimed water use ordinance. Is the supplier going to provide a level of service comparable to that of the potable system or will the service be "interruptible"? When reclaimed water is used for an essential service such as fire protection, a high degree of system reliability must be provided. However, if reclaimed water use is limited to irrigation, periodic shortages or service interruption may be tolerable. Finally, the supplier of reclaimed water may wish to retain the right in the ordinance to impose water use scheduling as a means of managing shortages or controlling peak system demands.

- ❑ Public Information - The ordinance may also contain requirements for public education about the reuse project. This educational program may include providing information on the hazards of reclaimed water, the requirements for service, the accepted uses, and the penalties for violation. In Cocoa Beach, Florida, the applicant for reclaimed water must be provided an informative brochure to explain public safety and reuse in accordance with their ordinance. A detailed discussion of public information programs is provided in Chapter 7.

- Allowable Operating Structures - A determination of the best municipal organizations or departments to operate a reclamation and reuse program should be made in the development phases of the reuse project. For example, even if the municipal wastewater treatment service is permitted by law to distribute reclaimed water, it might make more sense to organize a reuse system under the water supply agency or under a regional authority (assuming that such an authority can be established under the law). A regional authority could operate more effectively across municipal boundaries and could obtain distinct economies-of-scale in operation and financing (Okun, 1977). To form an authority, it might be possible to establish a new public entity under existing legislation, or it might be necessary to enact new legislation.

- Financing Power - Any financing constraints that apply to the reuse system should be identified. For example: Can it assume bonded indebtedness? What kinds of debt? To what limits? How must the debt be retired? How must the costs of operating the water reclamation facility be recovered? What restrictions are there on cost-recovery methods? What kinds of accounting practices are imposed upon the entity?

- Contracting Power - Finally, a determination should be made of any constraints on how and with whom services can be contracted. For example, can contracts be formed with other municipalities? Could contracts be formed under another operating structure? Is city council approval needed or can the controlling entity operate independently of the municipal governments?

5.4.2 User Agreements

Not all reclaimed water systems require development of a reclaimed water ordinance. This is particularly true where only a limited number of users are to receive reclaimed water. For example, it is not uncommon for a supplier of reclaimed water to a small number of large users, such as agriculture or industrial customers, to forgo development of a reuse ordinance and rely instead on user agreements. In water intensive activities, a single user may well encumber all of the water available from a given reclaimed water source. Where such conditions exist, it is often more appropriate to deal with the customer through the negotiation of a reclaimed water user agreement. However, all of the items discussed in Section 5.4.1 (Reuse Ordinance) should be addressed in developing user agreements.

5.4.3 Institutional Structures

Many different types of institutional structures can be utilized for implementation of a water reuse project. For example, the Irvine Ranch Water District in California is an independent, self-financing entity. Under its original enabling legislation, it was strictly a water supply entity, but in 1965, state law was amended to assign it sanitation responsibilities within its service area. Thus, the district is in a good position to deal directly, as one entity, with conventional potable water and nonpotable water services.

Where separate institutional entities exist for water supply and wastewater service, the water supply entity has to deal first with the wastewater service before procuring reclaimed water users. In Contra Costa County, California, this was the case. A reuse project was established as a joint venture between the county's Water and Sanitation Districts. The water district purchases reclaimed water from the Sanitation District, and then treats and redistributes it to its water customers (Weddle *et al.*, 1973).

In the Los Angeles area, the institutional arrangement is more complex. The Pomona Water Reclamation Plant is operated by the Sanitation Districts of Los Angeles County, which sells reclaimed water to several purveyors, including the municipal Pomona Water Department, who then redistribute it to a number of users.

In general, the simpler the structure the better. The Irvine Ranch Water District approach is preferred, even though it required new legislation to establish its combined responsibility. In Contra Costa, hurdles posed by having two water and wastewater agencies were overcome contractually. Even in this case, new legislation was required. Each district's board of directors adopted resolutions indicating their intent to work jointly (Weddle *et al.*, 1973).

5.5 Institutional Inventory and Assessment

Institutions that should be contacted can include federal and state regulatory agencies, administrative and operating organizations, and general units of local government. It is necessary to develop a thorough understanding of which organizations and institutions are concerned with which aspects of the proposed reuse system. This understanding should include an inventory of required permits and agency review requirements prior to construction and operation of the reuse system, economic arrangements, subsidies, ground and surface water management policies, and administrative guidelines and issues.

If the costs of a project are to be subsidized, the total cost of the project will not be paid by the users. In areas where subsidies for water are common, there tends to be a lack of willingness to change the water system and to accept new sources (i.e., reuse). Because some users receive water at a discounted rate, any change which may increase the cost of the water or affect the subsidy is resisted. The economic encouragement for going to reuse in areas where water is subsidized may be decreased. Further discussion of funding benefits and subsidies is presented in Chapter 6.

The various departments and agencies within government can come into conflict over the proposed reuse system unless steps are taken early in the planning stages to find out who will be involved and to what level. Close internal coordination between departments and branches of local government will be required to ensure a successful reuse program. Obtaining the support of other departments will help to minimize delays caused by interdepartmental conflicts.

In addition to internal coordination, several outside institutions may be concerned with the proposed project. These include the health department, the water management district or water control board, and regulatory agencies. An example of multi-institutional coordination is the development of island-wide reuse guidelines for Hilton Head Island, South Carolina, by the Hilton Head Island Utility Committee. This committee consisted of members of the four local wastewater management entities. The guidelines are used to assist in the development and planning of the island to accommodate maximum usage of reclaimed water (Hirsekorn and Ellison, 1987).

Often, different departments within one agency can come into conflict over the direction of the agency. For example, in 1982, the Kesterson National Wildlife Refuge reported high selenium concentrations and deformed birds. This required the coordination of two departments within the United States Department of the Interior, the Bureau of Reclamation, and the Fish and Wildlife Service. These agencies had different direction. The Bureau of Reclamation was assigned the role of promoting settlement in the West by providing irrigation water. The Fish and Wildlife Service was to protect and maintain migratory bird populations. Initially, these two goals appeared to be in conflict. Through careful coordination between the departments, a solution was reached.

One of the best ways to gain the support of the other agencies is to make sure that they are involved from the beginning of the project and are kept informed as the project progresses. Any potential conflicts between these agencies should be identified as soon as possible. Clarification on which direction the overall agency should follow will need to be determined. By doing this in the planning stages of the reuse project, delays in implementation may be avoided.

There is, on occasion, an overlap of jurisdiction of some agencies. For example, it is possible for one agency to control the water in the upper reaches of a stream and a separate agency to control the water in the lower reaches. Unless these agencies can work together, there may be little hope of a successful project which impacts both.

5.6 Guidelines for Implementation

The following institutional guidelines can assist with the planning and implementation of a reuse system:

- ❑ Maintain Contact with the Agencies - Throughout development of the reuse project, contact should be maintained with the federal, state and local agencies involved. The intent is to promote such agencies' understanding of the project and to keep them informed of impending permit reviews or the enactment of new legislation. Continued contact and an open flow of information can keep the process from becoming an obstacle.

- ❑ Develop a Realistic Schedule - A comprehensive implementation schedule, should be developed at the outset and periodically revised, including lengthy review procedures, the time needed to enact any required legislation, and the timing of any public hearing that must be held. It is especially important to identify any permit review procedures and whether they can occur concurrently or must occur consecutively, and in what order.

- ❑ Assess Cash Flow Needs - An accurate assessment of cash flow needs is required to anticipate funding requirements, formulate contract provisions, and devise cost-recovery techniques.

- Consider Institutional Structure - Consider in detail the alternative institutional structure for operation of the water reuse system and evaluate the advantages and disadvantages of each. Identify as early as possible any legislative changes that might be required to create the necessary institutions and the level of government at which the legislation must be enacted.

- Prepare Contracts - Formal contracts are usually required to establish usage of the reuse system and to govern its operation. Provisions relating to the quality and quantity of the reclaimed water are essential, and may include a range in which each can fluctuate, and the remedies, should the quantity or quality go outside that range. Responsibility for any storage facilities and/or supplemental sources of water should be defined. There must be an explicit statement as to how the reuser will pay for the recycled water, and to what extent, and for what reasons he is responsible and liable for costs. Both parties must be protected explicitly in case either party defaults, either by bankruptcy or by the inability to comply with the commitments of the agreement. The monitoring responsibility must be specified, especially if the reclaimed water is being utilized for irrigation purposes and a monitoring program is required.

  Specific compliance with environmental regulations must be assigned to each party. For example, if the crops grown are not to be utilized for human consumption, it is appropriate to assign the responsibility for compliance with such regulations to the user.

  Finally, the ownership and maintenance of the facilities must be stated, particularly for the transmission and distribution facilities of the reclaimed water. The point at which the water conveyance facilities become the property and responsibility of the user must be explicitly stated. In the case where the user is a private enterprise, that statement should be reasonably straightforward. However, in the case where the user is another municipal entity, it is especially important that each party knows its responsibility in the operations and maintenance of the facilities.

5.7 Case Studies

A summary of two state court cases, one decided in 1979 by the Supreme Court of Wyoming and the other decided in 1989 by the Supreme Court of Arizona, are provided to illustrate the legal issues that can arise regarding water reuse systems and how courts in these states resolved those issues. While the Wyoming case does not deal directly with a proposed reuse scheme, it does address, both in terms of majority and dissenting opinions, various issues that can arise when major reuse programs are considered.

It should be noted, however, that the rules, policies and guidelines enunciated by these courts apply only to the parties and factual circumstances of each case, and the outcome of similar disputes may be different depending on the state and the current statutes and case law in effect.

5.7.1 1979 Wyoming Case: Thayer vs. City of Rawlins, Wyoming (594 p.2d 951)

Faced with more stringent federal and state standards for the treatment of its municipal wastewater, the City of Rawlins, Wyoming proposed to construct a new treatment facility and to change the location of its existing effluent discharge point in Sugar Creek. Downstream of the existing discharge point, several parties since 1914 had been diverting the waters of Sugar Creek (comprised entirely of the city's effluent) for irrigation, stock water, and other purposes. Such diversions were made pursuant to certificates of appropriation issued by the State of Wyoming, and the holders of such certificates sought compensation from the city for the loss of water caused by the proposed change of location in the city's effluent discharge to a point further downstream and beyond the points of diversion authorized by the certificates.

The court by majority opinion held that since the waters of Sugar Creek were not "natural waters" and since a priority relates only to the natural supply of the stream at the time of appropriation, the downstream users had no priority of use and no right to compensation for the loss of such waters. The determination that such waters were not "natural waters" was based on the fact that the city, via its water supply system, imported these waters from basins outside the natural drainage basin of Sugar Creek. The majority opinion cited a 1925 Wyoming case (Wyoming Hereford Ranch v. Hammond Packing Company, 33 Wyo. 14, 236 P. 764) in support of a policy to the effect that a municipality should be able to utilize a means of sewage disposal that would completely consume water and to change the location of its effluent disposal point without any consideration of the demands of water users who might benefit from its disposal by other means. The court also held that the State Engineer and Board of Control had no jurisdiction over this dispute.

A strong dissenting opinion indicated that this dispute should be decided by the State Engineer and Board of Control on the basis of the concept of beneficial use, and should be subject to court review only after such expertise is applied. The dissent would not utilize a distinction between "natural waters" and "imported waters" as a basis for a decision, but would have the State Engineer and Board of Control apply the concept of beneficial use to determine whether the city would be required to compensate or otherwise respect the appropriation rights of downstream users of its wastewater effluent.

5.7.2 1989 Arizona Case Study: Arizona Public Service vs. Long (773 p.2d 988)

Several cities in the Phoenix metropolitan area, including the City of Phoenix, contracted in 1973 to sell reclaimed water to a group of electric utilities, including the Arizona Public Service Company, for use as cooling water for the Palo Verde nuclear power project. Pursuant to the contract, the utilities spent some $290 million to construct a 50-mile pipeline and a facility to further treat the effluent, and were utilizing approximately 60 mgd of effluent. Several parties brought suit seeking a court determination that the contract was invalid on various grounds. The Arizona Department of Water Resources filed an amicus brief siding with the parties seeking to have the contract ruled invalid.

The parties opposing the contract included a major real estate developer in the Phoenix area and owners of ranches located downstream of the effluent discharge point. The real estate developer argued that the contract was in violation of statutory restrictions on the transportation of groundwater contained in the Arizona Groundwater Code, and the ranch owners argued that the cities had no right to sell unconsumed effluent because surface waters belong to the public and unused surface waters must be returned to the river bed. The cities and utilities, on the other hand, argued that reclaimed water is water that has essentially lost its character as either ground or surface water and becomes the property of the entity which has expended funds to create it.

In deciding this case in 1989, the Supreme Court of Arizona, for the most part, rejected the basic arguments of all the parties. The Court's majority opinion validated the contract, holding that the cities can put the reclaimed water to any reasonable use they see fit. The Court determined that effluent is subject to appropriation by downstream users, but that the cities were not obligated to continue to discharge effluent to satisfy the needs of such appropriators. It was pointed out that if scientific and technical advances enabled the utilization of water to eliminate such waste, then the appropriators had no reason to complain.

In reaching this decision, reclaimed water was determined not to be subject to regulation under Arizona's Surface Water Code or Groundwater Code, and the available body of case law dealing with rights to and the use of effluent was found lacking. The Court indicated that a case-by-case approach to the questions of water use in a desert state was unsatisfactory and urged the state legislature to enact statutes in the area.

A dissenting opinion concluded that the sale of the groundwater portion of the reclaimed water is not regulated by the Arizona Groundwater Code and that the concept of beneficial use under the Arizona Surface Water Code should be applied to the surface water component. In this regard, although the sale of reclaimed water may be embodied within the concept of full beneficial use, the cities may be precluded from entering into the contract for the sale of reclaimed water on the grounds that the discharge constituted an abandonment of their right to increase consumptive use under applicable provisions of the Surface Water Code.

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CHAPTER 6

Funding Alternatives for Water Reuse Systems

In general, implementation of reuse facilities requires a substantial capital expense. Residential irrigation system reuse capital costs can range from $1,200 and $2,000 per single family home. Unless agricultural and industrial reuse sites, public parks, or golf courses are very close to the source of reclaimed water, new transmission facilities may be required. Also, capital improvements at the wastewater treatment facility are normally required.

In addition to capital costs associated with reclaimed water facilities, there are also additional operation, maintenance, and replacement (OM&R) and administration costs. Such costs include the repair and maintenance or replacement of the facilities, power for pumping, monitoring the water quality, as well as customer billing and administration. These costs are typically calculated into a reclaimed water rate, expressed either as a gallonage charge or fixed monthly fee. Consequently, multiple financial alternatives should be investigated in order to fund a reclaimed water system.

6.1 Decision Making Tools

As a means of clarifying the issues to be discussed, some general terms are defined below:

- Cost-effectiveness - the analysis of alternatives using an effectiveness scale as a measurement concept. U.S. EPA formulated "Cost-Effectiveness Analysis Guidelines" as part of its Federal Water Pollution Control Act (40 CFR Part 35, Subpart E, Appendix A). This technique requires the establishment of a single base criterion for evaluation such as annual water production of a specific quality expressed as an increase in supply or decrease in demand. Alternatives are ranked according to their ability to produce the same result. The alternatives can include such factors as their impact on quality of life, environmental effects, etc. which are not factored into a cost/benefit analysis.

- Cost/Benefit - is the relationship between the cost of resources and the benefits expected to be realized using a discounted cash-flow technique. Non-monetary issues are not factored into these calculations.

- Financial Feasibility - is the ability to finance both the capital costs and operating/maintenance costs through locally raised funds. Examples of revenue sources include user fees, bonds, taxes, grants, and general utility operating revenues.

In the context of the above definitions, the first analysis to be performed would be a cost-effectiveness analysis. In other words, given the alternative of providing additional water from fresh water sources versus reclaimed water, what are the relevant costs and benefits?

Such benefits which can be factored into the equation are:

- Environmental
  - the reduction of nutrient-rich effluent discharges to surface waters.
  - the conservation of fresh water supplies and reduction of salt-water intrusion
- Economic
  - delay in or avoidance of expansion of water supply and treatment facilities
  - increased levels of water and wastewater treatment delayed or eliminated (e.g., reverse osmosis treatment of water supply avoided or advanced wastewater treatment needs for wastewater reduced).

Examples of shared benefit are as follows: if a benefit is received by water customers (deferred rate increase) from a delay in expanding water supply, a portion of reclaimed water costs could be shared by existing and future water customers. A similar analysis can also be made for wastewater customers that benefit from a delay or elimination of AWT construction associated with reduced surface water discharges.

The cost/benefit analyses are conducted once feasible alternatives are selected. The emphasis of these analyses is on defining the economic impact of the project on various classes of users, i.e., industrial, commercial, residential, agricultural.

The importance of this step is that it relates the marketability of reuse in comparison to alternative sources, based on the end use. To elaborate, given the cost of supplying reclaimed water versus fresh water for urban use, what is the relationship of water demand to price, given both abundant and scarce resources? The present worth value of the benefits are compared to determine whether the project is economically justified and/or feasible.

Primarily, financial feasibility is addressed, or simply, can sufficient financial resources be developed to construct and operate the required reclamation facilities? Specific financial resources available will be explained in the following subsections.

6.2 Externally Generated Funding Alternatives

While not impossible, it is difficult to create a totally self-supporting reuse program financed wholly by reclaimed water user fees. To satisfy the capital requirements for implementation of a reuse program, the majority of the construction and related capital costs are generally financed through long-term water and wastewater revenue bonds. Supplemental funds may be provided by grants, developer contributions, etc. The various externally generated capital funding sources are described in further detail, with the following alternatives discussed:

- Municipal Tax-Exempt Bonds - The total capital cost of construction activities for the reuse project could be financed from the sale of long-term (20-30 yr) bonds.
- Grants and State Revolving Fund Programs - Capital needs could be funded partially through state or local grants programs or through state revolving fund loans, particularly those programs designed specifically to support reuse.
- Capital Contribution - At times, there are special agreements reached with developers or industrial users, requiring the contribution of either assets or money to offset the costs of a particular project.

6.2.1 Municipal Tax-Exempt Bonds

A major source of capital financing for a municipality is to assume debt—that is, to borrow money by selling municipal bonds. With many water reclamation projects, local community support will be required to finance the project. Although revenue bond financing is a means of matching the revenue stream from the use of reclaimed facilities with the costs of the debt used for construction, voter approval is not usually required. However, voter approval may be required for general obligation bonds. Among the types of bonds commonly used for financing public works projects are:

- General Obligation Bonds - Repaid through collected general property taxes or service charge revenues; and generally requires a referendum vote.
- Special Assessment Bonds - Repaid from the receipts of special benefit assessments to properties (and in most cases, backed by property liens if not paid by property owners).
- Revenue Bonds - Repaid through user fees and service charges derived from operating reuse facilities (useful in regional or sub-regional projects because revenues can be collected from outside the geographical limits of the borrower).
- Short-Term Notes - Usually repaid through general obligation or revenue bonds.

A municipal finance director and/or bond advisor can describe the requirements to justify the technical and economic feasibility of the reuse project. The municipality must substantiate projections of the required capital outlay, of the anticipated OM&R costs, of the revenue-generating activities (i.e., the user charge system, etc.) and of the "coverage" anticipated—that is, the extent to which anticipated revenues will more than cover the anticipated capital and operations, maintenance, and replacement costs.

6.2.2 Grant and State Revolving Fund Programs

Where available, grant programs are an attractive source to provide resources to fund reuse systems, provided that the proposed system meets grant eligibility requirements. Some funding agencies have an increasingly active role in facilitating water reuse projects. In addition, many funding agencies are receiving a clear legislative and executive mandate to encourage water reuse.

To be financially successful over time, a reuse program, however, must be able to "pay for itself." It is true that state-supported subsidies underwrite substantial portions of the capital improvements necessary in a reuse project—and grant funds can also help a program to establish itself in early years of operation. But grant funds should not be relied upon unless their availability is assured. Most federal and state programs require that funds be appropriated each year by Congress or the state legislature, and, in many instances, the amounts appropriated are far less than those needed to assist all eligible projects. For the same reason, once the project is underway, the program should strive to achieve self-sufficiency as quickly as possible—meeting OM&R costs and debt service on the local share of capital costs by generating an adequate stream of revenues through local budget set-asides, tax levies, special assessments and user charges.

6.2.2.1 State Revolving Fund

The State Revolving Fund (SRF) is a financial assistance program established and managed by the states under general EPA guidance and regulations and funded jointly by the federal government (80 percent) and state matching money (20 percent). It is designed to provide financial assistance to local agencies to construct water pollution control facilities and to implement non-point source, groundwater, and estuary management activities.

Under SRF, states make low-interest loans to local agencies. Interest rates are set by the states and must be below current market rates and may be as low as 0 percent. The amount of such loans may be up to 100 percent of the cost of eligible facilities. Loan repayments must begin within 1 year after completion of the facility and must be completely amortized in 20 years. Repayments are deposited back into the SRF to be loaned to other agencies. Cash balance in the SRF may be invested to earn interest which must accrue to the SRF.

States may establish eligibility criteria within the broad limits of the Clean Water Act. Basic eligibility includes secondary and AWT treatment plants, pump stations and force mains needed to achieve and maintain NPDES permit limits. States may also allow for eligibility, collection sewers, combined sewer overflow correction, storm water facilities and purchase of land for such facilities (only in some cases), combined sewer overflow correction, stormwater facilities, and purchase of land that is a functional part of the treatment process.

States select projects for funding based on a priority system, which is developed annually and must be subjected to public review. Such priority systems are typically structured to achieve the policy goals of the state and may range from "readiness to proceed" to very specific water quality or geographic area objectives.

Each state was allowed to write its own regulations, with different objectives being met. Many states provide assistance based on assessing the community's economic health, with poorer areas being more heavily subsidized with lower interest loans (e.g., Virginia). Other states target specific treatment objectives, such as Florida, with pollution abatement a priority. The availability of state revolving fund loans for reuse projects varies from state to state, with the priority list management specific to each state.

Further information on the SRF program is available from each state's water pollution control agency.

6.2.2.2 Federal Policy

The language of the Clean Water Act of 1977, and its subsequent amendments, supports water reuse projects through the following provisions:

- Section 201 of PL 92-500 was amended to ensure that municipalities are eligible for "201" funding only if they have "fully studied and evaluated" techniques for "reclaiming and reuse of water."
- Section 214 was added, which stipulates that the EPA administrator "shall develop and operate a continuing program of public information and education on recycling and reuse of wastewater. . ."
- Section 313, which describes pollution control activities at federal facilities, was amended to ensure that WWTFs will utilize "recycle and reuse techniques: if estimated life-cycle costs for such techniques are within 15 percent of the most cost-effective alternative."

6.2.2.3 Other Federal Sources

There are at least four other sources of potential federal support. First there is the Farmers Home Administration (FmHA) of the U.S. Department of Agriculture (USDA). Under the FmHA programs, grants and loans are available to public agencies and non-profit corporations which serve areas with populations under 10,000. The amount of the grant or loan is restricted by that amount necessary to lower the user costs to a reasonable rate, based on the median family income of the community. In addition, the sum of the FmHA grant and other state and federal grants cannot exceed 50 percent of the project costs. Thus, projects funded by Clean Water loans will not be eligible under FmHA program.

The U.S. Small Business Administration (SBA) provides low interest loans to small businesses for wastewater control equipment required by regulatory agencies. The funds can be used for pretreatment of industrial waste to reduce toxic and saline constituents in reclaimed water. For a project to be eligible for a loan from the SBA, the EPA must be able to certify that the project is required to comply with either federal or state water pollution control requirements and that other funds are not available.

Finally, the Office of Water Research and Technology (OWRT) of the Department of the Interior will provide research and development funds for water reclamation projects, particularly for demonstration projects, that meet OWRT-identified priority needs.

Information of specific source possibilities can be found in the *Catalog of Federal and Domestic Assistance,* prepared by the Federal Office of Management and Budget and available in federal depository libraries. It is the most comprehensive compilation of the types and sources of funding available.

6.2.2.4 State Grant Support

State support is generally available for wastewater treatment facilities, water reclamation facilities, conveyance facilities, and, under certain conditions, for onsite distribution systems. Obviously, a prime source of funding is the state support that usually accompanies SRF loans.

A comprehensive water reuse study in California recognized funding as the primary constraint in implementing new water reuse projects (State of California, 1991). The study recommended that large water agencies that provide regional service should financially support the development of local water reclamation projects. Water developed through local reclamation projects displaces a demand for potable water which can be used elsewhere in the service area, thereby providing a regional benefit. For instance, the Metropolitan Water District of Southern California through its Local Project Program provides financial assistance to its member public agencies for development of water reuse projects which reduce demand on Metropolitan's imported water supplies.

6.2.3 Capital Contributions

In certain circumstances where reclaimed water is to be used for a specific purpose, such as cooling water, it may be possible to obtain the capital financing for new transmission facilities directly from one or more major users that benefit from the available reclaimed water supply.

Another example of capital contribution for a major transmission line construction may be to have a major transmission line for reuse constructed by a developer and contributed (transfer ownership) to the utility for operation and maintenance. A residential housing developer, golf course, or industrial user may provide the pipeline, financing for the pipeline, or provide for a pro-rata share of construction costs for a specific pipeline.

6.3 Internally Generated Funding Alternatives

While the preceeding funding alternatives describe the means of generating construction capital, there is also a need to provide financing for OM&R costs as well as repay funds borrowed. Examples of various internally generated funding sources are highlighted with details provided in following sections.

In most cases, a combination of several funding sources will be used to cover capital and OM&R costs. The following alternatives may exist for funding water reuse programs.

- Operating budget and cash reserves of the utility
- Local property taxes and existing water and wastewater user charges
- Special assessments or special tax districts
- Connection fees
- Reuse user charges

6.3.1 Operating Budget and Cash Reserves

Activities associated with the planning and possibly preliminary design of reuse facilities could be funded out of an existing wastewater utility or department operating budget. (In some instances, a water supply agency seeking to expand its water resources would find it appropriate to apply a portion of its operating funds in a similar way). In addition, available cash balances in certain reserve accounts may possibly be utilized.

It may be appropriate, for example, to utilize funds from the operating budget for planning activities or business costs associated with assessing the reuse opportunity.

Furthermore, if cash reserves are accruing for unspecified future capital projects, those funds could be used or a portion of the operating revenues can be set aside in a cash reserve for future needs. The obvious advantage of using this alternative source of funding is that the utility board or governing body of the wastewater treatment department or utility can act on its own initiative to allocate the necessary resources.

These sources are especially practical when relatively limited expenditures are anticipated to implement or initiate the reuse program, or when the reuse project will provide a general benefit to the entire community (as represented by the present customers of the utility). In addition, utilizing such resources is practical when the reclaimed water will be distributed at little or no cost to the users, and therefore will generate no future stream of revenues to repay the cost of the project. While it is ideal to fully recover all direct costs of each utility service from customers, it may not be practical during early phases of a reuse system implementation.

6.3.2 Property Taxes and Existing User Charges

If the resources available in the operating budget or the cash reserves are not sufficient to cover the necessary system OM&R activities and capital financing debt, then another source of funds to consider is revenues generated by increasing existing levies or charges. If some utility costs are currently funded with property taxes, levies could be increased and the new revenues designated for expenses associated with the reuse project. Similarly, the user charge currently paid for water and sewer services could be increased. As with the use of the operating budget or cash reserves, the use of property taxes or user charges may be desirable if the expenditures for the project are not anticipated to be sizable or if a general benefit accrues to the entire community.

Ad valorem property taxes, unlike user charges, raise funds on the basis of assessed value of all taxable property, including residential, commercial and industrial. Property value can be an appropriate means of allocating the costs of the improvements of service if there is a "general good" to the community. It is also a useful means of allocating the cost of debt service for a project in which there is general good to the community and in which the specific OM&R costs are allocated to the direct beneficiaries. The *ad valorem* allocation of the costs might be appropriate for such reuse applications as:

- Irrigation of municipal landscaping,
- Fire protection,
- Water for flushing sewers,
- Groundwater recharge for saltwater intrusion barriers, and
- Parks and recreational facility irrigation.

All such projects have benefits, either to the residents of the municipality in general, or to those who can be isolated in an identifiable special district.

Similar use can be made with resources generated by increasing any existing user charges. However, to do so equitably, benefits of the proposed project should primarily accrue to those presently utilizing the services of the water or wastewater utility. This would be the case, for example, when water reuse precludes the need to develop costly advanced treatment facilities or a new water supply source.

Contributions from the water and wastewater systems may be warranted whenever there is a reduction in the average day or peak day water demand or when the reuse system serves as a means of effluent disposal for the wastewater system. The City of St. Petersburg, Florida, for example, provides as much as 50 percent of the urban reuse system operations costs from water and wastewater system funds. The significant reduction in potable water demand achieved through water reuse has allowed the city to postpone expansion of its water treatment plant.

6.3.3 Special Assessments or Special Tax Districts

When a reuse program is designed to be a self-supporting enterprise system, independent of both the existing water and wastewater utility systems, it may be appropriate to develop a special tax or assessment district to recover capital costs directly from the benefited properties. The advantage of this cost recovery mechanism is that it can be tailored to collect the costs appropriate to the benefits received. An example of an area using special assessments to fund dual water piping for fire protection and irrigation water is the City of Cape Coral, Florida, with an approximate cost of $1,600 per single family residence with financing over 8 years at 8 percent annual interest.

Special assessments may be based on lot front footage, lot square footage, or estimated gallon use relative to specific customer types. This revenue alternative is especially relevant if the existing debt for water and wastewater precludes the ability to support a reuse program, or if the area to be served is an independent service area with no jurisdictional control over the water or wastewater systems.

6.3.4 *Connection Fees*

Connection fees or impact fees are a means of collecting the costs of constructing an element of infrastructure, such as water, wastewater, or reuse facilities, from those new customers benefiting from the service. Connection fees collected may be used to generate construction capital or to repay borrowed funds. Frequently these fees are used to generate an equitable basis for cost recovery between customers connecting to the system in the early years of a program and those connecting in the later years. The carrying costs (interest and expense) are generally not fully recovered through the connection fee, although annual increases above a base cost do provide equity between groups connecting in the early years and those in later years.

Connection fees for water reuse systems are implemented at the discretion of the governing body. However, the requirement of a connection fee to be paid upon application for service prior to construction can provide a strong indication of public willingness to participate in the reuse program. Incentive programs can be implemented in conjunction with connection fees by waiving the fee for those users who make an early commitment to connect to the reclaimed water system (e.g., for the first 90 days after construction completion) and collecting the fee from later connections.

6.3.5 *Reclaimed Water User Charges*

A user charge may be imposed on customers receiving the reclaimed water. User charges would be utilized to generate a stream of revenues with which to defray the OM&R costs of the reuse facility and the debt service of any bonds issued.

With many current reuse applications, reclaimed water user charges tend to incorporate fixed fees that do not correlate to the actual cost of delivering the water. Historically, effluent had been thought of as something to be disposed of, not as a valuable product to be sold. Consequently, the fees associated with reclaimed water have not generally reflected actual reclaimed water usage or the full cost of the service. More recently, however, water reuse programs are shifting toward charges based on metered flow.

In a reclaimed water user charge system, the intent is to allocate the cost of providing reuse services to the recipient. With a user charge system, it is implicit both that there is a select and identifiable group of beneficiaries to which the costs of treatment and distribution can be allocated, and that the public in general is not the beneficiary.

Determining an equitable rate policy requires consideration of the different service needs of individual residential users as compared to other users with large irrigable areas, such as golf courses and green space areas. These "large" users may receive reclaimed water into onsite storage facilities and subsequently repump the water into the irrigation system. This enables the municipality to deliver the reclaimed water, independent of daily peak demands, using low-pressure pumps, rather than providing direct service from the distribution system during peak demand at the higher pressures required to drive a golf course irrigation system. Because of this flexibility in delivery and low-pressure requirements, a lower user rate can be justified for large users than for residential customers, who require high-pressure delivery on demand. Another consideration for large users is keeping reclaimed water rates competitive with any alternative sources of water, such as groundwater.

The residential customer categories are generally two types: single-family and multi-family. Some multi-family customers may be treated as large users if they provide onsite storage and accept reclaimed water at low pressures. However, if the reclaimed water is delivered to the multi-family customer at high pressures directly into the irrigation system, a residential reuse rate may apply.

The degree of participation from other sources, such as the general fund and other utility funds must be considered in determining the balance of the funding that must come from reuse rates. Again, residential user fees must be set to make water reuse an attractive option to potable water or groundwater. Although reclaimed water must be priced below potable water to encourage its use, reuse rates may also be set to discourage indiscriminate use by instituting volume (per gallon) charges rather than a flat fee.

There are two prime means of allocating costs that are to be incorporated into a user charge: the proportionate share cost basis and the incremental cost basis. These two methods will be discussed in more detail in the following section.

6.4 Incremental Versus Proportionate Share Costs

6.4.1 *Incremental Cost Basis*

The incremental cost basis allocates only the marginal costs of providing service. This system can be used if the community feels that the marginal user of reclaimed water is performing a social good by conserving potable water, and so should be allocated only the additional increment of cost of the service. However, if the total cost savings realized by reuse are being enjoyed only by the marginal user, then in effect the rest of the community is subsidizing the service.

6.4.2 Proportionate Share Cost Basis

Under the commonly used proportionate share basis, the total costs of the facilities are shared by the parties in proportion to usage of the facilities. In apportioning the costs, consideration must be given to the quantity and quality of the water, the reserve capacity that must be maintained, and the use of any joint facilities, particularly means of conveyance. In determining the eventual cost of reuse to the customer base, the appropriation of costs between wastewater users, potable water users, and reclaimed water users must be examined. The appropriation of costs between users also must consider the willingness of the local community to subsidize a reuse program.

A proportional allocation of costs can be reflected in the following equations:

Total $ wastewater service =	$ wastewater treatment to permitted disposal standards + $ effluent disposal + $ transmission + $ collection.
Total $ potable water service =	$ water treatment + $ water supply + $ transmission + $ distribution.
Total $ reclaimed water service =	[$ reclaimed water treatment - $ treatment to meet permitted disposal standards] + $ additional transmission + $ additional distribution

The above equations illustrate an example of distributing the full costs of each service to the appropriate system and users. The first equation distributes only the cost of treating wastewater to currently required disposal standards, with any additional costs for higher levels of treatment, such as filtration, coagulation, or disinfection, appropriated to the cost of reclaimed water service. In the event that the cost of wastewater treatment is lowered by the reuse alternative because current effluent disposal standards are more stringent than those required for the reuse system, the credit accrues to the total cost of reclaimed water service. This could occur, for example, if treatment for nutrient removal had been required for a surface water discharge but would not be necessary for agricultural reuse.

It has been noted that because reclaimed water is a different product from potable water, with restrictions on its use, it may be considered a separate, lower valued class of water and priced below potable water (Ferry, 1984). Thus, it may be important that the user charges for reuse be below or at least competitive with those for potable water service. However, often the current costs of constructing reuse facilities cannot compete with the historical costs of an existing potable water system. One means of creating a more equitable basis for comparison is to associate new costs of potable water supplies to the current costs of potable water, as well as any more costly treatment methods or changes in water treatment requirements that may be required to meet current regulations. In fact, when creating reuse user fees, it may be imperative to deduct incremental potable water costs from those charged for reuse because reuse is allowing the deferral or elimination of developing new potable water supplies or treatment facilities.

To promote certain objectives, local communities may desire to alter the manner of cost distribution. For example, to encourage reuse for pollution abatement by eliminating a surface water discharge, the capital costs of all wastewater treatment, transmission, and distribution can be allocated to the wastewater service costs. To promote water conservation, elements of the incremental costs of potable water may be subtracted from the reuse costs to encourage use of reclaimed water.

For water reuse systems, the proportionate share basis of allocation may be most appropriate. The allocation should not be especially difficult, because the facilities required to support the reuse system should be readily identifiable. A rule of thumb might be to allocate to wastewater charges the costs of all treatment required for compliance with NPDES permits; all additional costs, the costs of reclamation and conveyance of reclaimed water, would be allocated to the water reuse user charge.

General administrative costs could also be allocated proportionately: all wastewater administration would be charged to the sewer use charge, and all additional administration to the water reuse user charge. In some cases, a lesser degree of wastewater treatment will be required as a result of water reuse. The effect may be to reduce the wastewater user charge. In this case, depending on local circumstances, the savings could be allocated to either or both the wastewater discharger and the reclaimed water user.

With more than one reclaimed water user on the system, different qualities of reclaimed water may have to be produced. If so, the user charge becomes somewhat more complicated to calculate, but it is really no different than calculating the charges for treating different qualities of wastewater for discharge. If, for example, reclaimed water is distributed for two different irrigation needs, one requiring higher quality water than the other, then the user fee calculation can be based on the cost of treatment to reach the quality required.

The estimation of the operating cost of a reclaimed water distribution system involves determination of those components of treatment, distribution, and OM&R that are directly attributable to the reclaimed water system. Direct operation costs involve advanced treatment facilities, distribution, additional water quality monitoring, inspection and monitoring staff. The costs saved from effluent disposal may be considered as a credit. Indirect costs include a percentage of administration, management and overhead. Another cost is replacement reserve, i.e. the reserve fund to pay for system replacement in the future. In fiscal year 1986/87 the Irvine Ranch Water District calculated this cost at 1.5 percent of the original facility cost (Young *et al.*, 1987). The study also found that the total cost of producing and distributing reclaimed water (including acquisition of additional source water) was $303/ac ft ($0.93/1,000 gal). The cost of potable water distribution was $449/ac ft ($1.38/1,000 gal). The savings of $146/ac ft ($0.45/1,000 gal) over the life cycle of the project was considered nearly enough to pay the debt service to pay for the dual distribution system (Young *et al.*, 1987).

6.5 Phasing and Participation Incentives

The financing program can be structured to construct the water reuse facilities in phases, with a percentage financial commitment required prior to implementation of a phase. This commitment assures the municipal decision makers that the project is indeed desired and ensures the financial stability to begin implementation. Incentives can be used to promote early connections or participation, such as a reduction or waiver of the assessment or connection fee for those connections to the system within a set time frame.

Adequate participation to support implementation can be determined by conducting an initial survey in a service area, followed up with a formal voted service agreement by each neighborhood. If the required percent of the residents in a given neighborhood agree to participate, facilities will be constructed in that area. Once this type of measure is taken, there is an underlying basis for either assessing pipeline costs or charging through a monthly fixed fee, because the ability to serve exists. The rate policy may also include a provision for assessments or charges for undeveloped properties within a neighborhood served by a reclaimed water system.

6.6 Sample Rates and Fees

6.6.1 Connection Fees

Connection fees may be collected to pay for capital construction costs of all or a portion of a reclaimed water distribution system. These fees can be used to pay off bonds or loans of capital costs associated with the project. Depending on the specific circumstances, a reclaimed water rate structure may not be designed to be financially self-sufficient. In such cases, system costs are supplemented through alternative sources and the end user costs are less than the true cost of providing the service. Connection charges to a dual distribution system are often based on the size of the reclaimed water system being served. For example, in Cocoa Beach, Florida, customers are charged a connection fee based on the size of the reclaimed water service line. The connection fees are $100, $180, and $360 for a 3/4-in (19-mm), 1-in (25-mm), and 1-1/2-in (38-mm) service line, respectively.

As an alternative to connection fees, a flat monthly rate can be charged to each user for a specified length of time until the capital costs associated with the system are paid off. This alternative is often preferred because of the high initial costs associated with connection fees.

6.6.2 User Fees

To offset the costs associated with OM&R for a dual distribution, a monthly user fee may be collected. The procedure for establishing rates for reclaimed water can be similar to the procedure for establishing potable water and sewer rates. If reclaimed water is metered, then user rates can be based upon the amount of reclaimed water used. If meters are not utilized, then a flat rate can be charged. The use of meters will tend to temper excessive use of reclaimed water since customers are generally charged on the amount of reclaimed water used. For example, studies conducted on the Denver area potable water system revealed that water use in metered homes averaged about 453 gal (1,715 L)/d, while water use in flat-rate homes average above 566 gal (2,140 L)/d. Therefore, metering can reduce total potable water use by approximately 20 percent on an annual basis. It is recommended that all connections to the reuse system be metered. Table 29 presents user fees for a number of existing urban reuse systems.

Table 29. User Fees for Existing Urban Reuse Systems

Location	User Fee
Altamonte Springs, FL	Detached single-family residential units: • Inside City - \$5/month user fee for one acre lot, + \$1.50/month user fee for each additional one-half acre, + \$3/month availability charge • Outside City - \$6.25/month for one acre lot, + \$1.875/month for each additional one-half acre, + \$3.75/ month availability charge Multi-family, office, commercial, public, industrial and warehouse facilities: • \$0.50/1,000 gal (inside city) • \$0.625/1,000 gal (outside city)
Aurora, CO	\$0.78/1,000 gal
Cape Coral, FL	Single-family residential & duplexex: • \$5.00/month Multi-family • \$0.004/sq ft of total property area Commercial, professional, industrial, agricultural, and worship users with 1" meter or less • \$0.0004/sq ft of total property area Commercial, professional, industrial, agricultural, and worship users with greater than 1" meter • \$Metered and billed at \$0.25/1,000 gal
Cocoa Beach, FL	\$6/month for one acre tract, + \$1.20/ month/each additional one-half acre
Colorado Springs, CO	\$0.60/1,000 gal
St. Petersburg, FL	Flat Rate Customers: \$10.36/month for one acre lot , + \$1.20/month/each additional one-half acre. Metered Customers: \$0.30/1,000 gal
Venice, FL	\$1.25/month (5/8" meter) to \$5.60/month (2" meter) + \$0.50/1,000 gal used

6.7 Case Studies

6.7.1 Financial Incentives for Water Reuse: Los Angeles County, California

The Sanitation Districts of Los Angeles County has an established reuse program, which supplies water for such purposes as public area landscape irrigation, irrigation of food crops, livestock watering, groundwater recharge, recreational lakes, oil-bearing zone injections, and industrial processing.

Public support for reclaimed water has increased due to recent drought conditions, with expansion of the system expected to increase from the 1989 usage figure of over 66 mgd (2,890 L/s) to over 100 mgd (4,380 L/s) by the Year 2000. In addition to the shortage of water, there have been financial incentives which have made reclaimed water an attractive alternative to potable water. Various agencies have contributed to the ability of reclaimed water costs to compete with those of potable water. The following incentives have assisted in creating a cost-effective reuse program:

- Sanitation districts provide the reclaimed water supply at approximately 20 percent of the O&M costs for the water reclamation facilities. In 1989, reclaimed water was supplied at \$15/ac-ft.
- The State Water Resources Control Board provides low interest loans for reuse projects.
- The Metropolitan Water District of Southern California provided a rebate of \$154/ac-ft in 1990 for local conservation projects, including reclaimed water.
- "Greenbelt" areas have been developed near the water reclamation plants, making distribution facilities more economical.
- Nutrient levels from reclaimed water have decreased the dependence on standard fertilizer treatments, with a cost savings to one golf course of \$10,000 per year.

In summary, the district has successfully implemented a reclaimed water program that is cost-effective (lower than potable water costs). The end user cost ranges from a high of 85 percent to a low of 44 percent of the potable cost.

6.7.2 *The Economics of Urban Reuse: Irvine Ranch Water District, California*

In the early 1970's, the Irvine Ranch Water District completed studies showing water reclamation and reuse as a cost-effective alternative to ocean discharge of wastewater effluent. This finding was based on results indicating that comparable AWT levels of treatment were required for both alternatives, and ocean disposal was estimated to be more costly due to the governmental permitting process, and based upon the potential for revenues from reclaimed water sales. However, the cost comparison was affected when secondary treatment was allowed for ocean discharges. As a result, advanced treatment required for landscape irrigation made reclamation the more costly treatment alternative. Also, increased energy costs for reclaimed water pumping made the purchase of potable water from the Metropolitan Water District of Southern California (MWDSC) less costly than reclaiming wastewater. Given these changes, the economics of water reclamation were revisited in 1987.

Based on 1986-87 cost data, the tables below present the costs ($303/ac-ft) associated with water reclamation in the IRWD and the projected costs of potable water ($449/ac-ft) by the Year 2000.

Costs of Water Reclamation, Irvine Ranch Water District (1986-87)

Cost Category		$/ac-ft
Cost of Additional Treatment		
Wages & benefits		33
Energy		13
Chemicals		11
Maintenance		13
Other		4
	Subtotal	$74
Distribution O&M Costs		
Energy		58
Wages & benefits		29
Maintenance		13
Vehicle Usage		5
Monitoring		12
Other		15
	Subtotal	$132
Indirect Costs		50
Replacement reserve		47
	TOTAL	$303/ac-ft ($0.93/1,000 gal)

The IRWD receives potable water from a wholesaling agency at a rate of $230/ac-ft. Additional potable transmission facilities are expected to be required by the Year 2000 at a cost of $81/ac-ft. Expansion of the reclamation program is expected to reduce and possibly eliminate this potable transmission expansion. The cost of distributing this additional potable water is expected to be $60/ac-ft with indirect costs (accounting, administration and overhead) of $31/ac-ft. As with the reclaimed water distribution system, replacement reserves were estimated to be $47/ac-ft.

The comparison of the costs of reclamation vs. obtaining additional water from the MWDSC are $303 and $449/ac-ft, respectively. Based on the estimated costs presented above, reclaimed water will be $146/ac-ft less expensive than the purchase of additional potable water. This savings is likely to be conservative given expected increases in potable water costs.

This case study illustrates that although current wastewater discharge standards do not support cost savings with a reuse alternative, program costs for additional potable water supplies can be eliminated or delayed with implementation of a water reuse system to cost-effectively meet existing and future irrigation water needs.

Source: Young *et al.* 1987.

Projected Cost of Potable Water, Irvine Ranch Water District (2000)

Cost Category	$/ac-ft
Treated water	230
Additional source water	81
Direct distribution costs	60
Indirect distribution costs	31
Replacement	47
TOTAL	$449/ac-ft ($1.38/1,000 gal)

6.7.3 *Determining the Financial Feasibility of Reuse in Florida*

In Florida, water reuse is mandatory in areas designated as critical water supply problem areas, unless such reuse is not economically, environmentally, or technically feasible. To ensure consistency in the economic evaluations, the Florida Department of Environmental Regulation (FDER) released "Guidelines for Preparation of Reuse Feasibility Studies for Applicants Having Responsibility for Wastewater Management" in November 1991. The guidelines include a methodology for an economic evaluation of implementing reuse.

Generally, the reuse feasibility study considers the evaluation of at least two alternatives:

- No action
- Implementation of a public access/urban reuse system

The feasibility guidelines specify the means by which the present value of each alternative will be developed. The period of analysis is given as 20 years. The discount rate to be used in the analysis is the current discount rate as developed annually by the U.S. Bureau of Reclamation. Capital construction costs are to include the cost of wastewater collection and treatment, and reclaimed water transmission to the point of delivery for the end user, plus reasonable levels of other related costs such as engineering, legal service, and administration. Assumed levels of wastewater treatment must be commensurate with the proposed end use. For example, it is highly improbable that a secondary effluent could be discharged to a surface water in Florida. Therefore, it would be inappropriate to assume this level of treatment in comparison to an advanced secondary level of treatment required in most reuse systems.

Applicants under the same ownership/control as a public water system are able to consider the costs avoided in expanding potable water systems where reuse is anticipated to reduce that demand. The cost of potable water supplies must include the cost of water withdrawal, treatment, and transmission to the point where the potable water leaves the water treatment plant. In addition to outlining procedures for establishing some sunk costs, revenues, salvage values, replacement and the basis of the cost, the feasibility guidelines also allow for an economic evaluation of water saved by implementing the reuse alternatives. This water savings is over and above that obtained by deferring expansion to the potable water system and addresses the immediate reduction in potable water supplies that may be realized through the implementation of a reuse program. The volume of potable water saved is calculated by establishing anticipated potable water demands under the "no action alternative" and the prescribed reuse alternative. Subtracting the annual water use projected under no action and reuse alternatives yields the projected annual water savings. This water savings will be valued at the average residential rate for potable water charged by the predominant water supply utility within the proposed reuse service area. The value of this water may then be taken as a revenue (benefit) for the reuse alternative.

This method of evaluating water savings is proposed solely for the preparation of reuse feasibility studies but recognizes the inherent value of reclaimed water systems and, in essence, sets its worth equal to that of the potable supplies it will offset.

The following table presents an example of the economic evaluation.

Economic Evaluation for Water Reuse

Given:

Initial Capital Investment	20 Year Useful Life $3 million/year 0
Expansion	20 Year Useful Life $2 million/year 10
Average Annual O&M Costs	Years 1-10 = $500,000/yr Years 11-20 = $750,000/yr
Planning Parameters	20-year horizon Discount rate of 10 percent 1991 Dollars
Water Savings	Years 1-10 Reuse will save 0.5 mgd potable water Years 11-20 Reuse will save 1.0 mgd potable water Average residential water cost = $1.00/1,000 gal

Determine: **Present value of this project in 1991 dollars with and without the credit from the potable water savings**

Without Water Credit

	Capital Cost	Salvage Value	Annual Costs	Present Value
Construction cost				
Initial (a)	$3,000,000			$3,000,000
Salvage (b)		0		0
Expansion (c)	2,000,000			771,000
Salvage (d)		(1,000,000)		(149,000)
O&M Costs				
Years 1-10 (e)			500,000	3,072,000
Years 11-20 (f)			750,000	1,776,000
Total Present Value				$8,470,000

With Water Credit

The above costs minus:				
Water Savings				
Years 1-10 (g)		(182,500)		(1,121,000)
Years 11-20 (h)		(365,000)		(865,000)
Total Present Value Adjusted for Water Savings			$6,484,000	

(a) The initial construction is already at present value.

(b) The initial construction useful life is 20 years; therefore, there is no salvage value.

(c) The expansion construction cost is converted to present value, using the present worth factor for a single payment, which in this example is the present value for Year 10, with a 10 percent discount rate, or a factor of 0.3855.

(d) The expansion construction cost salvage value equals the ratio of the remaining useful life/useful life times construction cost ($1,000,000). The present value of the salvage value equals the present worth factor for a single payment, which in this example, is the present value for Year 20, with a 10 percent discount rate, or a factor of 0.1486.

(e) The present value of the O&M costs for Years 1-10 equals the present worth factor for payment in Years 1-n, given a discount rate of 10 percent. In this instance, the years are 10 and the present worth factor is 6.144 (6.144 times $500,000 = $3,072,000).

(f) The present value of the O&M costs for Years 11-20 equals the present worth factor for payments in Years 11-20 (or for 10 years) brought back to year 1 value using the present worth factor for a single payment, given a disount rate of 10 percent. In this instance, the years are 10 and the present worth factor is 6.144. The present worth factor for a single payment is 0.3855 ($750,000 times 6.144 times 0.3855 = $1,776,000 rounded to the nearest $1,000).

(g) The water savings in Years 1-10 were computed at the rate of 0.5 mgd for 365 days, or 182,500,000 gal/yr., with a value of $1.00/1,000 gal = $182,500/yr. The present value equals the present worth factor for payments in Years 1-n, given a discount rate of 10 percent. In this instance, the years are 10 and the present worth factor is 6.144 (6.144 times $182,500 = $1,121,000 rounded to the nearest $1,000).

(h) The water savings in Years 11-20 were computed at the rate of 1.0 mgd for 365 days, or 365,000 gal/yr, with a value of $1.00/1,000 gal = $365,000/year. The present value comparison is the same as footnote (f) or $365,000 times 6.144 times 0.3855 = $865,000 (rounded to nearest $1,000).

6.7.4 *An Innovative Funding Program for an Urban Reclaimed Water System: Boca Raton, Florida*

In 1989, the City of Boca Raton, Florida, established a water conservation rate structure for potable water. The purpose of this rate structure, which is shown in the table below, was to promote potable water conservation and to set aside funds, $2,500,000 annually, for a reclaimed water system. As the reclaimed water system becomes operational and potable water consumption is reduced, it will be necessary to increase these rates to some degree to maintain the annual $2,500,000 set aside. However, as the reclaimed water system expands, it will move toward being self-supporting, reducing these increases in potable water rates. In addition, the reclaimed water system will eliminate the need for an $8,500,000 expansion of the city's water treatment plant that would have been necessary without the reclaimed water system off-setting the current potable water system irrigation demand.

As of October 1990, the water conservation rate fund had a beginning balance of $4,858,000 and average annual contributions of $3,500,000 were budgeted. It is estimated by the Year 2000, the total accumulated fund amount will be $29,858,000. This accumulated total does not include accrued interest on the fund balance because this balance will be constantly changing depending upon the construction schedule. This funding program for the reclaimed water system may be assisted by a bond issue if it becomes desirable to complete the entire 15.0 mgd (657 L/s) program in a shorter period of time.

This program will provide reclaimed water service to 75 to 80 percent of the proposed service district over the 10-year period and will serve four large users: Florida Atlantic University, and three golf courses, and slightly more than 10,000 single-family homes together with other public and private landscaped areas within Phases 1 through 3 of the transmission main system. The estimated average daily reclaimed water use under this program in the Year 2000 will be 11.68 mgd (512 L/s), and the reduction in potable water consumption will be about 8.34 mgd (365 L/s). This program will serve approximately 79 percent of the single-family homes in the proposed service district and will use about 78 percent of the 15.0 mg/d (657 L/s) of reclaimed water projected to be available by the Year 2000. Construction of transmission and distribution mains to serve Phase 4 of the service district will take place after the Year 2000.

Potable Water Rate Structures (Bi-monthly)
City of Boca Raton

Consumption Rate (Gallons)	Charge (Per 1,000 Gallons)
Basic Rate Structure (Prior to 10/1/89):	
0 - 50,000	$ .30
50,000+	.50
Water Conservation Rate Structure (After 10/1/89)	
0-25,000	$ .35
25,000 - 50,000	.85
50,000+	1.10

6.8 References

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CHAPTER 7

Public Information Programs

A workable water reuse program grows out of successive stages of study in the technical, legal/institutional, and financial aspects of reuse as they apply to a community. Just as crucial to successful program implementation is the support and encouragement, from the outset, of active public involvement in the reuse planning and implementation process.

This chapter provides an overview of the key elements of public participation, as well as several case studies illustrating public involvement approaches.

7.1 Why Public Participation?

Public involvement begins with the earliest exploratory contacts with potential users, and can continue through to formation of an advisory committee and holding of public workshops on candidate reuse schemes. It involves the two-way flow of information, helping to ensure that adoption of a selected water reuse program will fulfill real user needs and generally recognized community goals regarding public safety, program cost, etc.

7.1.1 Source of Information

The term "two-way flow" cannot be too highly emphasized. In addition to building community support for a reuse program, public participation can also provide valuable community-specific information to the reuse planners. As stated in EPA's Public Involvement Activities Guide: "Local residents often have a more intimate understanding of particular community problems... Their information is pertinent and up-to-date... (reflecting) the community's values, concerns, and goals" (Rastatter, 1979). Citizens have legitimate concerns, quite often reflecting their knowledge of detailed technical information. In reuse planning, especially, where one sector of "the public" comprises potential users of reclaimed water, this point is critical. Potential users *generally* know what flow and quality of reclaimed water are acceptable for their applications.

7.1.2 Informed Constituency

By soliciting expression of public concerns and incorporating suggestions made by members of the public, a public participation program can build, over time, an informed constituency that is "at home" with the concept of reuse, knowledgeable about the issues involved in reclamation/reuse, and supportive of program implementation. Citizens who have taken part in the planning process will be effective proponents of the selected plans. Having educated themselves on the issues involved in adopting reclamation and reuse, they will understand how various interests have been accommodated in the final plan. Their understanding of the decision-making process will, in turn, be communicated to the larger interest groups—neighborhood residents, clubs, and municipal agencies—of which they are a part. Indeed the potential reuse customer enthusiastic about the prospect of receiving service may become one of the most effective means of generating support for a program. In the urban reuse programs in St. Petersburg and Venice, Florida, construction of distribution lines is contingent on the voluntary participation of a percentage of customers within a given area. Experience indicates that a small number of motivated individuals can often be responsible for developing the required commitment. Likewise, golf course superintendents and agricultural customers will discuss the merits of a program among themselves, thereby increasing overall awareness of the program.

Since many reuse programs may ultimately require a public referendum of some fashion to approve a bond issue for funding reuse system capital improvements, diligently soliciting community viewpoints and addressing any concerns early in the planning process can be invaluable in garnering support. Public involvement early in the planning process, even as alternatives are beginning to be identified, allows ample time for the dissemination and acceptance of new ideas among the constituents. Public involvement can even expedite a reuse program by uncovering any opposition early enough to adequately address citizen concerns.

7.2 Defining the "Public"

Many contemporary analyses of public involvement define "the public" as comprising various subsets of "publics" with differing interests, motivations, and approaches to policy issues. For example, in discussing public participation for wastewater facilities planning, one planning consultant identifies the following publics: general public, potential users, environmental groups, regulators, political leaders, and business/academic/community leaders (Heilman, 1979).

EPA regulations (EPA, 1979a) identify the public as the general public, the organized public (public and private interest groups), the representative public (elected and appointed officials), and the economically concerned public (in this case, those whose interests might be directly affected by a reuse program). Examples of groups falling under the organized, representative and economically concerned publics can include the news media and the chief elected officials of the involved communities, neighborhood organizations, any citizens advisory committee, the Sierra Club, the League of Women Voters, business groups such as the Chamber of Commerce, the Rotary Club, industries and unions, sportsmen's clubs, historical societies, public works departments, recreation commissions, health departments, and state legislatures (Stern and Reynolds, 1979).

If a program for reuse truly has minimal impact on the general public, limited public involvement may be appropriate. For example, use of reclaimed water for industrial cooling and processing—with no significant capital improvements required of the municipality—may require support only from technical and health experts in other municipal and state agencies and from representatives of the prospective user and its employees. Reuse for irrigation of pasture land in isolated areas might be another example warranting only limited public participation.

But consideration of a broad range of candidate reuse systems, as is being advocated in these *Guidelines*, involves choices among systems with widely varying economic and environmental impacts for many segments of the public. Successful plan implementation will be assured in these cases only when officials, interest groups, and citizens share "a significant voice in (project) development" (Hollnsteiner, 1976).

"The public," in reuse planning, encompasses area residents, potential users of reclaimed water, freshwater purveyors, citizens with special areas of expertise pertinent to reuse, and the interest groups whose support is vital as representing diverse viewpoints shared by many in the community. From the outset of reuse planning, informal consultation with members of each of these groups, and formal presentations before them, should both support the development of a sound base of local water-reuse information and, simultaneously, build a coalition that can effectively advocate reuse in the community. Keeping in mind that different groups have different interests at stake, the presentation should be tailored to the special needs and interests of the audience.

7.3 Overview of Public Perceptions

Surveys over the last two decades indicate a surprisingly large measure of public support for water reuse programs. In both 1984 and 1987, Bruvold presented summaries and evaluations of available surveys regarding a variety of reuse options (Bruvold, 1984 and 1987). The results of seven surveys carried out from 1972 to 1985 are summarized in Table 30. The primary goal of most of the surveys was to gauge the public reaction to reuse projects involving some form of potable reuse, but questions on a wide variety of reuse alternatives were also included. All surveys indicate that the public's reluctance to support reuse increases as the degree of human contact with the reclaimed water increases. As a result of this trend, the use of reclaimed water as a source of potable water received the greatest opposition. However, as Bruvold points out, the surveys indicate that there is even a sizable minority who are not opposed to potable reuse (Bruvold, 1984). Results of a survey done in Denver regarding the use of reclaimed water as a source of potable water suggest that approximately one third of the respondents have significant opposition to the program, one third express some opposition, and one third indicate little or no objections (Lohman, 1987). The results of the surveys also indicate that socioeconomic and environmental factors play a role in the perception of water reclamation. Acceptance tends to increase with income and education.

The public also tends to support reuse for environmental benefits such as conservation or water quality protection of water resources. Also reviewed were surveys conducted in communities where reclamation projects were being considered. For those persons where water reuse was an imminent possibility (i.e., construction to provide reclaimed water service was being considered), the issues of concern became in the following order: (1) the ability of the project to conserve water, (2)

Table 30. Percentage of Respondents Opposed to Various Uses of Reclaimed Water in General Opinion Surveys

Use	Bruvold (1972) (N=972)	Stone & Kahle (1974) (N=1,000)	Kasperson et al. (1974) (N=400)	Olson et al. (1979) (N=244)	Bruvold (1981) (N=140)	Milliken & Lohman (1983) (N=399)	Lohman & Milliken (1985) (N=403)
Drinking Water	56	46	44	54	58	63	67
Food Preparation in Restaurants	56	—	—	57	—	—	—
Cooking in the Home	55	38	42	52	—	55	55
Preparation of Canned Vegetables	54	38	42	52	—	55	55
Bathing in the Home	37	22	—	37	—	40	38
Swimming	24	20	15	25	—	—	—
Pumping Down Special Wells	23	—	—	40	—	—	—
Home Laundry	23	—	15	19	—	24	30
Commercial Laundry	22	16	—	18	—	—	—
Irrigation of Dairy Pasture	14	—	—	15	—	—	—
Irrigation of Vegetable Crops	14	—	16	15	21	7	9
Spreading on Sandy Areas	13	—	—	27	—	—	—
Vineyard Irrigation	13	—	—	15	—	—	—
Orchard Irrigation	10	—	—	10	—	—	—
Hay or Alfalfa Irrigation	8	9	—	8	—	—	—
Pleasure Boating	7	14	13	5	—	—	—
Commercial Air Conditioning	7	—	—	9	—	—	—
Electronic Plant Process Water	5	5	3	12	—	—	—
Home Toilet Flushing	4	5	—	7	—	3	4
Golf Course Hazard Lakes	3	8	—	5	8	—	—
Residential Lawn Irrigation	3	6	—	6	5	1	3
Irrigation of Recreation Parks	3	—	—	5	4	—	—
Golf Course Irrigation	2	5	2	3	4	—	—
Irrigation of Freeway Greenbelts	1	—	—	5	—	—	—
Road Construction	1	—	—	4	—	—	—

— Not included in survey.
Source: Bruvold, 1987.

environmental enhancements achieved by the project, (3) protection of public health, (4) the cost of treatment required, and (5) the cost of distribution.

From the results of the existing surveys, Bruvold concludes that the findings expressed in Table 30 are very stable and may be used in the development of reclamation policies. The basis for such policies should consider (1) the degree of contact envisioned, (2) public health protection, (3) the conservation and environmental benefits, and (4) treatment and distribution costs. As the initial objections are addressed and overcome, the issue of customer cost typically becomes the deciding factor in the success or failure of a program.

There is no question that the public's enthusiasm for reuse (as perceived in the cited studies) might more reflect the hypothetical conditions set up by the survey questions and interviews used than signify a genuine willingness to endorse local funding of real programs that could involve distribution of reclaimed water for nonpotable use in their neighborhood. Survey results do indicate, however, that, at least on the intellectual plane, "the public" is receptive to use of reclaimed water in well thought out programs. The results also support conclusions that this initial acceptance hinges in large measure on:

- The public's awareness of local water supply problems and perception of reclaimed water as having a place in the overall water supply allocation scheme.
- Public understanding of the quality of reclaimed water and how it would be used.
- Confidence in local management of the public utilities and in local application of modern technology. Stone (1976) found that residents in communities with good quality water were more accepting of the use of reclaimed water than were residents in communities with water quality problems.
- Assurance that the reuse applications being considered involve minimal risk of accidental personal exposure.

Bruvold and Ongerth (1974) concluded that "the public is not yet ready for intimate uses of reclaimed water... (nor does the public favor) a low level of treatment of wastewater and its discharge into the environment without further reuse." This assertion is reaffirmed in Bruvold's 1987 work. The reluctance to ingest reclaimed water is understandable.

The apparent opposition by the public to the disposal of water that may be reclaimed is encouraging. Often reuse enjoys its greatest public acceptance where both water resource issues and pollution abatement issues combine. Such is the case in southwest Florida. Many municipalities draw groundwater of poor quality requiring expensive treatment to produce their drinking water. At the same time, low flow conditions in local streams and rivers and poor flushing of the bay and estuaries make surface water discharge environmentally unacceptable.

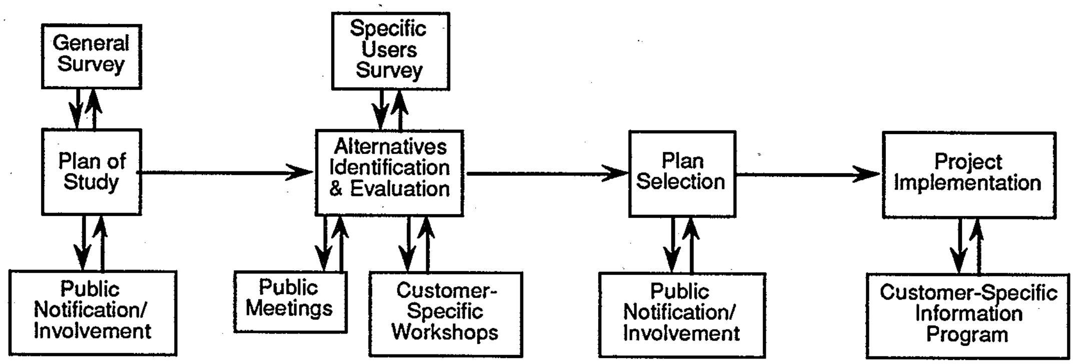
7.4 Involving the Public in Reuse Planning

Even where water reclamation is common, there is a need to establish a flow of information to and from the potential reuse customer. From an implementation standpoint, the designer requires information on the system(s) to receive the reclaimed water and to ensure compatibility. The customer, on the other hand, will wish to have a clear understanding of the program and provide input regarding their needs.

Of 200 reclamation projects surveyed in Florida, only 20 reported some type of problems in implementing reuse (Florida Department of Environmental Regulation, 1990). Twenty-five percent of the problems, the single largest factor reported, were associated with public acceptance (Wright, 1991). For example, the City of Cape Coral had developed plans to implement an urban irrigation program over a 110-sq mi (280 km^2) service area using treated canal water and reclaimed water from municipal wastewater. A formal public information program was considered unnecessary, as it was perceived that the publicity generated in the planning period was sufficient to create a basis of understanding in the residential customers. However, when residents received an assessment, this assumption was proven incorrect. The ensuing groundswell of opposition resulted in election of a counsel opposed to the project and years of delay to project implementation (Wright, 1991). However, the project was implemented after the incorporation of a public information/education program.

In order to avoid difficulty associated with public acceptance, it is of paramount importance that the expected benefits of the proposed project be established. If the project is intended to extend water resources, the preliminary studies should address how much water will be made available and compare the cost of reclamation to that of developing additional potable water sources. If the cost of reclamation is not competitive with potable water in cost, there must be overriding non-economic issues that equalize the value of the two alternative sources. Where reclamation occurs for environmental reasons, such as the reduction or elimination of a surface

Figure 33. **Public Participation Program for Water Reuse System Planning**



water discharge, the selected reuse alternative must again be competitive with other disposal options.

When firmly established, those benefits then become the planks of a public information program and it is possible to state "why" the program is necessary and desirable. Without such validation, reclamation projects will be unable to withstand public inspection and the likelihood of project failure is greatly increased.

7.4.1 General Requirements for Public Participation

Figure 33 provides a flow chart of a public participation program for water reuse system planning. In addition to the public meetings and workshops commonly included in public information efforts, the program includes surveys as a public education/information tool. In the early stages, a general distribution survey may be helpful in identifying level of interest, potential customers, and any initial concerns that the population might have. Where specific concerns are identified, later public information efforts can be tailored to address them. This could include participation of other public agencies that can provide information on water reuse and regulatory requirements, informal discussions with some potential users to determine interest or fill data gaps, and initial background reports to appropriate local decision making bodies. As the program progresses to alternative identification and evaluation, another survey might be considered. This survey could serve to confirm earlier results, monitor the effectiveness of the ongoing education program, or target specific users.

It might be helpful to identify at the outset the level of interest different individuals and groups will have in the reuse planning process. For example, Boston's Metropolitan District Commission (MDC) determined in a public participation program that some "publics" would want only to be kept informed on a regular basis, some would want periodic opportunities to ask questions and offer comments, and some would want to play a very active review and advisory role (Stern and Reynolds, 1979). The MDC's public participation program incorporated tasks and activities that ensured the desired degree of involvement for each group. Table 31 lists tools of public participation that might be useful in informing and involving the public to different degrees.

Table 31. The Tools of Public Participation

Purpose	Tools
Education/Information	Newspaper articles, radio and TV programs, speeches and presentations, field trips, exhibits, information depositories, school programs, films, brochures and newsletters, reports, letters, conferences.
Review/Reaction	Briefings, public meetings, public hearings, surveys and questionnaires, question and answer columns, advertised "hotlines" for telephone inquiries.
Interaction Dialogue	Workshops, special task forces, interviews, advisory boards, informal contacts, study group discussions, seminars.

Source: Rastatter, 1979.

7.4.1.1 Public Advisory Groups

If the scope or potential scope of the reuse program warrants it (e.g., reclaimed water may be distributed to several users or types of users), formation of a public advisory group will assist in defining system features and resolving problem areas. In its regulations for full-scale public participation programs, EPA requires that group membership contain "substantially equivalent" representation of the private (noninterested), organized, representative and affected segments of the public. It is recommended that group membership for reuse planning provide representation for potential users and their employees, interest groups, neighborhood residents, the other public agencies, and citizens with specialized expertise in areas (such as public health) that pertain directly to reclamation/reuse.

There is no reason to consider the group fixed at its original membership; other interested citizens can be added as the reuse program takes shape and as new issues or opportunities develop. What is important, however, is to institutionalize the group and its activities so that its efforts are directed effectively to the task at hand: planning and implementation of a reuse program in which the legitimate interests of various sectors of the public have been fully considered and addressed. In order to achieve this, the proposed formation of the advisory group should be publicized to solicit recommendations for, and expression of interest in, membership.

The group's responsibilities should be well-defined, whether it is intended that the group should simply conduct a study of some particular aspect of the reuse plan, or that it should serve throughout program planning and implementation as a broad-based representative body that can develop and advocate the program. Its meetings should be open to the public at times and places announced in advance. The group's members should designate at an early meeting a single individual who can serve as a contact point for the press and other news media. The group should fully recognize its shared responsibility for developing a sound reuse program that can serve both user requirements and community objectives. In subsequent public meetings, the group will assert its combined role as source of information representing numerous interests, and advocate of the reuse program as it gains definition.

7.4.1.2 Public Participation Coordinator

EPA regulations for full-scale public-participation programs require appointment of a public participation coordinator—an individual skilled in developing, publicizing, and conducting informal briefings and work sessions as well as formal presentations for various community groups. Whether or not a program requires designation of a public participation specialist, the significant value of providing public contact and liaison through a single individual should be considered. Such a person, whether an agency staff member, advisory group member or specialist engaged from the larger community, should be thoroughly informed of reuse planning progress, be objective in presenting information, and have the "clout" necessary to communicate and get fast response on issues or problems raised during

To accomplish this goal, many communities involved in urban and agricultural reuse have created a dedicated reuse coordinator position. The specifics of the areas of responsibility of such a position will vary according to specific conditions and preferences of a given municipality. In many Florida programs, the reuse coordinator is part of the wastewater treatment department. This position may be independent of both water and wastewater or associated with the water system.

7.4.2 Specific Customer Needs

As alternatives for water reuse are being considered, the customer associated with each alternative should be clearly identified. The needs of the customers must then be ascertained and addressed, as described in previous sections. In the past, failure to take this step has resulted in costly and disruptive delays to reclamation projects.

7.4.2.1 Urban Systems

In urban reuse programs, the customer base may consist of literally thousands of individuals. These people may be reached through the local newspaper, radio and public workshops. Identification of homeowner associations and civic organizations may allow for presentations to large numbers of potential customers at a single time.

The use of direct mail surveys may also be an effective means of informing the potential customer base of a proposed program, as well as receiving feedback from that base. In the City of Venice, Florida, a survey consisted of a one page letter of introduction and a one page survey. The letter of introduction explained what reclaimed water was, cited examples of local areas where it had been successfully used, explained why it was desirable in Venice, and requested completion and return of the survey. Approximately 30 percent of the surveys were returned. Reclamation was viewed as a favorable option by 71 percent of those responding city wide (CDM, 1990). Through this process, the city ultimately developed a voluntary urban reuse program involving over 2,000 single and multi-family units.

As part of the Denver potable reuse demonstration program, the effectiveness of different public information programs were studied. A control group was established that received no specific attention. A second group was provided literature on the program. A third group was provided literature and given a tour of the treatment facilities. The results of this study, indicate the group receiving the plant tour as having the greatest change in attitude (Olson *et al.*, 1979).

7.4.2.2 Agricultural Systems

In agricultural water reuse programs, the issues of concern may differ from those of the urban customer. In agricultural programs, the user is concerned with the suitability of the reclaimed water for the intended crop. Water quality issues that are of minor importance in residential irrigation may be of significant importance for agricultural production. For example, nitrogen in reclaimed water is generally considered a benefit in turf and landscape irrigation. However, as noted in the Sonoma Case Study in Chapter 3, the nitrogen in reclaimed water could result in excessive foliage growth at the expense of fruit production. While turf grass and many ornamental plants may not be harmed by elevated chlorides, similar chloride levels may delay crop maturation and effect the product marketability, as occurred in the strawberry irrigation study in the Irvine Ranch Water District discussed in Section 3.4.

In assessing the agricultural customer, it is necessary to modify the public participation approach used for the urban customer. Agencies traditionally associated with agricultural activities can provide an invaluable source of technical information and means of transmitting information to the potential user.

Local agricultural extension agents may prove to be the most important constituency to educate as to the benefits of reclamation. The agents will likely know most, if not all, of the major agricultural sites in the area. In addition, they will be familiar with the critical water quality and quantity issues facing the local agricultural market. Finally, the local farmers see the extension office as a reliable source of information and are likely to seek their opinion on issues of concern, as might be the case with new reclamation projects. The local extension agent will be able to discuss the issues with local farmers and hopefully endorse the project if familiar with the concept of reuse. The local soils conservation service may also prove an important target of a preliminary information program. Lack of endorsement from these agencies can hinder the implementation of agricultural reclamation.

7.4.3 Agency Communication

As noted in Chapters 4 and 5, the implementation of wastewater reclamation projects may be subject to review and approval of numerous state and local regulatory agencies. In locations where such projects are common, the procedures for agency review may be well established. Where reclamation is just being started, formal review procedures may not exist. In either case, establishing communication with these agencies early in the project is as important as addressing the needs of the potential customers. Early meetings may serve as an introduction or may involve detailed discussions of the permitability of a given project. As with the agricultural experts, the proposed project must be understood and endorsed by the permitting agencies. It may also be appropriate to contact other agencies that may still become involved with a public education program. Such is the case with local health departments, which may not participate directly in the permitting process but may be contacted by citizens with questions on the project. It would indeed be unfortunate for a potential customer to contact the local health department only to find that agency was unaware of the project in question; even worse would be the damage caused by a negative reaction from such an agency.

Where multiple departments in the same agency are involved, communication directly with all concerned departments will ensure coordination. It is worthwhile to establish a master list of the appropriate agencies and departments that will be copied on status reports and periodically asked to attend review meetings.

This communication will be beneficial in developing any reclamation project. It will be critical to establish communication with and between agencies when specific regulatory guidance on a proposed project does not exist. Such a condition is most likely to occur in states lacking detailed regulations or in states with very restrictive regulations that discourage reuse projects.

7.5 Case Studies

7.5.1 Using Public Surveys to Evaluate Reuse: Venice, Florida

In 1987, the City of Venice initiated the development of a water reuse program to irrigate golf courses and parks. By 1989, because of potable water use restrictions and state regulations that encourage reuse, the city began to consider the implementation of a water reuse program that would also serve single- and multi-family homes. To gauge public interest in residential reuse, public workshops and a reuse survey were conducted.

The public workshops included invited speakers such as the director of the neighboring St. Petersburg urban reuse system and public health experts. Some presentations to homeowners associations were also arranged. In addition, the City of Venice developed a reuse survey for distribution to all water customers. This survey consisted of a cover letter introducing the reuse project and a survey to develop an understanding of irrigation practices and citizen knowledge of reuse. The text of the letter and survey are provided on the following page.

Approximately 30 percent of the surveys were returned; of these, 71 percent indicated that they would use reclaimed water. The results of the survey were organized by subdivision and any objections noted. As the project proceeded, the public education program was modified to address the issues stated in the survey. Public health concerns were successfully addressed early in the project and the primary question became one of cost.

The survey consisted of eight questions that could be easily completed. This is credited for the high return rate. While the results of the survey did not yield detailed information, they did identify general objections to the use of reclaimed water the city might face. The cover letter was an important component of the public education process. Even after three years of workshops, program implementation, and newspaper articles, many customers' only awareness of the prospect of water reuse was the survey sent by the mayor.

Cover Letter

RE: City of Venice
Reclaimed Water for Irrigation

Dear Venice Resident:

I am writing to you to consider the possibility of using reclaimed water for residential irrigation. The City of Venice, like many cities in Southwest Florida, faces the constant problem of supplying high quality drinking water to its citizens. With an average rainfall of 55 in (140 cm)/yr and surrounded by canals, creeks, and ponds, it may surprise you to know that Venice is required to use an expensive reverse osmosis treatment process to provide the quality and quantity of drinking water needed. Unfortunately, as much as 1.3 mgd (57 L/s) of this highly treated water is used for residential and commercial landscape irrigation. To reduce the amount of drinking water used for irrigation, the city is considering the use of reclaimed water to meet residential irrigation needs.

What is reclaimed water?

Reclaimed water is wastewater that has received a high level of treatment and disinfection. The reclaimed water is odorless and virtually indistinguishable from drinking water. The city has plans to provide reclaimed water to four golf courses and residential developments in Venice. The City of St. Petersburg has practiced reuse for 10 years and supplies over 20 million gal/d of reclaimed water to over 3,000 homes. The use of reclaimed water is accepted and encouraged by the Water Management District and the Florida Department of Environmental Regulation as a proven method of conserving water resources.

We are asking for your help in considering the potential for reuse in the City of Venice. Enclosed please find a reuse survey form. Please complete this survey and return it to the city by folding and stapling the survey form so that the city's address and postage is showing. Returning the survey will not obligate you in any way. If sufficient interest in reuse is found in your area, the city will contact you regarding implementation of a reuse system. Thank you for your cooperation in this matter.

Harry E. Case

Mayor

Reuse Survey

1. Name: ____________________
2. Address: ____________________
3. Name of Subdivision: ____________________
4. Type of Irrigation:
   [ ] Residential Lawns
   [ ] Landscape Irrigation (Condominium)
   [ ] Plant Nurseries
   [ ] Other:
5. What is your current source of irrigation:
   [ ] City Water [ ] Well [ ] Other:
6. Would you use reclaimed water for irrigation?
   [ ] Yes [ ] No

   If your answer to question 6 was no, what is your objection to the use of reclaimed water?
7. Would you be interested in receiving more information on reuse?
   [ ] Yes [ ] No
8. Other Comments: ____________________

____

____

If you have any questions, please feel free to call the City of Venice.

RETURN INSTRUCTIONS: Please fold and staple or tape this self-addressed, postage paid form at your earliest convenience.

7.5.2 *Having the Public Evaluate Reuse Alternatives: San Diego*

Planning of a wastewater reclamation and reuse project in the San Diego Clean Water Program (CWP) included public involvement for the evaluation of system alternatives. As shown in the planning model depicted below, the public was involved early in the planning process in assessing the system options and again in ratifying the selected alternative.

The initial technical evaluation identified 21 alternatives, which were reduced through further analyses to seven before presentation to the public. A survey of the general population in the greater metropolitan area of San Diego was conducted in 1989. A total of 600 respondents, selected as representative of area demographics, were interviewed. The interviews were conducted in the respondents' homes by trained interviewers. Each 1-hour interview followed a prescribed format that noted appropriate demographics, carefully defined wastewater treatment and water reuse, assessed general attitudes towards various forms of reuse, and presented the seven alternatives and their associated costs, and obtained an assessment and ranking of each alternative.

Concurrent with the interview process, technical planners performed a comprehensive analysis for the seven alternatives. The technical and public rankings agreed on four alternatives, with both groups ranking the same alternative as their first choice.

Based on these results, the CWP proceeded with development of plans and specifications for the selected alternative. Two more surveys were conducted, each using 600 new respondents and focusing only on the selected alternative. These surveys confirmed the favorable evaluations of the first survey, and indicated a strong inclination to support public ratification of the program.

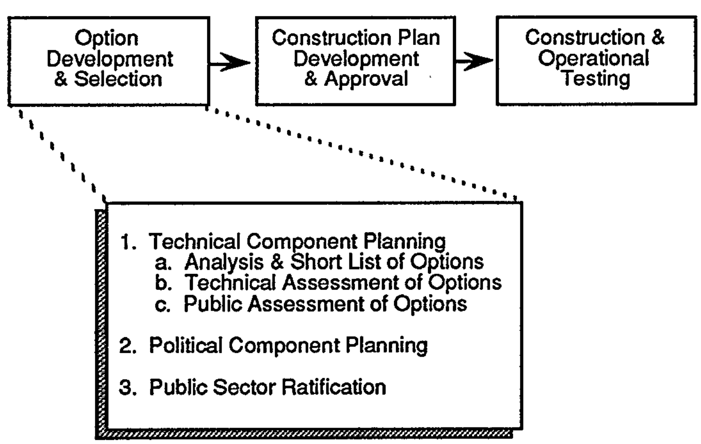
The San Diego survey illustrates several interesting points:

- Technical findings and public opinion may be in concert with one another when reuse alternatives are being considered.
- Preliminary surveys reliably predicted project acceptance for the reuse program.
- When the public is substantially involved in the planning process, the public support necessary to obtain funding for the projects proposed is more likely.

The experience and results of the San Diego survey illustrate how public involvement may be accomplished in a way that appears to appropriately balance the need for both technical expertise and public input in the planning and development of major wastewater treatment and reclamation facilities.

Source: Bruvold, 1987.

Public Involvement in Project Planning, San Diego Clean Water Program



7.5.3 *Accepting Produce Grown with Reclaimed Water: Monterey, California*

Surveys on reuse are frequently targeted at the end user. As part of the Monterey Wastewater Reclamation Study for Agriculture, individuals involved with produce distribution were interviewed regarding the use of reclaimed water for vegetable irrigation. One hundred and forty-four interviews were conducted with the following persons:

- Twenty four brokers and receivers at terminal markets throughout the U.S. and Canada where the bulk of study area produce is shipped.
- Ten buyers for major cooperative wholesalers in principal cities.
- Nineteen buyers and merchandisers with large chains, both at corporate and regional levels.
- Ten buyers with medium chains.
- Two buyers with small chains.
- Fifteen store managers.

The primary focus was the need or desire for labeling produce grown with reclaimed water. To balance the survey findings and obtain accurate responses, the interviewers were questioned about other possible situations analogous to the sale of crops grown with reclaimed water. This included questions on crops that had been genetically altered to grow in salty water and the use of hydroponics for crop production, as well as reclaimed water irrigation. The study assumed that each production alternative presented no health risk to the public and would yield acceptable produce. The results are given in the tables below.

The responses indicated the product would be accepted and that labels would not be considered necessary. According to federal, state, and local agency staff who were contacted, the source of the water used for irrigation is not subject to labeling requirements. Produce trade members indicated labeling would only be desirable if it added value to the product. Buyers stated that good appearance of the product is foremost.

The study was intended to gauge the marketability of produce irrigated with reclaimed water in the Monterey area but noted locations where this practice has been underway for a number of years. Many vegetables and fruits, such as tomatoes and strawberries, are grown in Mexico with reclaimed water and sold in the United States. The multi-year record of this practice suggests acceptance on the part of the distribution and consumers. In Orange County, California, the Irvine Company has been furrow-irrigating broccoli, celery, and sweet corn for almost 20 years.

Source: Engineering-Science, 1987.

Trade Reactions to Carrying Produce Grown in Reclaimed Water

	Knowledgeable About Reclaimed Water	Not Aware of Reclaimed Water	Total
Would Carry	28	12	40 (59%)
Would Not Carry	9	6	15 (22%)
Don't Know	7	6	13 (20%)
TOTAL	44 (65%)	24 (35%)	
Base = 68			

Trade Expectations About Labeling Produce Irrigted with Reclaimed Water

	Knowledgeable About Reclaimed Water	Not Aware of Reclaimed Water	Total
Would Not Expect it to be Labeled	30	16	46 (68%)
Would Expect it to be Labeled	9	6	15 (22%)
Don't Know	5	2	7 (10%)
TOTAL	44 (65%)	24 (35%)	
Base = 68			

7.5.4 *Water Independence in Cape Coral - An Implementation Update*

The City of Cape Coral is a rapidly developing southwest Florida community. As is the case throughout many parts of the country, the availability of an economically acceptable supply of potable water to meet a continually growing demand, was, and is, a major concern to the city. The situation facing Cape Coral was the need to support a population of nearly 400,000, almost eight times its 1985 population. Cape Coral is unique in that growth was predestined by the enterprising developer–the entire area is platted, every lot is sold, every street is paved, and street and stop signs are in place. Potable water is supplied solely from the saline groundwater aquifer through treatment by reverse osmosis (RO).

With water supply issues to consider, plus the need to find an acceptable method for ultimately disposing of 42 mgd of wastewater effluent, the city developed the "Water Independence in Cape Coral" (WICC) concept of a dual water system. Potable water would be provided through one piping system for potable needs only and secondary water would be provided through a second piping system for irrigation. The sources of secondary water would be reclaimed water and freshwater canals throughout the City.

Implementation of WICC did not come easy. The WICC master plan was prepared, presented and adopted by the city with relatively little interest from the public. However, when attempts were made to move forward with Phase 1 (issuance of special property assessment notices), certain elements of the public became very vocal and were successful in delaying the project. Though the WICC Program is now well underway, the following chronology provides a sense of how difficult implementation was. From the time the city committed to proceed, it took 6-1/2 years to start up Phase 1. This experience should prove to be a valuable lesson to other communities considering a reuse water system.

In summary, had the city implemented a formal public awareness and education program regarding the benefits of reuse in 1985, the city could have addressed citizen concerns prior to finalizing the special assessment program. A more timely consideration of concerns and program benefits could have prevented the delays in program implementation.

Chronology of WICC Implementation

November 1985	City WICC report prepared WICC concept is born!
January 1988	WICC master plan adopted
April 1988	Assessment hearing with 1,200 vocal citizens WICC Program stopped
October 1988	Phase 1 advertised for bids
November 9, 1988	City council election Pro-WICC/Anti-WICC campaign Low voter turnout/Anti-WICC prevailed
November 1988 to October 1989	Deadlocked city council State Water Management threatens potable allocation cut back Supportive rate study Supportive water resource study Supportive citizen's review committee Requested increase to potable water allocation denied
November 1989	WICC Referendum 60% voter turnout WICC wins 2 to 1
December 1989	Second assessment hearing
February 1990	Construction started for Phase 1
March 1992	Phase 1 starts up
September 1992	Phase 2 start up scheduled
October 1994	Phase 3 start up scheduled

Source: Curran and Kiss, 1992.

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CHAPTER 8

Water Reuse Outside the U.S.

Water reclamation and reuse are widely practiced outside the United States both in industrialized and developing countries. Reclamation and reuse practiced with proper attention to public health began understandably in cities and regions of industrialized countries, where wastewater collection and treatment have become common practice. Water reuse, for agricultural irrigation and nonpotable urban uses, also holds tremendous promise for developing countries, as well as countries in Eastern Europe and the Newly Independent States of the former Soviet Union.

This chapter provides an overview of water reuse in countries outside the United States, with particular emphasis on implementing reuse in developing countries, where the planning, technical, and institutional issues may differ markedly from industrialized countries. Examples are provided of reuse projects in industrialized and developing countries.

8.1 Water Reuse in Other Countries

Many cities in Asia, Africa and Latin America are unsewered; where sewers are available, they often discharge untreated wastewater to the nearest drainage channel or water course. Collecting the wastewaters for treatment is a formidable and expensive task. But reuse cannot begin until sewers, interceptors, trunk sewers and treatment plants are built.

In the countries of Eastern Europe and the Newly Independent States, the urban areas are generally sewered, but the wastewater treatment plants are often not providing sufficient treatment for reuse. As these countries rehabilitate their urban infrastructure, there will be significant opportunities to upgrade wastewater treatment plants to reclaim wastewater for urban reuse.

Although one of the two driving forces for reclamation, more economical pollution abatement, has only recently been put on the agenda of many of these countries, the need for additional water resources in urban areas may make water reclamation for nonpotable reuse less costly and more feasible than developing new sources of fresh water.

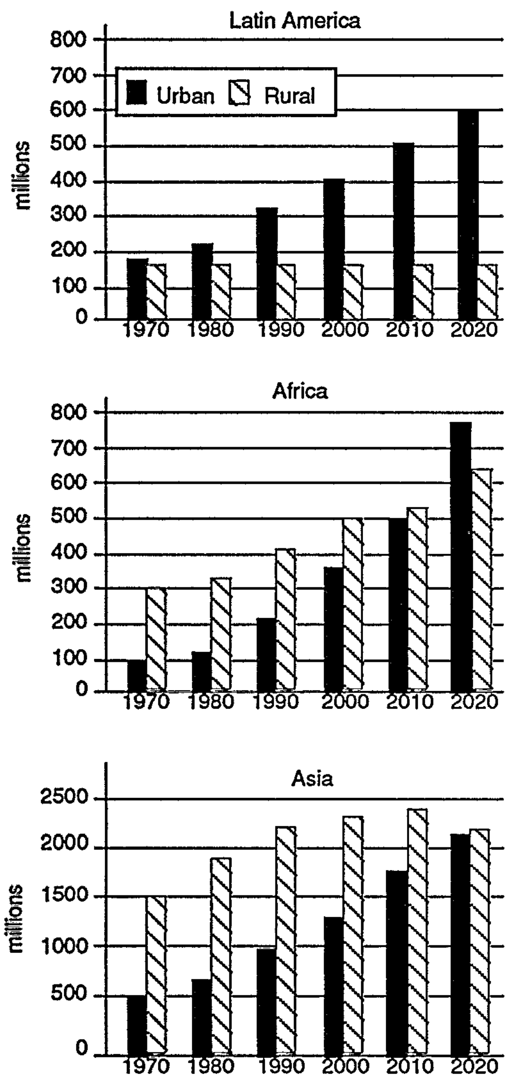
Urban growth impacts in developing countries are extremely pressing. Whereas only one of a total of three "giant" cities (with more than 10 million population) was in a developing country in 1950, it is projected that 18 of a total of 22 such cities will be in developing countries by the year 2000. By 2020, more than half the total population of Asia, Africa, and Latin America will be living in cities (Figure 34). All these cities will be needing additional water supplies, and one likely source will be reclaimed water.

Another driving force for properly planned water reclamation does exist in developing countries: public health protection. Because alternative low-cost sources of water are generally not available for irrigation of high value market crops near these cities, the common practice is to use raw wastewater directly or to withdraw from nearby streams that may be polluted with raw wastewater. The consequent contamination of foodstuffs to be eaten raw maintains a high level of enteric disease in the area and has serious impacts on visitors to the cities. Thus, the protection of the public health, as well as the provision of additional water supply, is an incentive to the initiation of agricultural reuse projects near the cities of developing countries. Accordingly, national and local public health agencies in developing countries may need to involve themselves more in reclamation projects than is the case in the U.S.

Almost all water reuse in developing countries is for agricultural purposes. Most often, however, the wastewater is applied untreated. Farmers who need water for market crops will use even heavily polluted water if it is available. The ubiquity of agricultural reuse was evidenced at a 1991 conference on Wastewater Reclamation and Reuse sponsored by the International

Association on Water Pollution Research and Control (IAWPRC, 1991) in Spain. Of some 35 papers, most were devoted to agricultural reuse and only a few to urban reuse.

Figure 34. Changes in Urban and Rural Populations in Latin America, Africa, and Asia



Source: United Nations, 1989.

The literature on agricultural reuse in developing countries is abundant, and guidelines and standards have been promulgated (International Reference Center for Waste Disposal, 1985; Shuval *et al.*, 1986: Mara and Cairncross, 1989; World Health Organization, 1989). These guidelines and standards advocate an appropriate level of treatment for the intended practices; however, they are not always followed. Any improvement over the use of untreated wastewater discharges, whether directly or via a river, represents a significant health improvement.

Although agricultural reuse is far more widely practiced in the developing world, there is also strong promise for reuse to meet nonpotable water demands in the rapidly growing urban areas of Asia, Africa, Latin America, Eastern Europe, and the Newly Independent States. Nonpotable urban reuse offers opportunities for sound water resources management, and has begun to be adopted in the industrial world; the U.S. and Japan are good examples. Similar opportunities exist in the urban areas of the developing world (Okun, 1990). Several advantages are realized by urban reuse that do not accrue to agricultural reuse:

- Much urban reuse, such as toilet flushing, vehicle washing, stack gas cleaning, and industrial processing are nonconsumptive, and the water can be reclaimed again for subsequent consumptive use in agriculture or evaporative cooling.
- The urban markets for reuse are generally closer to the points of origin of the reclaimed water than agricultural markets.
- The value of water in urban use is generally far greater than its value in agricultural irrigation. It can be metered and appropriate charges levied so that cost recovery is far more feasible in urban reuse than when the reclamation is solely for agricultural use. It must be remembered, however, that costs of providing potable quality water for domestic urban use are higher than providing water for irrigation use.

Agricultural irrigation will continue to dominate reuse practice in developing countries for many years into the future. However, reclamation projects are not likely to be built to serve agriculture; the primary objective of such wastewater treatment plants as are built will be to achieve pollution control in urban areas, particularly those that serve tourism. Nevertheless, reuse for agricultural purposes is important and the subject is covered extensively in Section 3.4.

8.1.1 Planning Water Reclamation Projects

Planning water reclamation and reuse projects in cities in developing countries is different from planning in the

United States. Cities in the U.S. are generally already fully sewered and almost all have wastewater treatment facilities, so that the funds required are limited to providing some additional treatment, storage, and distribution of the reclaimed water. For sewered areas in cities in the developing world, interceptors and treatment facilities, as well as the distribution system for the reclaimed water, would need to be built virtually in their entirety. The magnitude of up-front capital costs requires that the planning provide for implementation in stages, but with each stage contributing a benefit while fitting in with the ultimate plan.

One advantage that does accrue to reclamation in cities in developing countries is that planning can consider reuse from the outset. For example, reclamation facilities might be located near markets for the reclaimed water rather than at points of disposal, which is the common approach where reuse is not contemplated. Also, in cities where additions to the sewerage system are required, the simultaneous construction of pipe lines for reclaimed water will reduce the total cost. Retrofitting reclamation facilities in industrialized cities with fully developed sewerage and treatment facilities is far more costly than where the reclamation facilities can be installed with other new infrastructure.

Other major differences between planning for cities in developing and industrialized countries result from differences in their costs for labor and equipment. (Okun, 1982) The principles on which water reclamation facility design and operation are based are the same wherever they are installed. The difference between implementation of projects in industrialized and developing countries results from the fact that the former are capital-intensive while the latter are labor-intensive, although there is a threshold level in water reuse and wastewater technology that requires a certain level of capital input. In developing countries, factor costs of relatively inexpensive labor and higher capital costs dictate that a facility that can be built and operated with local labor will be more cost effective than a facility utilizing more modern capital-intensive technology.

Many instances arise, however, where mechanization and automation are appropriate in the developing world. This would be when the task to be performed cannot be readily performed by labor, no matter how low cost that labor may be. For example, the pumping of water in large quantities is a mechanical process not easily replaced by labor.

As an illustrative example, consider the difference in labor costs of operating a wastewater treatment facility in an industrialized country and a developing country. While this example is not based on actual salaries, it does serve to illustrate an important difference between capital-intensive and labor-intensive economies. Assume that the annual cost of labor for operating a wastewater facility in the United States or another industrialized country is about $600,000 for an around-the-clock attendant. (This is based on an assumed total cost of $20,000/yr for each of the four persons required to provide an attendant continuously, including all fringe benefits, 15-year equipment life, and 10 percent interest.) Under these assumptions, an automated device that replaces this labor and has a total investment cost less than $600,000 would result in savings. On the other hand, the lower labor costs in a developing country would probably not warrant an investment of more than about $20,000 to supplant an around-the-clock attendant. (This is based on an assumed total cost of $1,000/yr/person,10-year equipment life, and 20 percent interest.) The 30-fold disparity is exacerbated by the higher costs of equipment to developing countries because of transport and customs duty. Equipment for mechanization and automation that can replace labor must generally be manufactured in the industrialized world, so that spare parts and maintenance skills must be imported from the industrialized world and are available only at high cost and with long delay.

The difference in availability of qualified engineers, scientists and technicians calls for a different approach to planning. Not only are sufficient numbers of qualified staff available to utilities in the larger cities in the U.S., if they have problems they need only contact their consulting engineers, the manufacturers of their equipment, a nearby university, or their state agency. In a developing country, these supporting resources are less available. Accordingly, investments in reliability and simplicity, even at higher initial cost, may be warranted in developing countries.

The different situations can be illustrated by an example in the planning and design of transmission mains. A selection between a gravity transmission main or an intercepting sewer and lines which require pumping would be determined in the U.S. by the lowest annual cost, considering both capital cost and operation and maintenance. In the U.S., pumping with force mains would often be lower cost than gravity lines. Such an analysis of the same project in a developing country might show that gravity lines, despite the greater construction involved, might be lower cost because such labor-intensive construction is less costly in a developing country and the costs of pumps and power are greater. However, even if the gravity system were to cost out somewhat more in a developing country, it might be the wiser choice because the maintenance costs and the likelihood of failure are so much less. Power for the pumps is often unreliable, preventive maintenance of the pumps may be inadequate, and replacement parts for the pumps are difficult to obtain. If pumping cannot be avoided, constant-speed pumps are preferable to the more complex variable-speed pumps used in the U.S., even if the latter might save operating personnel. Design for projects in developing countries requires considerably greater planning than for similar projects in the industrialized world due to manpower and financial constraints.

Another difference affecting planning is in the institutional resources for reclamation and reuse, particularly with regard to sewerage, because relatively small investments have been committed to wastewater collection and treatment in developing countries. Virtually all cities in the industrialized world are provided with water-carried wastewater facilities. As shown in Table 32, as of 1990 only about 70 percent of the urban population in developing countries is provided with some type of sanitation facilities and those facilities that exist are often fragmentary, with few cities in Asia, Africa and Latin America having operable wastewater treatment plants. As noted in the examples in Section 8.2, reuse projects in the cities of developing countries are often not satisfactory; most constitute serious health hazards.

8.1.2 Technical Issues

This section provides an overview of some of the technical issues for water reuse in developing countries that may differ from those presented in Chapter 2 for the U.S. Many of the issues flow from the different technical solutions that are appropriate in a labor-intensive economy as compared with the capital-intensive economy of the U.S. Other differences occur from differences in financial resources, equipment and material resources, and human resources, and most particularly the differences in existing wastewater collection, treatment, and disposal facilities and the difference in the health status of the populations involved. The principles are essentially the same; the practices can be expected to be different.

8.1.2.1 Sources of Reclaimed Water

Whereas the principal sources of reclaimed water in the U.S. are the effluents from municipal wastewater treatment plants, in the developing countries the sources are frequently the raw wastewaters collected from existing sewerage systems. Other sources of reclaimed water, particularly appropriate in developing countries, are the polluted streams that flow through or near cities, essentially being used as natural interceptors, which provide water for irrigation of market crops. Treatment of the water would have substantial health benefits. As the cities grow and displace the agricultural areas, the treatment can be upgraded to serve other urban uses. Probably fewer than half of the 1.3 billion urban population in the developing countries have conventional sewerage, and a very small percent of these have any functioning treatment. In many cities, the sewerage systems are limited in extent, involving many separate points of discharge to local drainage channels and streams in or near the city. The first requirement, which would involve a substantial portion of the investment, is for the construction of trunk and intercepting sewers to carry water to sites for treatment.

Table 32. Extent of Water and Sanitation Services in Urban Areas of Developing Countries

Service	Provision	Number of people in 1980 (mil)	Percentage of urban population	Number of people in 1990 (mil)	Percentage of urban population	Change in number from 1980 to 1990 (mil)	Percentage change from 1980 to 1990
Water supply	Served	720	77	1,088	82	+368	+51
	Unserved	213	23	244	18	+ 31	+15
Sanitation	Served	641	69	955	72	+314	+49
	Unserved	292	.31	377	28	+ 85	+29
Total Urban Population		933			1,332	+399	

Source: Okun, 1991.

While the planning and design of sewerage systems is beyond the scope of these *Guidelines,* it is an important consideration for water reclamation and reuse in developing countries where the installation of sewers will often be a major part of reclamation projects. Although the cost of sewers provided for the purpose of sanitation in urban areas cannot be charged entirely to water reclamation, some attention needs to be given to what will undoubtedly be a significant element of many reclamation projects in cities in developing countries.

Sewerage is costly, particularly where cities have been permitted to grow over decades, with many high-rise residential, public, and commercial buildings provided with water supply but without sewers, and where sewers have to be retrofitted. "Low cost" sanitation alternatives involving onsite disposal are generally not feasible in urban areas, particularly where high-rise buildings are to be served. Several approaches to reducing the cost of sewers in developing countries are appropriate. These involve modifying the design and construction standards that govern conventional U.S. practice. For example:

- Reducing the minimum slopes specified in U.S. standards. This could sharply reduce construction and pumping costs at the price of more frequent maintenance. With the low cost of labor in developing countries, the greater maintenance costs would be offset by the savings in construction.

- Increasing the distance between manholes. Again, the more costly maintenance would be acceptable.

- Using indigenous materials which may be labor-intensive as compared with sewerage practice in the U.S., which is designed to minimize costs of construction.

- Using computer-aided design to obtain least-cost sewerage system layouts.

Such modifications require strong institutions that can provide the personnel required for preventive maintenance and other labor-intensive programs of construction and operation.

One situation that does not permit a low cost approach to water reclamation is in the provision of sewers in coastal areas where they may be impacted by saltwater infiltration. If the sewers cannot be kept above the water table, sewers with tight joints properly laid to avoid subsidence are essential to prevent chloride contamination.

The best prospects for reclamation and reuse are in the newly developing areas of the larger, richer, rapidly growing cities of the developing world where water supplies are short, where some sewerage already exists, and where pressures to control pollution are being exerted. One example is Sao Paulo, Brazil (Section 8.2.2), the third largest metropolis in the world, where the high quality effluent produced by the first module of an activated sludge treatment plant inspired thoughts of reuse for industry and for new developments being constructed as the city expands (Okun and Crook, 1989).

8.1.2.2 Water Quality

Few developing countries have established water quality criteria or standards for water reuse. Guidance in establishing regulations is provided by the World Health Organization (WHO). In 1971, WHO sponsored a meeting of experts on reuse, culminating in a report recommending health criteria and treatment processes for various reuse applications (WHO, 1973). The applications ranged from irrigation of crops not intended for human consumption, for which the criteria were freedom from gross solids and significant removal of parasite eggs, all the way to potable reuse for which secondary treatment followed by filtration, nitrification, denitrification, chemical clarification, carbon absorption, ion exchange or membranes, and disinfection were recommended.

For nonpotable urban reuse and contact recreation, secondary treatment followed by sand filtration and disinfection were recommended. However, the health criteria differed in that for the urban reuse only a general requirement for effective bacterial removal and some removal of viruses was specified, while for contact recreation a bacterial standard of no more than 100 coliform/100 mL in 80 percent of samples and the absence of skin-irritating chemicals were specified.

In 1985, a meeting of scientists and epidemiologists was held in Engelberg, Switzerland, to discuss the health risks associated with the use of reclaimed water for agricultural irrigation. (This meeting did not consider other nonpotable uses.) The meeting was sponsored by WHO, the World Bank, United Nations Development Programme, United Nations Environment Programme, and the International Reference Centre for Wastes Disposal. Health-related and other research made available since publication of the 1973 WHO guidelines were reviewed, and a revised approach to the nature of health risks associated with agriculture and aquaculture was developed. A model was developed of the relative health risks from the use of untreated excreta and wastewater in agriculture or aquaculture. It also concluded that the health risks of irrigation with well treated wastewater were minimal and that the California bacterial standards were unjustifiably restrictive (International Reference Center for Waste Disposal, 1985).

The Engelberg Report developed tentative microbial quality guidelines for reclaimed water used for irrigation. It was recommended that the number of intestinal nematodes should not exceed one viable egg/L for all irrigation and that for the irrigation of edible crops, sports fields, and public parks, the number of fecal coliform organisms should not exceed 1,000/100 mL. The participants recognized, in addition, that social and behavioral patterns are of fundamental importance in the design and implementation of reuse projects.

A WHO Scientific Group on Health Aspects of Use of Treated Wastewater for Agriculture and Aquaculture met in Geneva in 1987, and their report has been published by WHO as "Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture" (WHO, 1989). These WHO guidelines reaffirm the recommendations of the Engelberg Report. The recommended microbiological quality guidelines for reclaimed water used mainly for agricultural irrigation are summarized in Table 33.

The guidelines are based on the conclusion that the main health risks associated with reuse in developing countries are associated with helminthic diseases and, therefore, a high degree of helminth removal is necessary for the safe use of wastewater in agriculture and aquaculture. The intestinal nematodes covered serve as indicator organisms for all of the large settleable pathogens. The guidelines indicate that other pathogens of interest apparently become non-viable in long-retention pond systems, implying that all helminth eggs and protozoan cysts will be removed to the same extent. The helminth egg guidelines are intended to provide a design standard, not a standard requiring routine testing of the effluent.

The Scientific Group concluded that no bacterial guideline is necessary in cases where the only exposed populations are farm workers, due to a lack of evidence indicating a health risk to workers from bacteria. The recommended bacterial guideline of a geometric mean fecal coliform level of 1,000/100 mL was based on the most recent epidemiological evidence and is considered to be technically feasible in developing countries. The Scientific Group indicated that the potential health risks associated with the use of reclaimed water for lawn and park irrigation may present greater potential health risks than those associated with the irrigation of vegetables eaten raw and, hence, recommended a fecal coliform limit of 200/100 mL for such urban irrigation.

A number of infections caused by excreted pathogens are of concern in connection with aquaculture using wastewater. A review of the literature (Strauss, 1985) concluded that:

- Invasion of fish muscle by bacteria is very likely when fish are grown in ponds containing concentrations of fecal coliforms and salmonella greater than 10^4 and 10^5/100 mL, respectively. The potential for muscle invasion increases with the duration of exposure of the fish to the contaminated water.

- Some evidence suggests there is little accumulation of enteric organisms and pathogens on, or penetration into, edible fish tissue when the fecal coliform concentration in the pond water is below 1,000 /100 mL (Buras *et al.*, 1985).

- Even at lower contamination levels, high pathogen concentrations may be present in the digestive tract and the intraperitoneal fluid of the fish.

The guidelines recognize that there are limited health effects data for reclaimed water used for aquaculture and do not recommend definitive bacteriological quality standards for this use. However, a tentative bacterial guideline of a geometric mean number of fecal coliforms of 1,000/100 mL is recommended in the guidelines, which is intended to insure that invasion of fish muscle is prevented. The same fecal coliform standard is recommended for pond water in which aquatic vegetables (macrophytes) are grown. Since pathogens may be accumulated in the digestive tract and intraperitoneal fluid of fish and pose a risk through cross-contamination of fish flesh or other edible parts, and subsequently to consumers if standards of hygiene in fish preparation are inadequate, a further recommended public health measure is to ensure that high standards of hygiene are maintained during fish handling and gutting. A total absence of viable trematode eggs, which is readily achieved by stabilization pond treatment, is recommended as the appropriate helminth quality guideline for aquacultural use of reclaimed water. A comprehensive review of the use of human wastes, as excreta or in wastewater, in aquaculture describes current practices and health hazards, concluding that the economic benefits can defray some of the costs of sanitation while assisting in fish production (Edwards, 1992).

The 1989 WHO guidelines identify waste stabilization ponds as the method of choice in meeting these

Table 33. Recommended Microbiological Guidelines for Wastewater Use in Agriculture (a)

Category	Reuse Conditions	Exposed Group	Intestinal nematodes (b), (arithmetic mean no. of eggs per litre) (c)	Faecal coliforms (geometric mean no. per 100 mL) (c)	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks (d)	Workers, consumers, public	≤1	≤1,000 (d)	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees (e)	Workers	≤1	No standards recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in Category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

(a) In specific cases, local epidemiological, sociocultural, and environmental factors should be taken into account, and the guidelines modified accordingly.
(b) *Ascaris* and Trichuris species and hookworms.
(c) During the irrigation period.
(d) A more stringent guideline (≤200 fecal coliforms/100 mL) is appropriate for public lawns such as hotel lawns, with which the public may come into direct contact.
(e) In the case of fruit trees, irrigation should cease 2 weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

Source: WHO, 1989.

guidelines in warm climates where land is available at reasonable cost. Based on helminth removal, the guidelines call for pond retention time of 8 to 10 days, with at least twice that time required in hot climates to reduce bacterial levels to the guideline level of 1,000 FC/100 mL. Comprehensive manuals and publications are available addressing the planning, design, operation, and maintenance of stabilization ponds (EPA, 1983; World Bank, 1983; WHO, 1983). It was recognized that tertiary treatment of conventional biological secondary-treatment effluent may also be used to meet the recommended microbial guidelines. The expected removal efficiencies of major microbial pathogens in various wastewater treatment processes are shown in Table 34, although the most widely used tertiary treatment for nonpotable reuse in the U.S., filtration, is not mentioned.

The WHO guidelines, which apply mainly to agricultural and aquacultural applications and for unrestricted irrigation, are considerably less stringent than U.S. standards. Many of the standards for reuse in the U.S., which are designed mainly for application in urban settings, are more rigorous. As practiced in the U.S. and Japan, reuse includes residential and landscape irrigation, roadway and parkland landscaping, air conditioning, toilet flushing, construction, vehicle washing, fire protection, industrial processing and cooling, and myriad other nonpotable uses. It involves the exposure of large populations and hence should have appropriate standards to protect public health.

In instances where urban dual systems are used, and these are growing, the reclaimed water system serves many functions. If one of these should be agricultural irrigation near the city and the reclaimed water system is designed to serve the urban uses, the water used for irrigation would necessarily meet the water quality requirements for urban uses.

Table 34. Expected Removal of Excreted Microorganisms in Various Wastewater Systems

Treatment Process (a)	Removal (log 10 units) (i) Bacteria	Helminths	Viruses	Cysts
Primary sedimentation				
Plain	0-1	0-2	0-1	0-1
Chemically assisted(b)	1-2	1-3(h)	0-1	0-1
Activated sludge(c)	0-2	0-2	0-1	0-1
Biofiltration(d)	0-2	0-2	0-1	0-1
Aerated lagoon (d)	1-2	1-3(h)	1-2	0-1
Oxidation ditch (c)	1-2	0-2	1-2	0-1
Disinfection(e)	2-6(h)	0-1	0-4	0-3
Waste stabilization ponds (f)	1-6(h)	1-3(h)	1-4	1-4
Effluent storage reservoirs(g)	1-6(h)	1-3(h)	1-4	1-4

(a) Conventional filtration is not included among the processes in the original table.
(b) Further research is needed to confirm performance.
(c) Including secondary sedimentation.
(d) Including settling pond.
(e) Chlorination or ozonation.
(f) Performance depends on number of ponds in series and other environmental factors.
(g) Performance depends on retention time, which varies with demand.
(h) With good design and proper operation, the recommended guidelines are achievable.
(i) A log 10 removal represents a 90 percent reduction; 2 log 10 units represents 99 percent removal, etc.

Source: Adapted from Mara and Cairncross, 1989.

In instances where space for wastewater treatment is limited, and this too is increasing in developing countries, especially in and near the larger cities that are likely to have the sewerage necessary for water reclamation, the use of ponds is generally not feasible economically or aesthetically. With conventional wastewater treatment, chlorine disinfection is required for irrigation of market crops. The use of filtration following conventional secondary (biological) treatment sharply reduces the cost of chlorination and increases its effectiveness. This treatment results in a higher quality water than required by WHO guidelines.

In many developing countries in warm climates, major sources of income are tourism and export of fruits and vegetables that are out of season in other countries. In such instances, the perception of appropriate standards may well change, as the objective is the same as with any product in the importing country rather than the country of origin. For tourists from Europe and for consumers in Europe, the target for water quality must be Europe. Shelef (1991) has proposed standards for Israel that meet these objectives (Table 35). Cyprus is a developing country that is facing just such issues and their approach is described in Section 8.2.4.

Integral to quality guidelines and standards is the necessity for reliability of operations, including the establishment of a protocol for monitoring quality. Because reclaimed water is a product, and not just an effluent, the provision of promised quantity and quality must be assured. For agricultural applications, brief intervals of nondelivery may be tolerable; for urban applications, a continuous supply is mandatory. With regard to quality, deviations may be permissible for wastewater discharges to a river where only the long-term effect is important; for reclaimed water, particularly in urban reuse, deviations above the standard are no more acceptable than they are for drinking water. Accordingly, monitoring is important. Although not always feasible in developing countries, on-line, real-time monitoring is preferable to sampling and laboratory analysis where the results arrive too late to take corrective action. A simple and useful measure of reclaimed water quality is turbidity. Experience can relate turbidity to other parameters of interest but, more importantly, a sudden increase in turbidity beyond the operating standard provides a warning that corrective action is required. For example, practice in the U.S. often requires that, should the turbidity exceed 2 NTU for more than 10 minutes, the reclaimed water be diverted to storage to be retreated. More information on monitoring is available in Section 2.4.

It is fair to say that the WHO guidelines continue to be controversial. For the many instances where raw sewage or rivers heavily polluted with raw sewage are used for irrigation, any treatment would be an improvement. If ponds are feasible and WHO guidelines can be attained, that would be a major public health advance. If ponds are not feasible, the standards may be approached in stages, but certainly should not be perceived as a constraint to any improvements that are affordable. The approach might well be to begin with a first stage of primary treatment, a very major first step in cities that now provide no treatment because it necessarily includes interceptors and trunk sewers, and proceed to secondary treatment and finally filtration as resources and public health conditions dictate.

Those responsible for public health decisions need to consider the health status of their communities. The higher the level of infectious disease in a community, the more prudent health authorities need to be. The unfortunate circumstance is that such communities are the least likely to be able to afford the investments required and the reuse of wastewater may be ill-advised

Table 35. Quality Criteria of Treated Wastewater Effluent to be Reused for Agricultural Irrigation in Israel

Group of Crops	A	B	C	D
Principal Crops	Cotton, sugar beet, cereals, dry fodder seeds, forest irrigation	Green fodder, olives, peanuts, citrus, bananas, almonds, nuts, etc.	Deciduous fruits (a), conserved vegetables, cooked and peeled vegetables, green-belts, football fields, and golf courses	Unrestricted crops, including vegetables eaten uncooked (raw), parks, and lawns
Effluent Quality	(requirements should be met in at least 80 percent of samples taken)			
BOD_5, total, mg/L	60(b)	45(b)	35	15
BOD_5, dissolved, mg/L	—	—	20	10
Suspended solids, mg/L	50(b)	40(b)	30	15
Dissolved oxygen, mg/L	0.5	0.5	0.5	0.5
Coliforms counts/100 mL	—	—	250	12 (80%) 2.2 (50%)
Residual avail. chlorine, mg/L	—	—	0.15	0.5
Mandatory Treatment				
Sand filtration or equiv.	—	—	—	required
Chlorination, minimum contact time, minutes	—	—	60	120
Distances				
From residential areas, m	300	250	—	—
From paved road, m	30	25	—	—

(a) Irrigation must stop 2 weeks before fruit picking; no fruit should be picked from the ground.
(b) Different standards will be set for stabilization ponds with retention time of at least 15 days.

Source: Shelef, 1991.

because of the increased risk to public health from the greater exposure that would result.

8.1.2.3 Treatment Requirements

In developing countries, the choice between modes of treatment, either conventional treatment comprising primary sedimentation, biological secondary treatment (activated sludge, trickling filtration, rotating biological contactors or something similar), sand filtration, and disinfection, or the use of stabilization ponds depends upon the local circumstances. Where smaller communities have or can expect to have sewerage, ponds may be most appropriate if land is available nearby at reasonable cost. The effluent produced will be suitable for agricultural irrigation, and the WHO guidelines may be acceptable, even for market crops, with recognition that the fruit and vegetable products may need to be disinfected before use. Filtration and chemical disinfection of pond effluents are not likely to be feasible operationally and because of high cost.

However, in the larger cities with existing sewerage, the most likely situations where reclamation and reuse are promising, conventional treatment is likely to be the treatment of choice because of limited availability of appropriate land, its high cost, the considerable distance of transmission to reach the treatment site, and public acceptability particularly as the city expands to the vicinity of the sites. As a guide to selection, Table 36 indicates the land requirements for conventional and pond treatment for towns and cities of various sizes.

Table 36. Typical Land Area Required for Pond Treatment Svstems and Secondary Treatment Plants

Population Served	Wastewater Flows (a) (mgd)	(L/s)	Pond Area Required (b) (ac)	(ha)	Secondary WWTF Land Requirements(c) (ac)	(ha)
5,000	0.06	2.6	2	0.8	0.1	0.04
10,000	0.13	5.7	4	1.6	0.3	0.12
50,000	0.65	28.5	20	8	1.4	0.56
100,000	1.3	57.0	40	16	3.0	1.2
250,000	3.25	142.4	100	40	7.0	2.8
1,000,000	526.0	50,000	400	160	30.0	12.0

(a) Assumes wastewater flows of approximately 13 gcd (50 L/capita/d) (Shuval *et al.*, 1986).
(b) Area required to meet effluent standard of 1,000 FC/100 mL, Temperature = 25°C; includes anaerobic pond (World Bank, 1983).
(c) Excluding ancillary facilities.

The design of facilities for developing countries is similar to practice in the U.S., presented in Chapter 2, except for recognition of the need to minimize equipment and instrumentation requirements. With regard to the wastewater elements of treatment, including the handling of sludge, WHO has published Community Wastewater Collection and Disposal (Okun and Ponghis, 1975) and with regard to tertiary treatment, filtration, the Water and Sanitation for Health (WASH) project has published Surface Water Treatment for Communities in Developing Countries (Schulz and Okun, 1984), which covers filtration practices that are applicable to reclamation.

Examples of simple technology that serve with much the same effectiveness as conventional U.S. practice are the use of steep hopper bottoms for primary sedimentation (in the fashion of Imhoff tank sedimentation compartments) rather than sludge collection mechanisms, hydraulic in place of mechanical mixing, pipe and manifold filter bottoms rather than proprietary underdrains, hypochlorite rather than chlorine disinfection, etc.

Requirements for reliability are little different, but they can be met in developing countries by using more personnel and larger detention periods in treatment units, neither of which entails the relatively high costs that they do in the U.S. The institutional problems associated with assuring quantity and quality reliability in cities in developing countries are discussed in Section 8.1.3. While agricultural reuse projects not involving market crops are appropriate throughout Asia, Africa and Latin America, unrestricted urban reuse projects need to be undertaken selectively because of the potential health consequences resulting from wide public exposure to the reclaimed water.

8.1.3 Institutional and Legal Issues

Despite the frequent assertion that urban sanitation is as important as water supply, the fact is that in developing countries the sewerage service is far behind water service both in the fraction of the population that is served and the quality of the service. The water distribution system requires a source of water, transmission lines, and treatment. The sewerage system, on the other hand, often serves only the commercial buildings and the more wealthy households and, even then, only carries the wastewater away from the buildings; trunk sewers or interceptors and wastewater treatment plants are seldom available.

8.1.3.1 Managing Reclaimed Water

While reasonably strong institutions for managing water supply systems exist in developing countries, agencies for managing wastewater collection, treatment, and disposal are poorly organized and lacking in funds.

Furthermore, the water supply agencies, which have a potential for recovering some of their costs through user fees for water service, hesitate to join with those responsible for sewerage who depend almost entirely upon the very limited financial resources of local government.

Leadership in the initiation of studies of water reclamation and reuse in the U.S. may be undertaken by the water supply agency if increased water resources are the driving force or the sewerage agency if pollution abatement is the primary objective, or by both together, particularly if they exist in a single agency. In developing countries, where the purpose of reclamation is to provide additional water, the leadership most often will fall upon the water supply agency or a large water user, such as the Ministry of Agriculture.

The need for water reclamation may, in fact, be a factor in institution-building in the water sector. When large investments are to be made in urban sewerage, it is often recommended that the water agency undertake sewerage and wastewater treatment responsibilities rather than creating or strengthening a sewerage agency. This approach has the advantages of bringing an operating organization with experienced officials to the enterprise, of profiting from economies and efficiencies of scale, and of providing an accepted mechanism for cost recovery. The advantages of such joint enterprise are enhanced where water reclamation and reuse are being considered.

Sao Paulo, Brazil, offers a good example (Section 8.2.2) of how a joint water and sewerage agency, SABESP, with responsibilities for seeking additional sources of water and for reducing pollution of nearby waters, was able to initiate a program of water reclamation and reuse with no interagency or bureaucratic conflicts (Okun and Crook, 1989). Just the opposite situation exists in Beijing, China, where the urgent need for water reuse had been established and widely recognized but where the existence of entirely separate municipal water and sewerage agencies has blocked action towards even planning for implementation (Section 8.2.10).

Sound planning and implementation of reuse projects is possible where separate water and sewerage agencies exist if both of these agencies are relatively strong. An example is in the Los Angeles Metropolitan area where six separate agencies, the water and sanitation agencies of the City of Los Angeles, Los Angeles County, and Orange County, joined in making a plan for water reclamation for an area serving some 15 million people. Joint efforts may be more difficult where one agency is strong and the other weak.

Recognizing that initiating significant institutional changes while undertaking a major capital program is difficult, an examination of the existing relevant institutions and a plan for their modification to permit them to undertake the capital program should be the first order of business (Okun, 1991; UN Development Programme, 1991).

8.1.3.2 Legal Issues

Water reuse in developing countries generally creates two types of legal issues: (1) the protection and creation of water rights and the power of government to allocate water among competing users; and (2) the protection of public health and environmental quality. Other legal issues may also be relevant in specific circumstances.

a. *Water Rights and Water Allocation*

Untreated wastewater is often used near large cities in developing countries for irrigating crops, particularly vegetable crops that are sold in the city. The water may be drawn from the raw wastewater flow or from rivers and streams that receive wastewater discharges. Diverting existing wastewater flows to a treatment facility will, at a minimum, change the point at which the flow is discharged to surface waters, and may change the amount of water available to current users. A water reuse project may completely deprive existing users of their current supply if reclaimed water is sold to new users (e.g., industrial facilities) or allocated to new uses (e.g., municipal use).

Traditional practice and customary law in most developing countries, and formal law in many, recognize that a water user acquires vested rights to use a certain quantity of water under defined circumstances. Changing the amount of water that is available to a current user with vested rights may entitle the user to some type of remedy, including monetary compensation or a supplemental water supply. Municipalities may need express authority to condemn private water rights. Persons planning a water reuse project should be careful to analyze its potential impact on current patterns of water use and to determine what remedies, if any, are available to or should be created for current users if the project interferes with their water uses.

b. *Public Health and Environmental Protection*

The use of reclaimed water for agricultural irrigation and various municipal uses may result in human exposure to pathogens or chemicals, creating potential public health problems. Water reclamation and reuse and the disposal of sludge from wastewater treatment may also have adverse effects on environmental quality if not managed properly.

Planning for water reuse projects should include the development and implementation of regulations that will prevent or mitigate public health and environmental problems. Such regulations include:

- A permit system for authorizing wastewater discharges; technical controls on wastewater treatment;
- Water quality standards for reclaimed water that are appropriate to various uses;
- Controls that will reduce human exposure, such as restrictions on the uses of reclaimed water;
- Controls on access to the wastewater collection system, and controls to prevent cross-connections between the distribution networks for drinking water and reclaimed water;
- Regulations concerning sludge disposal and facility siting; and
- Mechanisms for enforcing all of the above regulations, including monitoring requirements, authority to conduct inspections, and authority to assess penalties for violations.

c. Other Legal Issues

A number of other legal issues discussed in Chapter 5 of this document may also arise in developing countries. The FAO/WHO Working Group on Legal Aspects of Water Supply and Wastewater Management (WHO, 1990) has recommended that any regime for wastewater management include the following provisions, which have been abbreviated for inclusion herein:

- Define "wastewater" or "reclaimed water." ["Wastewater" is used water piped from a community, including discharges from residences, commercial buildings, industrial facilities and the like, which is disposed of into the environment; "reclaimed water" is treated wastewater collected for reuse.]
- Specify who has rights of ownership in reclaimed water.
- Establish a system for licensing the use of reclaimed water.
- Determine how persons with vested rights will be protected from harm due to wastewater diversions that reduce stream flows.
- Establish restrictions on uses, reclaimed water quality, and facility siting to protect public health and the environment.
- Identify mechanisms for enforcing such restrictions.
- Specify procedures for pricing reclaimed water and allocating system costs.
- Specify institutional arrangements for system administration.
- Specify the legal and institutional relationships between the water reclamation project and existing programs in water supply, sewerage, and environmental protection.

8.1.4 Economic and Financial Issues

A principal difference between the U.S. and the developing countries in addressing economic and financial issues concerning reuse arises from the acceptance in the U.S. that the user is responsible for meeting the costs of water and sanitation services. (Exceptions are in the heavy subsidies for agricultural irrigation in the West and, until recently, for wastewater treatment facilities for cities throughout the country.) In the developing countries, however, water has often been provided free or at a nominal charge. Only in recent years have any attempts been made at cost recovery, and that only for O&M. Costs for sewerage are still commonly funded from the local or national exchequers, or property taxes.

The economic justification for water reclamation and reuse depends principally on offsetting the costs of developing necessary additional water sources. Where these costs are subsidized by governments or from low-interest loans or grants from external support agencies (ESAs), and are not passed through to users, costs of water are under-reported and appear low. Unless the real cost of providing water and sewerage services becomes more transparent, consumers are unlikely to be interested in changing existing services if they are adequate. Also, because ESAs approach water supply and sewerage projects separately, and the ministries of government as well as local utilities also deal with them separately, assessments of economic benefits are difficult to perform. Whereas economic justification in the U.S. involves only the local government and its agencies, in developing countries the national agencies and ESAs need to be involved from the start.

For water reclamation and reuse, water supply and sewerage costs need to be considered together, which obliges all the agencies involved to approach water reclamation projects in an integrated fashion, an approach being assiduously pursued by the UN family of agencies led by the UN Development Programme (1991) in its Capacity Building initiative.

The economic rationale for water reuse is little different from that set out in Chapter 6. Cost savings, based on the additional water sources, additional water transmissions mains, and additional treatment that would not be required or that would be postponed, would represent benefits and, therefore, decrease the present value of the necessary investments. Further, in developing countries the costs for collection and treatment of wastewater can be construed as benefits in terms of providing sewerage services that would be necessary even in the absence of reclamation and reuse.

The financial strategies, specifically in terms of alternative capital financing scenarios in the U.S. context, as described in Chapter 6, are probably not feasible in many developing countries. This is mainly due to the immaturity of the capital markets in many of these countries.

Benefits other than cost need to be considered more extensively than in the U.S. For example, a water reclamation project in a developing country, through substitution for potable water used needlessly, may permit potable water service and accompanying benefits to be extended to people who otherwise would have to fetch water themselves for their households, purchase water at a high price from water vendors, or use water from contaminated sources. Given the considerable variety of situations in urban areas of developing countries, specific approaches cannot be generalized, but need to be developed on a case-by-case basis.

A reclamation program can be the vehicle for introducing a rational pricing structure, based on a rational market mechanism for water. The price for fresh or reclaimed water to residential, commercial, industrial, and agricultural customers should reflect their full cost of production plus opportunity costs. The lack of the ability to appreciate the opportunity cost of water will undervalue it as a resource and lead to misallocations among users. The premium or scarcity value of fresh water implicit in the use of reclaimed water should assure that the full resource costs of reclaimed water are less than that of fresh water. Market mechanisms need to reflect this differential.

8.1.5 Implementation of Reuse in Developing Countries

Where water is scarce in urban areas in developing countries, reuse of untreated wastewaters directly or indirectly, via drainage canals or streams, is widely practiced without initiatives from or regulation by public authorities. The health effects of such practices, particularly when used for irrigation of market crops near cities, are well known.

Constraints to implementation of engineered and regulated reclamation and reuse programs in developing countries result from inadequate sewerage systems, most particularly the absence of sewerage, interceptors and trunk sewers, and the absence of functioning treatment facilities. The decades of urban construction without a concomitant investment in wastewater collection and treatment has left a heavy burden on present populations not faced by people in the industrialized countries. Accordingly, implementation of reuse in most cities in the developing world must begin with the provision of these basic sanitation needs, which is beyond the scope of these guidelines.

Where adequate treatment has been provided for a portion of a city, as is the case in Sao Paulo and Cairo, the availability of a high quality effluent stimulates interest in reuse, and the approach to implementation would follow paths similar to those discussed in earlier sections.

8.2 Examples of Reuse Programs Outside the U.S.

This section illustrates practice by means of brief descriptions of projects in several industrialized countries other than the U.S., including specialized situations such as the oil-rich countries of the Middle East, where practices are essentially those of the industrialized countries. Also included are brief descriptions of practices and standards for reuse in several developing countries where an interest in reuse has been demonstrated. This inventory is intended to be illustrative rather than exhaustive.

One conclusion that can be drawn from these examples is that reuse of urban wastewaters, generally untreated, occurs where sewerage and wastewater treatment facilities are not in place, often with highly undesirable health and environmental effects. On the other hand, where treatment facilities are constructed, and operated to discharge a reasonably good effluent, reuse is likely to be exploited beneficially.

For cities where stabilization ponds are the selected method of treatment, restricted reuse may well be economically attractive, particularly for crops that are not to be eaten raw. Where conventional treatment is provided, potential exists for providing tertiary treatment, including filtration and chlorination, which permits unrestricted agricultural irrigation and, more importantly, a wide range of nonpotable urban uses may become economically attractive by permitting substitution of the reclaimed water for limited supplies of high quality fresh water.

The appropriateness of water reclamation and reuse internationally depends on local circumstances and varies considerably from country to country, and even, as in the U.S., among cities in any one country.

8.2.1 Argentina

Effluent from the primary treatment facility of Campo Espejo in Mendoza Province drains into an agricultural canal and is used for unrestricted irrigation of 5,000 ac (2,000 ha) of land. At the city of Ortega, stabilization pond effluent of poor quality is mixed with river water and used for unrestricted irrigation of vegetable crops. It was found that the use of these effluents poses a relatively high health risk. There are no crop restrictions in Argentina, and both workers and consumers were stated to be at risk (Strauss and Blumenthal, 1990).

8.2.2 Brazil

Sao Paulo, with a metropolitan population of about 17 million people, is the third largest city in the world. Its rapid growth promises to raise it to the second largest, after Mexico City, by the end of the 20th century. With the prospect of a limited supply of water, SABESP, the water supply and sewerage agency for the State of Sao Paulo, initiated a study of the feasibility of reclaiming its secondary (activated sludge) effluent for industrial purposes.

Average water demand in Sao Paulo is about 1,000 mgd (43,800 L/s). Some 30,000 industries and large commercial establishments account for about 25 percent of the demand. Because only about 50 percent of the population was served by sewers in 1990, increasing sewerage service now enjoys a high priority.

One unit, 80 mgd (3,500 L/s) of the Barueri activated sludge treatment plant, which is to have an ultimate capacity of 640 mgd (28,000 L/s), was placed in operation in 1988 in the rapidly growing area west of the city. Its effluent was of such high quality that tertiary treatment pilot plants, consisting of coagulation, filtration and disinfection, were built to assess the potential for reclamation for industrial use. An initial pilot plant of about 600 gpd (2 m^3/d) was so successful that a second pilot plant of 20,000 gpd (80 m^3/d) was started up in 1989. The reclaimed water turbidity of this pilot plant effluent ranged from 0.3 to 0.6 NTU, with a COD of 9.8 mg/L.

Although SABESP had assumed that the greatest potential for reuse is in industry, a nonpotable distribution system would be required because the demand of no single plant or grouped set of plants is large enough to provide a market for a major transmission main. A study sponsored by the Pan American Health Organization (Okun and Crook, 1989) on behalf of SABESP revealed many other potential uses in the newly developing areas of Sao Paulo:

- ❑ Urban irrigation: Sao Paulo experiences dry periods from July through September and watering of parks and gardens requires significant amounts of water.
- ❑ Toilet flushing: The largest residential and commercial uses for water are for toilet flushing. While not currently economical for single-family houses, or for retrofitting existing high-rise buildings, it can be economical for new high-rise residential and commercial buildings which constitute the major form of new construction in Sao Paulo.
- ❑ Cleansing: The cleansing of streets, sidewalks, vehicles, etc. are suitable markets for reclaimed water.
- ❑ Urban beautification: Fountains, ponds, and lakes are ideal uses for reclaimed water, reducing fresh water losses from evaporation.
- ❑ Construction: Most major construction in Sao Paulo is reinforced concrete, which requires significant amounts of water for cement mixes.
- ❑ Air pollution control: Scrubbers to wash contaminants from industrial air emissions.
- ❑ Agricultural irrigation: Market crops grown in the vicinity of Sao Paulo can be irrigated with high quality reclaimed water, which might be provided by a single transmission main. Such uses are likely to be transient as urbanization replaces agriculture, but in the interim it is a useful market.

The only major use currently not appropriate in Sao Paulo is for cooling towers associated with power production because electricity is generated by hydropower.

The need for a market survey in Sao Paulo is evident, as is the need for a larger, more flexible pilot plant to determine the next steps in implementation of the reclamation program.

8.2.3 Chile

All of Santiago's wastewater is used indirectly for crop irrigation. Seventy to 80 percent of Santiago's raw wastewater is collected into an open drainage canal, which is then distributed for irrigation. Fecal coliforms average 10^6 - 10^8/100 mL. The irrigated area immediately outside the city provides almost all the salad vegetables and low-growing fruits to the population of Santiago. Circumstantial evidence suggests a connection between the use of raw wastewater for irrigation and the higher incidence of typhoid in Santiago than in the rest of Chile (Strauss and Blumenthal, 1990).

8.2.4 Cyprus

An island with a population of 700,000 in the Mediterranean and a vigorous tourism industry, Cyprus is facing two major obstacles to its continued development: a growing scarcity of water resources in the semi-arid regions of the country and degradation of water at its beaches. The government perceives that a program of water reclamation and reuse would address both problems. It has begun implementation of new sewerage and wastewater treatment and reuse in two major tourist areas, Limassol on the south coast and Larnaca and Ayia Napa-Paralimini on the southeast coast.

An objective of both projects is to prevent discharge of wastewater to the sea, even after filtration and disinfection, to curtail eutrophication of shore waters that has already begun. Accordingly, storage is to be provided to hold reclaimed waters for reuse during dry periods.

While interest is initially in reuse for agricultural irrigation, studies are being inaugurated in Limassol into other uses and the economic aspects of reuse. Water quality for reuse is an issue in Cyprus, with the government opting for standards similar to U.S. practices. Others have believed these to be unnecessarily rigorous and costly for Cyprus and that, in keeping with WHO guidelines, stabilization ponds are all that are necessary. Also, stabilization ponds are seen as performing better in removing helminths than conventional secondary treatment, although helminths have not been identified as a problem in Cyprus.

While stabilization ponds are used in Cyprus, because of the high cost of land in coastal areas and the need for protection of environmental and aesthetic amenities for tourism, conventional secondary treatment is appropriate for specific sites.

The resolution of the quality controversy is that standards and the treatment required are seen to be site-specific, even in so small a country as Cyprus. Conventional biological treatment and tertiary filtration and disinfection are more feasible and acceptable in some situations in Cyprus, such as tourist areas along the coast, than the use of ponds. In other areas, and depending upon the crops to be grown, ponds may be the proper alternative.

The Limassol area is expected to have a population of about 150,000 in 2010. The current project area will serve about 50,000. Later phases will serve another 50,000. The initial phase of the project, for which the World Bank is providing assistance, is to include laterals, main sewers, a conventional secondary (activated sludge) treatment plant of 5 mgd (219 L/s) capacity and a 36-in (90-cm) sea outfall that is to discharge 2,000 ft (600 m) from shore into waters about 40 ft (12 m) deep. The outfall is sized to take only the initial phase effluent. Storage for higher flows is to be provided in impoundments to permit full use of the reclaimed water and limit sea discharges.

The initial phase of the project includes *inter alia* effluent and sludge reuse and studies to identify the range of appropriate options for other cities in Cyprus. The first phase of the study will identify the most promising uses, taking into account for each use the quality and quantity of the reclaimed water to be produced, potential markets, health hazards, costs and benefits, etc. The required treatment and infrastructure needs will be identified and pilot demonstration projects will be designed. The second phase will include a review of the pricing policy for reclaimed water.

The Southeast Coast Sewerage and Drainage Project in Larnaca, which is to serve Larnaca and the communities of Ayia Napa and Paralimni some 25 mi (40 km) to the east, includes sewerage systems, treatment plants (with a common plant serving Ayia Napa and Paralimni), and distribution systems for the reclaimed water. Some service areas in Larnaca are low-lying, and because of the potential danger from saltwater infiltration care is to be taken to protect the quality of the reclaimed water. Financial arrangements for cost recovery are to be integrated (as a surcharge on water consumption) for the sewerage and the reclaimed water services.

The benefits to be addressed by the project include improved sanitation, simplicity, and reliability over what is provided by onsite systems, environmental protection, promotion of the tourist industry, and development of a perennial reliable source of water for irrigation in a water-scarce environment.

8.2.5 India

Irrigation with untreated wastewater is widely practiced in India. Some 180,000 ac (73,000 ha) of land were irrigated with wastewater in 1985 on at least 200 sewage farms.

The law prohibits irrigation of salad vegetables with wastewater, yet the practice is widespread and government agencies reportedly do not actively enforce regulations governing reuse. Furthermore, in many states there is no microbiological standard and hence no parameter with which to control the level of treatment. Enteric diseases, anemia and gastrointestinal illnesses are high among sewage farm workers, and quite possibly consumers of salad and vegetable crops are at risk. A Ganges River program is to include treatment facilities for six cities in Uttar Pradesh. These projects are to incorporate reuse for agriculture and forestry.

8.2.6 *Israel*

Some 230 reclaimed water projects in Israel in 1987 produced about 70 mgd (3,000 L/s) of reclaimed water from a population of over 4 million people (Argaman, 1989). Nearly 70 percent of the wastewater was reused; approximately 92 percent of the wastewater was collected by municipal sewers and of this 72 percent was reused for irrigation (42 percent) or groundwater recharge (30 percent). Reuse constitutes approximately 10 percent of the water supply in Israel, but by 2010 it is projected that reuse will account for about 20 percent, with about one-third of the total water resource allocated to agricultural irrigation.

Reuse up to 1982 amounted to about 25 percent of the wastewater generated. Since that time the development of several large projects, namely the Kishon project at Haifa and the Dan Region Phase II project at Tel Aviv, led to a large increase in water reuse. The majority of reuse projects in Israel make use of surface impoundments to store the water during the winter and have it available for the summer irrigation season. There are more than 120 seasonal reservoirs in operation throughout Israel with capacities ranging from 130,000 to 3,000 million gal capacity (50,000 to 12 million m^3).

The Kishon reclamation project receives an average of about 15 mgd (657 L/s) of reclaimed water from the Haifa sewage treatment facility. The water is pumped 50 mi (30 km) to the farms in the Yzre'el Valley, where it is used for irrigation. The facility includes reservoirs for seasonal storage because irrigation normally occurs over a 4-month period. The reclaimed water is chlorinated at different points and its quality generally meets Israeli standards for unrestricted irrigation. (Table 35) The irrigated area is approximately 40,000 ac (15,000 ha), with the main crop being cotton.

The Dan Region Wastewater Reclamation Project, with an average flow of about 50 mgd (2,200 L/s) was developed in two phases. Each phase involves reclamation for groundwater recharge for agricultural irrigation. Phase I, which receives wastewater from southern Tel Aviv (receiving pond treatment and chemical precipitation), has been in operation since 1970. Water is applied by means of intermittent flooding to spreading basins and percolates to the local coastal aquifer. Phase II uses conventional activated sludge treatment with nitrogen removal. The reclaimed water is recharged by spreading into a sandy aquifer with a minimum of 300 days detention time. It is withdrawn by recovery wells and conveyed by a 70-in (178-cm) diameter pipe for distances up to 50 mi (80 km) to irrigation sites. Following disinfection and storage, the reclaimed water meets the Israel standards for unrestricted irrigation, including those for vegetables to be eaten raw.

The use of reclaimed water must be approved by local, regional, and national authorities. Effluent used for irrigation must meet water quality standards set by the Ministry of Health. The trend is toward unrestricted use with wider crop rotation ,which will necessitate more storage and higher levels of treatment in the future. This trend toward higher levels of treatment, approaching drinking water quality, is being promoted by environmental concerns and by farmers who export produce to highly competitive foreign markets.

8.2.7 *Japan*

Because of the great density of population in Japan and its limited water resources, programs of reclamation and reuse were begun early. The principal target to reduce water demand was through provision of reclaimed water for toilet flushing in multi-family, commercial, and school buildings. In one respect, Japan is in a situation faced by cities in the developing world; only about 40 percent of its total population are sewered. Buildings being retrofitted for flush toilets and new buildings offer excellent opportunities for reuse. Their program began by recycling in a building or group of buildings, with a reclamation plant treating all the wastewaters to furnish water for toilets and other incidental nonpotable purposes. It was soon perceived that using municipal treatment works and a reclaimed water system as part of a dual system would be more effective and economical than individual reclamation facilities.

As of 1986, Japan used about 71 mgd (3,100 L/s) distributed as shown in Table 37. At that time about 40 percent of the reclaimed water was being distributed in dual systems. Of this, as shown in Table 38, more than one-third was being used for toilet flushing, and about 15 percent each for urban irrigation and cleansing. A wide variety of buildings were fitted for reclaimed water, as shown in Table 39, with schools and office buildings being most numerous. In Tokyo, the use of reclaimed water is mandated in all new buildings larger in floor area than

300,000 sq. ft. (30,000 m^2). Multi-family dwellings of about 200 household units (10 floors with 20 units each), which would meet this criterion for such buildings, are not large by current urban housing standards in many developing countries.

Table 37. Uses of Reclaimed Water in Japan

Use	%	1,000 m^3/d	mgd
Nonpotable in dual systems	40	110	29
Industrial	29	77	20
Agricultural	15	40	11
Stream flow augmentation	12	32	8
Snow removal	4	11	3
	100	270	71

Source: Murakami, 1989.

Table 38. Uses of Reclaimed Water in Dual Systems in Japan

Use	Percent
Toilet flushing	37
Cooling water	9
Landscape irrigation	15
Car washing	7
Washing and cleansing	16
Flow augmentation	6
Other	10
	100

Source: Murakami, 1989.

Table 39. Types of Buildings Using Reclaimed Water in Japan

Buildings	Percent
Schools	18
Office Buildings	17
Public Halls	9
Factories	8
Hotels	4
Others(residences, shopping centers, etc.)	44
	100

Source: Murakami, 1989

Japan offers a very good model for urban cities in developing countries because their historical usage has been for meeting urban water needs rather than only agricultural irrigation requirements. Their reclaimed water quality requirements, shown in Table 40, are different from those in the U.S., more stringent for coliform counts for unrestricted use, while less restrictive for other applications.

8.2.8 Kuwait

With a population estimated at about 2 million, most of Kuwait can be considered urban. The country is arid, with average annual rainfall less than 5 in (12.5 cm). With no surface sources, water is drawn from groundwater at the rate of about 0.6 mgd (26 L/s), mainly for producing bottled water. Most water needs are met by desalination. About 85 percent of the population is on a central sewerage system.

Kuwait provides tertiary treatment (activated sludge treatment, filtration ,and chlorination) for reclamation for agricultural irrigation. Their standards are shown in Table 41. Three reclamation plants have a total capacity of more than 80 mgd (3,500 L/s), with plans to use all of it for agricultural irrigation and some landscape irrigation.

8.2.9 Mexico

Approximately 90 percent of Mexico City's wastewater is reused in agriculture in the Mezquital Valley (Tula) and 10 percent is reused for green belt irrigation. Approximately 80 percent, 900 mgd (40,000 L/s), of an average of about 1,200 mgd (52,600 L/s) of irrigation water is provided by sewage and storm runoff from Mexico City. The concentrations of fecal coliform in the irrigation water varies between 10^6 - 10^8/100 mL. Farmers interviewed by a visiting team of researchers complained of enteric and other diseases (Strauss and Blumenthal, 1990). The irrigation district practices crop restriction; however irrigation of maize, beans, chili, green tomatoes, and alfalfa is not restricted. The distribution of the irrigation water is managed by six irrigation districts, and plans have been developed for the creation of 11 more districts in other parts of Mexico. The long term National Water Development Program envisages that irrigation with reclaimed water will be extended to 125,000 ac (50,000 ha). Industrial reuse is projected to increase from about 100 mgd (4,380 L/s) to 300 mgd (13,150 L/s).

8.2.10 People's Republic of China

Beijing and Tianjin, the principal ports in northern China, are two of the country's largest and most important cities. The Beijing-Tianjin region, an extensively industrialized area with 18 million people, sits at the bottom of the Hei River basin, where little flow remains in the river after water is drawn for the household, industrial, and

Table 40. Reclaimed Water Criteria in Japan

Parameter	Toilet Flush Water	Landscape Irrigation	Ornamental Lakes & Streams	Environmental (aesthetic setting)	Environmental (limited public contact)
E. Coli (count/100 mL)	≤10	not detected	not detected	—	—
Combined Chlorine Residual (mg/L)	retained(a)	≥0.4	—	—	—
Total Coliform (count/100 mL)	—	—	—	<1,000	<50
Appearance	not unpleasant	not unpleasant	not unpleasant	—	—
Turbidity (units)	—	—	≤10	<10	<5
BOD (mg/L)	—	—	≤10	<10	<3
Odor	not unpleasant	not unpleasant	not unpleasant	not unpleasant	not unpleasant
pH	5.8 - 8.6	5.8 - 8.6	5.8 - 8.6	5.8 - 8.6	5.8 - 8.6
Color (units)	—	—	—	<40	<10

(a) At last holding tank in distribution line.

Source: Murakami, 1989.

agricultural needs of the approximately 100 million people living in the upper reaches of the basin. About 40 percent of this region's population lives in rural areas, and agricultural irrigation requires about 65 percent of the available water. The situation here is typical of urban centers throughout the world: falling groundwater tables and increasing land subsidence. Saltwater intrusion and heavy pollution are rendering much of the region's water unusable.

Table 41. Reclaimed Water Standards in Kuwait

Parameter	Irrigation of Fodder & Food Crops not Eaten Raw, Forestland	Irrigation of Food Crops Eaten Raw
Level of Treatment	Advanced	Advanced
SS (mg/L)	10	10
BOD (mg/L)	10	10
COD (mg/L)	40	40
Chlorine Residual (mg/L), after 12 hrs @ 20°C	1	1
Coliform Bacteria (count/100 mL)	10,000	100

Heroic efforts have succeeded in bringing water into the region from outside the basin. Plans are being made for a $1 billion project to bring water in from the silt-laden Yellow River about 100 mi (160 km) away. If constructed, this project would meet the current needs of the region. When asked about the future, however, officials rest their hopes on bringing water from the Yangtze, more than 500 mi (800 km) away.

Studies of the water resources in the region have concluded that the reduction of agricultural water use through more efficient irrigation practices and the reclamation of wastewater for nonpotable urban and industrial needs should have the highest priority in the region's water management plans (East-West Institute, 1988). These approaches could meet the region's water needs at a far lower cost than those of the proposed massive capital projects. However, although these approaches are technically and financially feasible, they suffer from the same problems that face major urban areas in all developing countries: the inability to allocate scarce water resources effectively because of the many authorities responsible for water management, the absence of a rational policy for pricing water, and the difficulty of initiating urban water reclamation and reuse projects because of institutional inflexibility at the municipal level. This situation, so common throughout the world, reveals that the solutions to water resource problems do not flounder from lack of technology or even from a lack of funds but from the lack of a capacity to effect change. One bright spot in China is a modern wastewater treatment plant that serves about 25 percent of Tianjin with a well operated activated sludge plant followed by polishing ponds that produce an effluent that is beginning to be reclaimed for urban use.

8.2.11 Peru

Reuse is widely practiced in communities along the coastal desert strip. In Lima, about 12,000 ac (5,000 ha) are irrigated with raw wastewater. A project is being prepared to irrigate about 10,000 ac (4,000 ha) south of Lima, with effluent that will receive primary pond treatment followed by infiltration or finishing ponds. Ica, located 180 mi (300 km) south of Lima, uses effluent treated in facultative lagoons for restricted irrigation of 1,000 ac (400 ha). At Tacna, Peru's southernmost town, effluent treated in lagoons is used to irrigate 500 ac (200 ha) of land. Typical of the situation in many developing countries are several cities cited by Yanez (1992) where raw sewage is used for irrigation of market vegetables that are eaten without processing. Furthermore, the effluent produced by stabilization ponds throughout Peru is of generally low quality because of design deficiencies, operational problems, or overloading. Numerous enteric bacterial and viral infections are reported, although the many possible transmission routes preclude attributing a direct link to irrigation practices (Strauss and Blumenthal, 1990).

8.2.12 Republic of South Africa

The Republic of South Africa has adopted standards similar in character to those in the U.S. Elements of their research establishment had long been advocates of potable reuse, although the practice has never been adopted by the utilities in the country. They do require tertiary treatment with no fecal coliform permitted for unrestricted nonpotable uses such as for irrigation of sports fields, pasture for milking animals, toilet flushing and dust control, with reclaimed water meeting the contaminant levels called for in their drinking water standards for food crops eaten raw, residential lawns, children's play parks, and human washing. Their requirements are listed in Table 42.

8.2.13 Saudi Arabia

Saudi Arabia is committed to a policy of complete reuse. In 1978, the amount of reclaimed water used was estimated at 25 mgd (1,100 L/s), and the projection for the year 2000 is about 500 mgd (22,000 L/s). By 2000 the Kingdom expects to meet almost 10 percent of its water demand through reuse. Regulations require secondary treatment with tertiary treatment for unrestricted irrigation, with standards shown in Table 43 (Kalthem and Jamaan, 1985).

Table 42. Reclaimed Water Guidelines in South Africa

Reuse Application	Level of Treatment	Maxiumum Fecal Coliform (count/100 mL)
Irrigation of dry fodder, seed crops, trees, non-recreational parks, nurseries (restricted access)	Primary and secondary; humus tank effluent	<1,000
Food crops not eaten raw, cut flowers, orchards and vineyards, pasture, parks, sports fields, school grounds (restricted access)	Primary, secondary, and tertiary; oxidation pond system	<1,000
Pasture for milking animals, sports fields, school grounds (unrestricted access)	Standard - primary, secondary, and tertiary	0.0
Food crops eaten raw, lawns, nurseries, school grounds, play parks (unrestricted access)	Advanced (general drinking water standards)	—
Industrial reuse	Primary, secondary, and tertirary; oxidation pond system	<1,000
Toilet flushing and dust control	Standard - primary, secondary, and tertiary	0.0
Human washing	Advanced (general drinking water standards)	—

Of special interest are the projects at Riyadh, Jeddah, and Mecca and Jubail Industrial City. At Riyadh the trickling filter facility treats over 30 mgd (1,300 L/s). Of this, about 15 percent is used by the General Petroleum and Minerals Organization (Petromin) for industrial reuse, and the rest is available for agricultural irrigation on about 7,800 ac (3,100 ha). A 10-mgd (440-L/s) activated sludge facility at Jeddah is designed to exceed WHO standards and is the first in the region which was designed to meet the equivalent of drinking water standards. Advanced treatment includes reverse osmosis, desalination, filtration, and disinfection. Other plants are planned for

Jeddah and Mecca. In both cities the reclaimed water will be used for municipal, industrial, and agricultural reuse. The City of Jubail is planned to have a 30-mgd (1,300-L/s) treatment capacity by 1992, with plans for nonpotable industrial, urban landscaping, and other reuses.

In all, 22 wastewater treatment plants are in operation, 10 of which are waste stabilization ponds. Most are currently discharging to wadis or to the sea, although plans are underway to increase reuse (Yanez, 1989).

Table 43. Reclaimed Water Standards for Unrestricted Irrigation in Saudi Arabia

Parameter (a)	Maxiumum Contaminant Level
BOD	10.0
TSS	10.0
pH	6 - 8.4
Coliform (count/100 mL)	2.2
Turbidity (NTU)	1.0
Aluminum	5.0
Arsenic	0.1
Beryllium	0.1
Boron	0.5
Cadmium	0.01
Chloride	280
Chromium	0.1
Cobalt	0.05
Copper	0.4
Cyanide	0.05
Fluoride	2.0
Iron	5.0
Lead	0.1
Lithium	0.07
Manganese	0.2
Mercury	0.001
Molybdenum	0.01
Nickel	0.02
Nitrate	10.0
Selenium	0.02
Zinc	4.0
Oil & Grease	Absent
Phenol	0.002

(a) In mg/L unless otherwise specified.

8.2.14 Singapore

Singapore is a city-state with a dense and growing population of almost 3,000,000 people on an island with heavy rainfall, averaging 100 in (250 cm)/yr, but limited water resources because of its small size, only about 210 sq mi (540 sq km). Several secondary (activated sludge) plants discharge their effluents to the sea. At one location, near the Jurong Industrial Estate, a portion (10 mgd, [440 L/s]) of the effluent is withdrawn from the outfall for serving industrial needs on the estate. Treatment involves conventional sand filtration and chlorination, and the reclaimed water is pumped to a covered tank on a hilltop on the estate. When a major housing development for the estate was built, for a population of about 25,000 in 15-story buildings, all the toilets were served with reclaimed water.

Originally, operation of the reclamation facility was the responsibility of the estate but, after some difficulties, O&M was taken over by the Singapore Public Utilities Board, which is responsible for wastewater collection and treatment in Singapore.

8.2.15 Sultanate of Oman

In Oman, water has been reused in the Capital Area around Muscat since 1987. Currently effluent from two treatment plants—at Darsait and at Shatti al Qurm—is used mainly to irrigate extensive amenity plantings by drip irrigation. Spray irrigation is not used in recreation areas, but between 1 a.m. and 6 a.m., some spray irrigation is conducted in controlled areas. Pressure in the distribution system, which extends to more than 2.5 mi (40 km) is some 30 to 45 psi (210 to 310 kPa). Effluent requirements are set in the Regulations for Wastewater Reuse and Discharge.

The Darsait plant is currently operating at capacity and treating about 3.2 mgd (140 L/s) of wastewater. This plant serves the local business district and also receives septage and wastewater pumped from holding tanks. The treatment processes include screening, grit removal in aerated grit chambers, primary settling, activated sludge treatment by contact stabilization, dual-media filtration, and chlorination. If the chlorine concentration exceeds 0.2 mg/L after chlorine contact, air is added to strip out the excess chlorine. Effluent is pumped to a storage tank that provides pressure to the water reuse transmission system.

The Shatti al Qurm plant is a package extended-aeration plant followed by filtration in pressure units and disinfection. This plant has a capacity of about 0.36 mgd (16 L/s); plant flow is about 0.2 mgd (9 L/s). The wastewater to this plant comes from embassies and residences in the area. Treated effluent is stored and pumped into the water reclamation transmission system.

A third plant, at Al Ansab, treats only wastes from septage and wastewater haulers. The plant capacity is about 3.5 mgd (150 L/s), and current flows are about 1.3 mgd (57 L/s). Treatment processes include screening, degritting, denitrification in an anoxic zone, nitrification, secondary settling, filtration, and disinfection, and storage. The plant has facilities to load trucks that can apply treated effluent.

Plans are to connect the plant to the reclamation distribution system.

During the summer, all the reclaimed water in the area is used, and demands are not met. But during the winter about 40 percent of the effluent from the Darsait plant is discharged through an outfall to the Gulf of Oman. In the future, the reuse network will be expanded so that all the effluent is reused.

8.2.16 Tunisia

Although all the countries of North Africa have an interest in water reclamation, Tunisia has done the most, making reuse a priority in their national water resources strategy (Bahri, 1991; Asano and Mujeriego, 1992).

Some 1,500 ac (600 ha) of citrus and olive tree orchards near Tunis had been irrigated with groundwater from shallow aquifers since the 1960s but, because of overdraft and seawater intrusion, secondary effluent from a portion of Tunis wastewaters was used for irrigation seasonally, in spring and summer. The effluent is pumped into a 1.5-million gal (5.7-million L) pond and then to a 1-million gal (3.8-million L) reservoir, and then flows by gravity about 5 mi (8 km) to the farmers.

Currently, the effluent from four treatment plants, with a total flow of about 65 mgd (2,850 L/s) is used to irrigate about 12,000 ac (4,500 ha) of orchards, forage crops, cotton, cereals, golf courses and lawns. About 70 percent of the irrigated area around Tunis will use about 60 percent of the available wastewater effluent.

Considerable research has been undertaken, particularly to assess the fertilizer value of reclaimed water and the sewage produced in treatment. Reclaimed water irrigation produced higher yields than groundwater irrigation. Studies of the contamination of crops and groundwater when reclaimed water is used revealed little significant impact on soils, crops, or groundwater (Bahri, 1991).

The National Sewerage and Sanitation Agency is responsible for the construction and operation of all sewerage and treatment infrastructure in the larger cities in Tunisia. When effluent is to be used for agricultural irrigation, the Ministry of Agriculture is responsible for execution of the projects, which include the construction and operation of all facilities for pumping, storing and distributing the reclaimed water. Various departments of the Ministry are responsible for the several functions, while regional departments supervise the Water Code and collection of charges, about \$0.10/1,000 gal (\$0.02-0.03/m³).

The Water Code, enacted in 1975, prohibits the use of untreated wastewater in agriculture to be eaten raw. More recent legislation covers the regulation of contaminants in the environment, including reclaimed water, and specifies the responsibilities of the Ministries of Agriculture and Public Health, and the National Environmental Protection Agency. Table 44 illustrates the maximum concentrations for several contaminants in reclaimed water to be used in agriculture.

Table 44. Maximum Concentrations for Reclaimed Water Reused in Agriculture in Tunisia

Parameters (a)	Maximum Concentration
pH	6.5 - 8.5
Electrical Conductivity (US/cm)	7000 (b)
Chemical Oxygen Demand	90
Biochemical Oxygen Demand	30b)
Suspended Matters	30b)
Chloride	2000
Fluoride	3
Halogenated Hydrocarbons	0.001
Arsenic	0.1
Boron	3
Cadmium	0.01
Cobalt	0.1
Chromium	0.1
Copper	0.5
Fluoride	3
Iron	5
Manganese	0.5
Mercury	0.001
Nickel	0.2
Lead	1
Selenium	0.05
Zinc	5
Intestinal nematodes (Arithmetic man no. of eggs/L)	< 1/1

(a) All units in mg/L unless otherwise specified.
(b) 24-hour composite sample.

Source: Bahri, 1991.

8.2.17 United Arab Emirates

Extensive nonpotable reuse has been practiced in Abu Dhabi since 1976. The system, designed for 50 mgd (219 L/s), includes a dual distribution network which uses reclaimed water for urban irrigation of public gardens, trees, shrubs and grassed areas along roadways. The treatment facility provides tertiary treatment with rapid sand filtration and disinfection by chlorination and ozonation. The reclaimed water distribution system is operated at lower pressure than the potable system to reduce wind spraying; elements of the system are marked and labeled to avoid cross-connections.

Al-Ain, with a projected population of 250,000 by the year 2000, produces reclaimed water that may be used only for restricted irrigation. The reclaimed water is pumped about 7 mi (12 km) outside the city where it is used for irrigation in designated areas. Treatment includes dual-media filtration and chlorination for disinfection.

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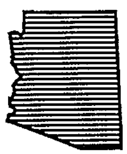
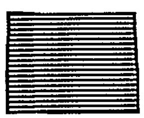
Appendix A

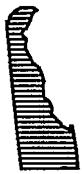
State Reuse Regulations and Guidelines

Table A-1. Unrestricted Urban Reuse (Page 1 of 6)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates [1]	Groundwater Monitoring [1]	Setback Distances [1][2]	Other
 Arkansas	• Secondary treatment and disinfection			• Based on water balance using divisional average annual 90 percentile rainfall	• Hydraulic - 0.5 to 4.0 in/wk • Nitrogen - Percolate nitrate-nitrogen not to exceed 10 mg/l	• Required • 1 well upgradient • 1 well within site • 1 well down-gradient	• Determined on case-by-case basis	
 Arizona	• pH - 4.5 - 9.0 • Fecal coliform - 25/100 ml (median) 75/100 ml (single sample) • Turbidity - 5 NTU	• pH - 1/month • Fecal coliform - 1/day • Turbidity - continuous		• Minimum of five days when only surface irrigation available				• Have limit on certain pathogenic organisms and trace substances
 California	• Disinfected, oxidized, coagulated, clarified and filtered • Total coliform - 2.2/100 ml (median) 23/100 ml (single sample) • Turbidity - 2 NTU	• Total coliform - 1/day • Turbidity - continuous	• Warning alarms • Back-up power source • Emergency storage: short-term, 1 day; long term, 20 days • Multiple treatment unit processes or disposal options					• For landscape impoundment reclaimed water shall be disinfected and oxidized with the median total coliform ≤23/100 ml
 Colorado	*Irrigation:* • Disinfected, oxidized, coagulated, clarified and filtered • Total coliform - 2.2/100 ml (median) 23/100 ml (single sample) *Landscape impoundments:* • Disinfected and oxidized • Total coliform - 23/100 ml (median)						• 500 ft. to domestic supply well • 100 ft. to any irrigation well	

(1) For irrigation use only.
(2) Distances are from edge of wetted perimeter unless otherwise noted.

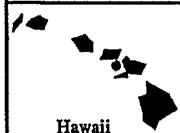
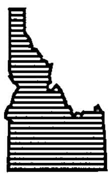
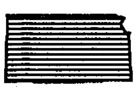
Table A-1. Unrestricted Urban Reuse (Page 2 of 6)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
 Delaware	• Biological treatment • 30 mg/l BOD • 30 mg/l TSS • Fecal coliform - 30/100 ml	• Site specific		• Minimum 15 days • Must determine operational, wet weather, and water balance storage based on site conditions and 5-year return monthly precipitation	• Based on nitrogen loading • Hydraulic - ≤2.5 in/wk ≤0.25 in/hr	• Required • 1 well upgradient of site • 1 well within wetted field area • 2 wells down-gradient in each drainage basin intersected by site	• Determined on a case-by-case basis	• Regulations pertain to sites open to public access
 Florida	• Secondary treatment with filtration, high level disinfection and chemical feed facilities • 20 mg/l CBOD (annual average) • 5 mg/l TSS (single sample) • Minimum chlorine residual of 1 mg/l after 15 min. contact time at peak hourly flow • Fecal coliform - over 30 day period - 75% of samples below detection 25/100 ml (single sample)	• TSS limit achieved prior to disinfection and sampled daily • Continuous on-line monitoring of turbidity and chlorine residual • Fecal coliform 1/day for treatment facility >0.5 mgd • Operating Protocol Required • Annual analysis of primary and secondary drinking water parameters	• Class I reliability - requires multiple or backup treatment units and a secondary power source • Minimum of 1 day reject storage • Minimum system size of 0.1 mgd - except 0.5 mgd for residential irrigation • Staffing - 24 hr/day 7 days a wk or 6 hrs/day 7 days a wk with operator presence during diversion of reclaimed water to reuse system	• Minimum of three (3) days • Water balance required with volume of storage based on a 10-year recurrence interval	• Site specific • Hydraulic - Maximum of 2.0 in/wk recommended • Based on nutrient and water balance assessments	• Required • 1 well upgradient • 1 well within reuse site • 1 well down-gradient • Monitoring required quarterly and can be done on representative sites	• 75 ft. to potable water supply well • 75 ft. from transmission facility to public water supply well • Low trajectory nozzles required within 100 ft. of outdoor public eating, drinking, and bathing facilities	• Includes use of reclaimed water for toilet flushing, fire protection, construction dust control, and aesthetic purposes • Tank trucks can be used to apply reclaimed water • Hose bibbs allowed in underground service box • Cross-Connection control program required
 Georgia	• Biological treatment • 30 mg/l BOD • 30 mg/1 TSS • Fecal coliform - 30/100 ml	• Site specific		• Minimum of 12 days storage • Must determine operational, wet weather, and water balance storage based on site specific conditions and 5-year return monthly precipitation	• Based on nitrogen loading • Hydraulic ≤2.5 in/wk ≤0.25 in/hr	• Required • 1 well upgradient of site • 1 well in wetted field area • 2 wells down-gradient in each drainage basin intersected by site	• Determined on a case-by-case basis	• Regulations pertain to sites open to public access

(1) For irrigation use only.

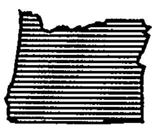
(2) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-1. Unrestricted Urban Reuse
(Page 3 of 6)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
 Hawaii	• Oxidized, coagulated, filtered and disinfected • Total coliform - 2.2/100 ml (7 day mean) 23/100 ml (single sample) • Detectable enteric animal viruses - <1 PFU per 40 liters	• Total coliform - 1/day	• Reliability features to insure necessary treatment levels required • Minimum of 1 day reject storage unless another reuse or disposal system provided	• Volume of storage based on water balance using 50 year rainfall recurrence interval		• Required • Groundwater wells to extend approx. ten feet below the water table	• None required	• Includes use of reclaimed water for fire fighting, corporate vehicle washing, toilet flushing, decorative fountains and street cleaning
 Idaho	• Disinfected, oxidized, coagulated, clarified, and filtered • Total coliform - 2.2/100 ml (median)							
 Illinois	• Two cell lagoon system with sand filtration and disinfection or mechanical secondary treatment with disinfection			• Minimum of 150 days • Water balance required based on wettest year with a 20-year frequency	• Based on hydraulic, nitrogen, phosphorus and BOD loadings	• Required • 1 well upgradient • 2 wells down-gradient	*Non-spray application:* • 50 ft. to residential lot • 10 ft. to public road right-of-way *Spray irrigation:* • 150 ft. to residential lot	
 Kansas	• Secondary treatment with filtration and disinfection			• Minimum of 90 days when no discharge to surface water is available	• Hydraulic - ≤40 in/ac/yr • Based on nutrient requirements of selected crop	• Site specific • May be required	• None required	• Public access prohibited during and after irrigation

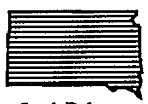
(1) For irrigation use only.
(2) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-1. Unrestricted Urban Reuse
(Page 4 of 6)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1)(2)	Other
 Montana	• Disinfected, oxidized, coagulated, clarified, and filtered • Fecal coliform - 2.2/100 ml (7 day median) 23/100 ml (single sample) • Turbidity-2NT (avg.) 5 NTU (5% during 24 hr. period)				• Nitrogen and hydraulic loadings determined based on methods in EPA Manual 625/1-81-013	• Required when groundwater levels are within 20 feet of the natural ground surface in the irrigation zone	• 200 ft. to any dwelling	
 Nevada	• Secondary treatment with disinfection • Fecal coliform - 2.2/100 ml (mean) 23/100 ml (single sample) • Turbidity - 3 NTU (single sample)	• Samples taken prior to application point and after final treatment					• None required	
 New Mexico	• Adequately treated and disinfected • Fecal coliform - 100/100 ml	• Fecal coliform sample taken at point of diversion to irrigation						
 Oregon	• Biological treatment, disinfection, coagulation and filtration • Total coliform - 2.2/100 ml (mean) 23/100 ml (single sample) • Turbidity - 2 NTU (24 hr mean) 5 NTU (5% of time during 24 hrs.)	• Total coliform - 1/day • Turbidity - hourly	• Standby power for all essential treatment processes • Multiple treatment units and monitoring equipment to insure required levels of treatment				• None required	• Includes use of reclaimed water for landscape impoundments and construction use.

(1) For irrigation use only.
(2) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-1. Unrestricted Urban Reuse (Page 5 of 6)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
 South Carolina	• Secondary treatment with disinfection, chemical addition & filtration • BOD ≤ 5 mg/l (monthly avg.) • SS ≤ 5 mg/l (monthly avg.) • Total coliform - ≤4/100 ml (mo. avg.)	• Continuous monitoring of turbidity • Virus monitoring	• Operator presence 24 hrs/day, 7 days/wk • Minimum system size of 1.0 mgd • Back-up effluent disposal system required for inclement weather and/or unusual operating conditions	• Minimum of 7 days • Water balance required as documented in EPA manual 625/1-81-013	• Hydraulic - ≤2 in/wk (Coastal Plain area) ≤1 in/wk (Piedmont area)	• Required • 1 well upgradient • 2 wells down-gradient		• Irrigation of landscaped areas limited to night or early morning
 South Dakota	• Secondary treatment and disinfection • Total coliform - 200/100 ml (mean)			• Minimum of 210 days	• Hydraulic - ≤2 in/acre/wk ≤24 in/acre/yr	• Shallow wells in all directions of groundwater flow from site and not more than 200 ft. outside of site		
 Tennessee	• Treatment requirements on a case-by-case basis • Disinfection required • BOD ≤ 30 mg/l • TSS ≤ 30 mg/l • Fecal coliform - ≤200/100 ml			• Based on water balance using five-year return monthly precipitation	• Nitrogen - Percolate nitrate-nitrogen not to exceed 10 mg/l • Hydraulic - Based on water balance using five-year return monthly precipitation	• Required	*Surface Irrigation:* • 100 ft. to site boundary • 50 ft. to on-site streams, ponds and roads *Spray Irrigation:* [1] Open Fields • 300 ft. to site boundary • 150 ft. to on-site streams, ponds and roads [2] Forested • 150 ft. to site boundary • 75 ft. to on-site streams, ponds and roads	• Pertains to irrigation of parks, green areas and other public land where public exposure is likely to occur

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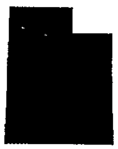
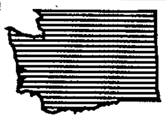
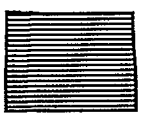
(2) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-1. Unrestricted Urban Reuse (Page 6 of 6)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates[1]	Groundwater Monitoring [1]	Setback Distances [1][2]	Other
 Texas	• 5 mg/l BOD (10 mg/l for landscape impoundments) • Turbidity - 3 NTU (30 day av.) • Fecal coliform not to exceed 75/100 ml	• Sampling and analysis 1/wk		• Based on water balance using average monthly precipitation records	• Site specific • Based on water balance			• Includes use of reclaimed water for toilet flushing
 Utah	• Advanced treatment • BOD ≤ 10 mg/l at any time • TSS ≤ 5 mg/l at any time • Total coliform - ≤ 3/100 ml at any time							
 Washington	• Secondary treatment • Total coliform - 20/100 ml (mean)		• Warning alarms • Back-up power source • Emergency storage: short-term, 1 day; long term, 20 days • Multiple treatment unit processes or storage disposal options • Personnel available or on call at all times the irrigation system is operating	• Storage required • Volume of storage based on site conditions		• Required • Minimum of one well in each direction of groundwater movement from site and one well upgradient of site	• Site specific	
 Wyoming	• BOD ≤ 10 mg/l (daytime) • BOD ≤ 30 mg/l (dusk - dawn) • pH 4.5 - 9.0 • Fecal coliforms - ≤ 200/100 ml • TDS ≤ 480 mg/l • Chlorides - ≤ 213 mg/l				• Hydraulic - < 4.0 in/wk recommended		• 100 ft. buffer zone around spray site	• Pertains to unrestricted irrigation of parks, playgrounds, highway rest areas and rights-of-way

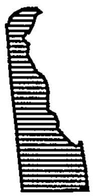
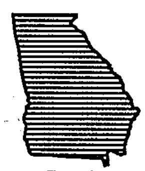
(1) For irrigation use only.
(2) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-2. Restricted Urban Reuse
(Page 1 of 8)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Arkansas	• Secondary treatment and disinfection			• Based on water balance using divisional average annual 90 percentile rainfall	• Hydraulic - 0.5 to 4.0 in/wk. • Nitrogen - Percolate nitrate-nitrogen not to exceed 10 mg/l	• Required • 1 well upgradient • 1 well within site • 1 well down-gradient	• Determined on case-by-case basis	
 Arizona	• pH - 4.5 - 9.0 • Fecal coliform - 200/100 ml (median) 1000/100 ml (single sample)	• pH - 1/month • Fecal coliform - 1/wk.		• Minimum of five days when only surface irrigation available				• Have limits on trace substances
 California	• Disinfected and oxidized • Total coliform - 23/100 ml (median) 240/100 ml (single sample)	• Total coliform - 1/day	• Warning alarms • Back-up power source • Emergency storage: short-term, 1 day; long term, 20 days • Multiple treatment unit processes or storage or disposal provisions					
 Colorado	• Disinfected and oxidized • Total coliform - 23/100 ml (median) 240/100 ml (2 consecutive samples)						• 500 ft. to domestic supply well • 100 ft. to any irrigation well	

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-2. (Page 2 of 8) **Restricted Urban Reuse**

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Delaware	• Biological treatment • 30 mg/l BOD • 30 mg/l TSS • Fecal coliform - 30/100 ml	• Site specific		• Minimum of 15 days • Must determine operational, wet weather, and water balance storage based on site conditions and 5-year return monthly precipitation	• Based on nitrogen loading • Hydraulic - ≤2.5 in/wk. ≤0.25 in/hr.	• Required • 1 well upgradient of site • 1 well within wetted field area • 2 wells down-gradient in each drainage basin intersected by site	• Determined on a case-by-case basis	• Regulations pertain to sites open to public access
 Florida	• Secondary treatment with filtration, high level disinfection and chemical feed facilities • 20 mg/l CBOD (annual average) • 5 mg/l TSS (single sample) • Minimum chlorine residual of 1 mg/l after 15 min. contact time at peak hourly flow • Fecal coliform - over 30 day period - 75% of samples below detection 25/100 ml (single sample)	• TSS limit achieved prior to disinfection and sampled daily • Continuous on-line monitoring of turbidity and chlorine residual • Fecal coliform - 1/day for treatment facility >0.5 mgd • Operating protocol required • Annual analysis of primary and secondary drinking water standards	• Minimum system size of 0.1 mgd • Class I reliability - requires multiple or backup treatment units and a secondary power source • Minimum of 1 day reject storage • Staffing - 24 hr /day 7 days a wk. or 6 hrs/day 7 days a wk. with operator presence during diversion of reclaimed water to reuse system	• Minimum of three (3) days • Water balance required with volume of storage based on a 10-year recurrence interval	• Site specific • Hydraulic - maximum of 2.0 in/wk. recommended • Based on nutrient and water balance assessments	• Required • 1 well upgradient • 1 well within reuse site • 1 well down-gradient • Monitoring required quarterly and can be done on representative sites	• 75 ft. to potable water supply well • Low trajectory nozzles required within 100 ft. of outdoor public eating, drinking, and bathing facilities • 75 ft. from transmission facility to public water supply well	• Rules do not differentiate between unrestricted and restricted urban reuse • Cross-connection control program required
 Georgia	• Biological treatment • 30 mg/l BOD • 30 mg/l TSS • Fecal coliform - 30/100 ml	• Site specific		• Minimum of 12 days • Must determine operational, wet weather, and water balance storage based on site specific conditions and 5-year return monthly precipitation	• Based on nitrogen loading • Hydraulic ≤2.5 in/wk. ≤0.25 in/hr.	• Required • 1 well upgradient of site • 1 well in wetted field area • 2 wells down-gradient in each drainage basin intersected by site	• Determined on a case-by-case basis	• Regulations pertain to sites open to public access

[1] Distances are from edge of wetted perimeter unless otherwise noted.

Table A-2. Restricted Urban Reuse
(Page 3 of 8)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Hawaii	• Disinfection and oxidized • Total coliform - 23/100 ml (7 day mean) 240/100 ml (2 consecutive samples)	• Total coliform - 1/day	• Reliability features to insure necessary treatment levels required • Minimum of 1 day reject storage unless another reuse or disposal system provided	• Volume of storage based on water balance using 50 year rainfall recurrence interval		• Required • Groundwater wells to extend approx. ten feet below the water table	*Spray Irrigation* • 500 ft. to residences or property lines, however not required if irrigating from 9:00pm to 5:00am *Drip Irrigation* • 5 ft. to residences or property lines, however not required if irrigating from 9:00pm to 5:00am *Surface Irrigation:* • No setback requirements	
 Idaho	• Disinfected and oxidized • Total coliform - 230/100 ml (median)							
 Illinois	• Two cell lagoon system with sand filtration and disinfection or mechanical secondary treatment with disinfection			• Minimum of 150 days • Water balance required based on wettest year with a 20-year frequency	• Based on hydraulic, nitrogen, phosphorus and BOD loadings	• Required • 1 well upgradient • 2 wells down-gradient	*Non-spray application:* • 50 ft. to residential lot • 10 ft. to public road right-of-way *Spray irrigation:* • 150 ft. to residential lot	

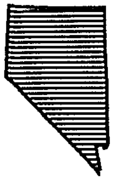
(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-2. Restricted Urban Reuse
(Page 4 of 8)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
 Kansas	• Secondary treatment with disinfection			• Minimum of 90 days when no discharge to surface water is available	• Based on nutrient requirements of selected crop • Hydraulic - ≤40 in/ac/yr.	• Site specific • May be required	• None required	
 Maryland	• 30 mg/l BOD • 90 mg/l TSS • Fecal coliform - 3/100 ml • pH - 6.5-8.5			• Minimum of 60 days • Water balance required based on wettest year with a 10-year frequency	Hydraulic - 0 - 2 in/wk.	• Required • 1 well upgradient of site • 2 wells down-gradient	• 200 ft. to property lines, waterways, and roads for spray irrigation. • 50 ft. for non-spray systems • 500 ft. to housing developments and parks for spray irrigation. • 50 ft. for non-spray irrigation	• Regulations pertain to golf course irrigation.
 Missouri	• Secondary treatment equivalent to treatment obtained from primary waste-water pond cell • Disinfected prior to application (not storage) • Fecal coliform - 200/100 ml			• Minimum of 60 days in south with no discharge • Minimum of 120 days in north with no discharge • Water balance required with storage based on one in 10-year frequency for storage period selected	• Hydraulic - 40 - 100in/yr. ≤0.5 in/hr. ≤1.0 in/day ≤3.0 in/wk. • Nitrogen loading not to exceed nitrogen utilization of crop	• Minimum of 1 well between site and public supply well	• 150 ft. to existing dwellings or public use areas • 50 ft. to property lines • 300 ft. to potable water supply wells not on property, sinkholes, and losing streams	• Public restricted from area during application
 Montana	• Disinfected and oxidized • Fecal coliform - 200/100 ml (7 day median) 400/100 ml (2 consecutive samples)				• Nitrogen and hydraulic loadings determined based on methods in EPA Manual 625/1-81-013	• Required when groundwater levels are within 20 feet of the natural ground surface in the irrigation zone	• 200 ft. to any dwelling	

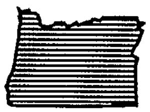
(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-2. **Restricted Urban Reuse**
(Page 5 of 8)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Nebraska	• Biological treatment • Disinfected prior to application	• Site specific			• Nitrogen loading not to exceed crop uptake • Hydraulic ≤4.0 in/wk.	• Site specific		
 Nevada	• Secondary treatment with disinfection *No buffer zone:* • Fecal coliform 2.2/100 ml (mean) 23/100 ml (single sample) • Turbidity - 3 NTU (single sample) *100' buffer zone:* • Fecal coliform 23/100 ml (mean) 240/100 ml (single sample) • Turbidity - 5 NTU (single sample)	• Samples taken prior to application point and after final treatment					• None or 100 ft., depending on level of disinfection	
 New Mexico	• Adequately treated and disinfected • Fecal coliform - 1000/100 ml	• Fecal coliform sample taken at point of diversion to irrigation system						
 North Carolina	• 5 mg/l TSS (monthly avg.) 10 mg/l TSS (daily maximum) • Maximum fecal coliform level of 1/100 ml	• TSS and fecal coliform limits met prior to discharge to detention pond	• All essential treatment units provided in duplicate • Back-up power source	• 5 day detention pond plus irrigation pond with size determined by mass water balance for worse conditions on record	• Hydraulic - ≤1.75 in/wk.		• 100 ft. vegetative buffer to nearest dwelling	

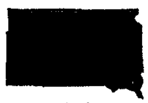
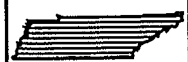
(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-2. **Restricted Urban Reuse**
(Page 6 of 8)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Oklahoma	• Waste stabilization pond effluent limitations as defined by the Oklahoma State Department of Health Design Requirements OR • Minimum of primary treatment		• Emergency storage should be considered in case of system failure ∘ Reliability features including factors of safety, back-up systems, and contingency plans should be considered	∘ Based on water balance using 90 percentile annual rainfall isopleths ∘ Must also consider cessation of irrigation operation during winter months	∘ Based on nutrient, organic, and water balance assessments	• Network of monitoring wells may be necessary and should be evaluated for systems with deep percolation rates	• Spray irrigation may require buffer zones to ensure that aerosols are contained on the site	
 Oregon	• Biological treatment and disinfection • Total coliform - 240/100 ml (2 consecutive samples) 23/100 ml (median)	• Total coliform - 1/week	• Standby power for all essential treatment processes ∘ Multiple treatment units and monitoring equipment to insure required levels of treatment				• 10 ft. buffer with surface irrigation • 70 ft. buffer with spray irrigation • 100 ft. to drinking fountains and areas of food preparation	
 South Carolina	∘ Secondary treatment with disinfection, chemical addition & filtration (filtration & chemical addition not required for golf course irrigation) • BOD ≤ 5 mg/l (monthly avg.) • SS ≤ 5 mg/l (monthly avg.) • Total coliform - ≤4/100 ml (mo. • For golf course irrigation - total coliform ≤200/100 ml	∘ Continuous monitoring of turbidity ∘ Virus monitoring	∘ Operator presence 24 hrs/day, 7 days/wk. • Minimum system size of 1.0 mgd ∘ Back-up effluent disposal system required for inclement weather and/or unusual operating conditions	• Minimum of 7 days ∘ Water balance required as documented in EPA manual 625/1-81-013	• Hydraulic - ≤2in/wk. (Coastal Plain area) ≤1 in/wk. (Piedmont area)	• Required • 1 well upgradient • 2 wells down-gradient • For golf courses a minimum of 9 wells are suggested for each 18 fairways	• 75 ft. to residences for golf course irrigation	• Irrigation of landscaped areas limited to night or early morning (does not include golf courses)

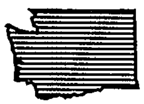
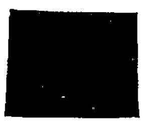
(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-2. Restricted Urban Reuse
(Page 7 of 8)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 South Dakota	• Secondary treatment and disinfection • Total coliform - 200/100 ml (mean)			• Minimum of 210 days	• Hydraulic - ≤2in/acre/wk. ≤24 in/acre/yr.	• Shallow wells in all directions of groundwater flow from site and not more than 200 ft. outside of site		
 Tennessee	• Treatment requirements on a case-by-case basis • Disinfection required • BOD ≤ 30 mg/l • TSS ≤ 30 mg/l • Fecal coliform - ≤ 200/100 ml			• Based on water balance using five-year return monthly precipitation	• Nitrogen - Percolate nitrate-nitrogen not to exceed 10 mg/l • Hydraulic - Based on water balance using five-year return monthly precipitation	• Required	*Surface Irrigation:* • 100 ft. to site boundary • 50 ft. to on-site streams, ponds and roads *Spray Irrigation:* [1] Open Fields • 300 ft. to site boundary • 150 ft. to on-site streams, ponds and roads [2] Forested • 150 ft. to site boundary • 75 ft. to on-site streams, ponds and roads	
 Texas	• 30 mg/l BOD with treatment using pond system (30 day av.) • 20 mg/l BOD with treatment other than pond system (30 day av.) • Fecal coliform not to exceed 800/100 ml	• Sampling and analysis 1/month		• Based on water balance using average monthly precipitation records	• Site specific • Based on water balance			

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-2. Restricted Urban Reuse
(Page 8 of 8)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Utah	• Advanced treatment • BOD ≤ 10 mg/l at any time • TSS ≤ 5 mg/l at any time • Total coliform - ≤ 3/100 ml at any time							
 Washington	• Secondary treatment • Total coliform - 20/100 ml (mean)		• Warning alarms • Back-up power source • Emergency storage: short-term, 1 day; long term, 20 days • Multiple treatment unit processes or storage disposal options • Personnel available or on call at all times the irrigation system is operating	• Storage required • Volume of storage based on site conditions		• Minimum of one well in each direction of groundwater movement from site and one well upgradient of site		
 Wyoming	• BOD ≤ 10 mg/l (daytime) • BOD ≤ 30 mg/l (dusk - dawn) • pH 4.5 - 9.0 • Fecal coliforms - ≤ 200/100 ml • TDS ≤ 480 mg/l • Chlorides - ≤ 213 mg/l				• Hydraulic - < 4.0 in/wk. recommended		• 100 ft. buffer zone around spray site	

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse – Food Crops (Page 1 of 9)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Arkansas	• Primary treatment			• Based on water balance using divisional average annual 90 percentile rainfall	• Hydraulic - 0.5 to 4.0 in/wk • Nitrogen - Percolate nitrate-nitrogen not to exceed 10 mg/l	• Required • 1 well upgradient • 1 well within site • 1 well down-gradient	*Spray irrigation:* • 200 ft. • 1320 ft. to populated area *Non-spray system:* • 50 ft. • 660 ft. to populated area	• Pertains to processed food crops only and evaluated on a case-by-case basis. Irrigation of raw food crops is not permitted
 Arizona	*Consumed raw:* • pH - 4.5 - 9.0 • Fecal coliform - 2.2/100 ml (median) 25/100 ml (single sample) • Turbidity - 1 NTU *Processed food:* • pH - 4.5 - 9.0 • Fecal coliform - 1000/100 ml (median) 2500/100 ml (single sample)	*Consumed raw:* • pH - 1/month • Fecal coliform - 1/day • Turbidity - continuous *Processed food:* • pH - 1/month • Fecal coliform - 1/month		• Minimum of five days when only surface irrigation available				• Have limits on certain pathogenic organisms and trace substances
 California	*Spray irrigation:* • Disinfected, oxidized, coagulated, clarified, & filtered • Total coliform - 2.2/100 ml (median) 23/100 ml (single sample) • Turbidity - 2 NTU *Surface irrigation:* • Disinfected and oxidized (primary treatment for orchards & vineyards) • Total coliform - 2.2/100 ml (median)	• Total coliform - 1/day • Turbidity - continuous	• Warning alarms • Back-up power source • Emergency storage: short-term, 1 day; long term, 20 days • Multiple treatment unit processes or storage or disposal provisions					

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse -- Food Crops (Page 2 of 9)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
Colorado	*Consumed raw:* [1] Surface irrigation ∘ Disinfected and oxidized ∘ Total coliform - 2.2/100 ml (median) [not acceptable for root crops or crops where edible portions contact ground] [2] Spray irrigation ∘ Disinfected, oxidized, coagulated, clarified, and filtered ∘ Total coliform - 2.2/100 ml (median) *Processed food:* ∘ Disinfected and oxidized ∘ Total coliform - 23/100 ml (median) *Orchards & Vineyards:* [1] Surface irrigation ∘ Disinfected and oxidized • Total coliform - 23/100 ml (median) [edible portion of plant cannot contact ground] [2] Spray irrigation ∘ Disinfected, oxidized, coagulated, clarified, and filtered • Total coliform - 2.2/100 ml (median)						• 500 ft. to domestic supply well • 100 ft. to any irrigation well ∘ Setback from property lines based upon use of adjoining property	

[(1)] Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse – Food Crops
(Page 3 of 9)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Florida	• Secondary treatment with filtration, high level disinfection and chemical feed facilities • 20 mg/l COD (annual average) • 5 mg/l TSS (single sample) • Minimum chlorine residual of 1 mg/l after 15 minutes contact time at peak hourly flow • Fecal coliform - over 30 day period, 75% of samples below detection 25/100 ml (single sample)	• TSS limit achieved prior to disinfection and sampled daily • Continuous on-line monitoring of turbidity and chlorine residual • Fecal coliform - 1/day for treatment facility >0.5 mgd • Operating protocol required • Annual analysis of primary and secondary drinking water standards	• Class I reliability - requires multiple or backup treatment units and a secondary power source • Minimum of 1 day reject storage • Minimum system size of 0.5 mgd except 0.1 mgd for processed citrus • Staffing - 24 hr/day 7 days a wk or 6 hrs/day 7 days a week with operator presence during diversion of reclaimed water to reuse system	• Minimum of three (3) days • Water balance required with volume of storage based on a 10-year recurrence interval	• Site specific • Hydraulic - maximum of 2.0 in/wk recommended • Based on nutrient and water balance assessments	• Required • 1 well upgradient • 1 well within reuse site • 1 well down-gradient • Monitoring required quarterly	• 75 ft. to potable water supply well • 75 ft. from transmission facility to public supply well • Low trajectory nozzles required within 100 feet of outdoor public eating, drinking, and bathing facilities	• Direct contact irrigation of edible crops that will not be peeled, skinned, cooked or thermally processed before consumption is not allowed except for tobacco and citrus • Indirect contact irrigation methods can be used for any edible crop

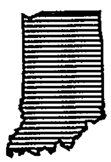
Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse – Food Crops (Page 4 of 9)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Hawaii	*Root food crop and spray irrigation of orchards and vineyards with < 30 days to fruit formation:* • Oxidized, coagulated, filtered and disinfected • Total coliform - 2.2/100 ml (7 day mean) 23/100 ml (single sample) • Detectable enteric animal viruses - <1 PFU per 40 liters *Non-root food crop with edible portion not in touch with ground or within two ft. of reclaimed water* • Oxidized and disinfected • Total coliform - 2.2/100 ml (7 day mean) 23/100 ml (single sample) *Spray Irrigation of orchards >30 days to fruit formation or surface or drip irrigation of orchards and vineyards* • Oxidized and disinfected • Total coliform - 23/100 ml (7 day mean) 240/100 ml (2 consecutive days)	• Total coliform - 1/day	• Reliability features to insure necessary treatment levels required • Minimum of 1 day reject storage unless another reuse or disposal system provided.	• Volume of storage based on water balance using 50 year rainfall recurrence interval		• Required • Groundwater wells to extend approx. ten feet below the water table	*Non-Root Food Crop and orchards and vineyards with >30 days to fruit formation:* [1] Spray Irrigation • 500 ft. to residences or property lines, however not required if irrigating from 9:00pm to 5:00am [2] Drip Irrigation • 5 ft. to residences or property lines, however not required if irrigating from 9:00pm to 5:00am [3] Surface Irrigation • No setback requirements	• Also have limits on certain pathogenic organisms for root crops and spray irrigation of vineyards and orchards with less than 30 days to fruit formation

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse – Food Crops
(Page 5 of 9)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Idaho	*Consumed raw:* • Disinfected, oxidized, coagulated, clarified, and filtered • Total coliform - 2.2/100 ml (median) *Processed foods & orchards & vineyards with no direct contact of reclaimed water:* [1] Unrestricted public access • Disinfected primary effluent • Total coliform - 230/100 ml (median) [2] Restricted public access • Primary effluent							
 Indiana	• Disinfection may be required if: Fecal coliform >1000/100 ml (median) >2000/100 ml (single sample) • pH of effluent and soil mixture >6.5			• Minimum of 90 days	• Hydraulic - ≤2.0 in/wk • Organic - ≤933 lbs. BOD/ac/wk • Nitrogen - not to exceed uptake rate of crop • Cadmium - ≤0.45 lbs./ac/yr		• 300 ft. from any body of fresh water • 300 ft. from nearest residence	• Includes feed for animals which are used for human consumption
 Kansas								• Irrigation of unprocessed food for direct human consumption prohibited

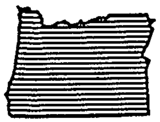
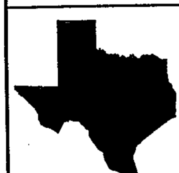
(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse – Food Crops (Page 6 of 9)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Michigan	• Case-by-case basis • Governed by Michigan Water Resources Commission issued NPDES permits				• Nitrogen application not to exceed normal nitrogen requirements of crop		• 150 ft. to private drinking water wells and property lines • Can be reduced to 50 ft. from property lines with adjacent land owners permission	• Crops for human consumption shall be limited to crops requiring processing prior to consumption
 Montana	• Disinfected, oxidized, coagulated, clarified, and filtered • Fecal coliform - 2.2/100 ml (7 day median) 23/100 ml (single sample) • Turbidity - 2 TU (avg.) 5 TU (5% during 24 hr. period)				• Nitrogen and hydraulic loadings determined based on methods in EPA Manual 625/1-81-013	Required when groundwater levels are within 20 feet of the natural ground surface in the irrigation zone	• 200 ft. to any dwelling	• Exceptions to reclaimed water quality requirements may be considered for food crops which undergo extensive commercial, physical, or chemical processing
 Nevada	• Secondary treatment • Disinfection not required for surface application	• Samples taken prior to application point and after final treatment					• None required	• Only surface irrigation of fruit or nut bearing trees permitted
 New Mexico	• Adequately treated and disinfected • Fecal coliform - 1000/100 ml	• Fecal coliform sample taken at point of diversion to irrigation system						• Only surface irrigation on food crops with no contact of reclaimed water on edible portion permitted

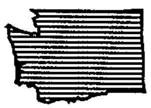
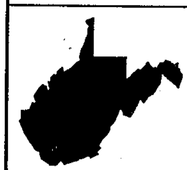
[1] Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse – Food Crops (Page 7 of 9)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Oregon	*Unprocessed food excluding orchards and vineyards:* • Biological treatment, disinfection, coagulation, and filtration • Total coliform - 2.2/100 ml (median) 23/100 ml (single sample) • Turbidity - 2 NTU (24 hr mean) 5 NTU (5% of time during 24 hrs.) *Processed food:* • Biological treatment & disinfection • Total coliform - 240/100 ml (2 consecutive samples) 23/100 ml (median)	*Unprocessed food:* • Total coliform - 1/day • Turbidity - hourly *Processed food:* • Total coliform - 1/week	• Standby power for all essential treatment processes • Multiple treatment units and monitoring equipment to insure required levels of treatment				*Unprocessed food:* • None required *Processed food:* • 10 ft. buffer for surface irrigation • 70 ft. buffer for spray irrigation	
 Texas	• 30 mg/l BOD with treatment using pond system (30 day avg.) • 10 mg/l BOD with treatment other than pond system (30 day avg.) • Turbidity - 3 NTU (30 day avg.) • Fecal coliform - not to exceed 75/100 ml	• Sampling and analysis 1/wk		• Based on water balance using average monthly precipitation records	• Site specific, based on water balance			• Spray irrigation not permitted on foods to be consumed raw

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse – Food Crops (Page 8 of 9)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Utah	• Secondary treatment • 25 mg/l BOD (30 day mean) • 25 mg/l TSS (30 day mean) • Total coliform - 2000/100 ml (30 day mean) • Fecal coliform - 200/100 ml (30 day mean) • pH 6.5 - 9.0						None required with spray irrigation of advanced treated reclaimed water	• Reclaimed water cannot be sprayed unless advanced treatment is provided • Considers only certain crops such as grains, cereals, nuts, fruits, and spices on case-by-case basis • Irrigation area must be fenced
 Washington	*Spray irrigation:* • Secondary treatment and filtration • Total coliform - 2.2/100 ml (mean) 24/100 ml (single sample) *Surface irrigation:* • Secondary treatment • Total coliform - 2.2/100 ml (mean) 23/100 ml (mean) for orchards and vineyards	• Continuous on-line monitoring of turbidity	• Warning alarms • Back-up power source • Emergency storage: short-term, 1 day; long term, 20 days • Multiple treatment unit processes or storage or disposal provisions • Personnel available or on call at all times the irrigation system is operating	• Storage required • Volume of storage based on site conditions		• Minimum of one well in each direction of groundwater movement from site and one well upgradient of site	• Site specific	• Effluent quality requirements for processed food determined on case-by-case basis
 West Virginia	• Secondary treatment and disinfection • 30 mg/l BOD • 30 mg/l TSS	• Analysis of crop required if used for human consumption		• Minimum of 90 days	• Hydraulic - maximum of 0.25 in/hr. 0.50 in/day 2.0 in/wk	• Minimum of one well between project site and public well(s) or high capacity private wells	• Fence shall be placed at least 50 ft. beyond spray area • 350 ft. from fence to adjacent property lines or highways unless low trajectory spray and/or physical buffers are provided	

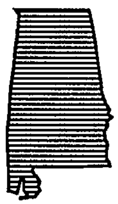
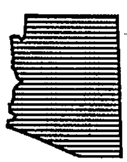
[1] Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse – Food Crops (Page 9 of 9)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Wyoming	• BOD ≤ 10 mg/l (daytime) • BOD ≤ 30 mg/l (dusk - dawn) • pH 4.5 - 9.0 • Fecal coliforms - ≤ 200/100 ml • TDS ≤ 480 mg/l • Chlorides - ≤ 213 mg/l				• Hydraulic - < 4.0 in/wk recommended		• 100 ft. buffer zone around spray site	

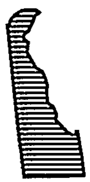
(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops (Page 1 of 10)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Alabama	• Secondary treatment			• Based on water balance using five-year monthly return period with minimum 30 year base period	• Based on water and nutrient balances		• 100 ft. to property lines • 300 ft. to habitable residences • 100 ft. to any perennial lake or stream • 200 ft. to 500 ft. to drinking water supply sources depending on the system capacity	• Irrigation of feed crops used for dairy cattle not permitted
 Arkansas	• Primary treatment • Disinfection also required when irrigating dairy cattle pasture land			• Based on water balance using divisional average annual 90 percentile rainfall	• Hydraulic - 0.5 to 4.0 in/wk • Nitrogen - Percolate nitrate-nitrogen not to exceed 10 mg/l	• Required • 1 well upgradient • 1 well within site • 1 well down-gradient	*Spray irrigations:* • 200 ft. • 1320 ft. to populated area *Non-spray system:* • 50 ft. • 660 ft. to populated area	
 Arizona	• pH - 4.5 - 9.0 • Fecal coliform - 100/100 ml (median) 4000/100 ml (single sample)	• pH - 1/month • Fecal coliform - 1/month		• Minimum of five days when only surface irrigation available				• Have limit on common tapeworm for pastures as well as limit on trace substances
 California	*Fodder, fiber & seed:* • Primary treatment *Pasture for milking animals:* • Disinfected and oxidized • Total coliform - 23/100 ml (median)	• Total coliform - 1/day	• Warning alarms • Back-up power source • Emergency storage: short-term, 1 day; long term, 20 days • Multiple treatment unit processes or storage or disposal provisions					

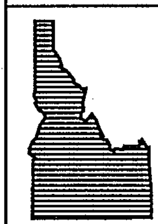
(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops (Page 2 of 10)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Colorado	• Disinfected and oxidized • Total coliform - 23/100 ml (median)						• 500 ft. to domestic supply well • 100 ft. to any irrigation well • Setback from property lines based upon use of adjoining property	• Includes irrigation of pasture for milking animals
 Delaware	• Biological treatment • BOD - 50 mg/l avg. flow 75 mg/l peak flow • 50 mg/l TSS • Fecal coliform - 200/100 ml (at all times)	• Site specific		• Minimum 15 days • Must determine operational, wet weather, and water balance storage based on site conditions and 5-year return monthly precipitation	• Based on nitrogen loading • Hydraulic - ≤2.5 in/wk ≤0.25 in/hr	• Required • 1 well upgradient • 1 well within wetted field area • 2 wells down-gradient in each drainage basin intersected by site	• 150 ft. to all property boundaries • 100 ft. to perennial lake or stream	• Regulations pertain to sites closed to public access
 Florida	• Secondary treatment and basic disinfection • 20 mg/l CBOD (annual average) • 20 mg/l TSS (annual average) • 10 mg/l TSS for subsurface application systems (single sample) • Chlorine residual of 0.5 mg/l • Fecal coliform - 200/100 ml (monthly mean) 800/100 ml (single sample)	• Limitations to be met after disinfection • Monitoring frequencies specified by treatment facility size • Annual scan of primary and secondary drinking water standards	Class III reliability	• Minimum of three (3) days • Water balance required with volume of storage based on a 10-year recurrence interval	• Site specific • Hydraulic • Maximum of 2.0 in/wk recommended • Based on nutrient and water balance assessments	• Required quarterly • 1 well upgradient • 1 well within reuse site • 1 well down-gradient	• 100 ft. to property lines • 500 ft. to potable water supply wells • 100 ft. from transmission facility to public supply well • Setback distances can be reduced if additional treatment and reliability are provided	Milking cows are not permitted to graze on land for a period of 15 days after last application of reclaimed water

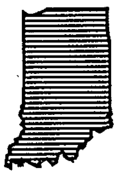
(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops (Page 3 of 10)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Georgia	• Biological treatment • BOD - 50 mg/l ad. flow 75 mg/l peak flow • 50 mg/1 TSS • Disinfection not required	• Site specific		• Minimum of 12 days storage • Must determine operational, wet weather, and water balance storage based on site conditions and 5-year return monthly precipitation	• Based on nitrogen loading • Hydraulic ≤2.5 in/wk ≤0.25 in/hr	• Required • 1 well upgradient • 1 well in wetted field area • 2 wells down-gradient in each drainage basin intersected by site	• 150 ft. to all property lines and public roads • 100 ft. to perennial lake or stream • 300 ft. between any structure and treatment facility and storage pond • 300 ft. to any structure	• Regulations pertain to sites closed to public access
 Hawaii	*Fodder and seed crops, pasture and tree farms:* • Oxidized and disinfected • Total coliform - 23/100 ml (7 day mean) 240/100 ml (2 consecutive days) *Sod farms and ornamental nursery stock:* • Oxidized and disinfected • Total coliform - 2.2/100 ml (7 day mean) 23/100 ml (single sample)	• Total coliform - 1/day	• Reliability features to insure necessary treatment levels required • Minimum of 1 day reject storage unless another reuse or disposal system provided	• Volume of storage based on water balance using 50 year rainfall recurrence interval		• Required • Groundwater wells to extend approx. ten feet below the water table	*Spray Irrigation:* • 500 ft. to residences or property lines; however not required if irrigating from 9:00pm to 5:00am *Drip Irrigation:* • 5 ft. to residences or property lines; however not required if irrigating from 9:00pm to 5:00am *Surface Irrigation:* • No setback requirements	
 Idaho	*Unrestricted public access:* • Disinfected primary effluent • Total coliform - 230/100 ml (single sample) *Restricted public access:* • Primary effluent							• No grazing of animals where effluent applied

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops (Page 4 of 10)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Illinois	• Two cell lagoon or mechanical secondary treatment			• Minimum of 150 days • Water balance required based on wettest year with a 20-year frequency	• Site specific • Based on hydraulic, nitrogen, phosphorus and BOD loadings	• Required • 1 well upgradient • 2 wells down-gradient	*Non-spray application:* • 50 ft. to residential lot • 10 ft. to public road right-of-way Spray irrigation: • 150 ft. to residential lot	
 Indiana	• Disinfection may be required if: Fecal coliform >1000/100 ml (median) >2000/100 ml (single sample)			• Minimum of 90 days	• Hydraulic ≤2.0 in/wk • Organic ≤933 lbs. BOD/ac/wk		• 300 ft. from any body of fresh water	• Grazing of dairy animals prohibited for one month after application on site
 Kansas	• Secondary treatment with periodic discharge to surface waters • Primary treatment with no discharge to surface water			• Minimum of 90 days when no discharge to surface water is available	• Maximum of 40 in/ac/yr • Based on nutrient requirements of selected crop	• Site specific	• 500 ft. to residential areas • 200 ft. to wells and water supplies off of site property • 100 ft. to adjacent properties	
 Maryland	• 30 mg/l BOD • 90 mg/l TSS • pH - 6.5-8.5 • Fecal coliform - 200/100 ml			• Minimum of 60 days • Water balance required based on wettest year with a 10-year frequency	• Hydraulic - 0.0 - 2.0 in/wk	• Required • 1 well upgradient • 2 wells down-gradient	• 200 ft. to property lines, waterways, and roads for spray irrigation. • 50 ft. for non-spray systems • 500 ft. to housing developments and parks for spray irrigation. • 50 ft. for non-spray irrigation	

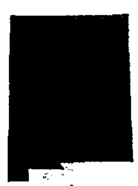
[1] Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops (Page 5 of 10)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Michigan	• Case-by-case basis • Governed by Michigan Water Resources Commission issued NPDES permits				• Nitrogen application not to exceed normal nitrogen requirements of crop		• 150 ft. to private drinking water wells and property lines • Can be reduced to 50 ft. from property lines with adjacent land owners permission	• Dairy cattle cannot graze on site until season following the final season of irrigation
 Missouri	• Secondary treatment equivalent to treatment obtained from primary wastewater pond cell			• Minimum of 60 days in south with no discharge • Minimum of 120 days in north with no discharge • Water balance required with storage based on one in 10-year frequency for storage period selected	• Hydraulic - ≤0.5 in/hr ≤1.0 in/day ≤3.0 in/wk • Nitrogen loading not to exceed nitrogen utilization of crop	• Minimum of 1 well between project site and public well(s)	• 150 ft. to existing dwellings or public use areas • 50 ft. to property lines • 300 ft. to potable water supply wells not on property, sinkholes, and losing streams	• Grazing of animals and harvesting of forage crops not permitted up to 30 days after irrigation
 Montana	*Fodder, fiber, and seed crops:* • Secondary treatment • Fecal coliform ≤ 1000/100 ml *Pasture for milking animals:* • Disinfected and oxidized • Fecal coliform 23/100 ml (7 day median)				• Nitrogen and hydraulic loadings determined based on methods in EPA Manual 625/1-81-013	• Required when groundwater levels are within 20 feet of the natural ground surface in the irrigation zone	• 200 feet to any dwelling • 250 feet between fencing and irrigated area when reclaimed water is not disinfected	
 Nebraska	• Biological treatment	• Site specific			• Hydraulic ≤4.0 in/wk • Nitrogen loading not to exceed uptake of crop	• Site specific		

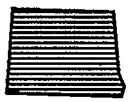
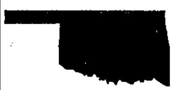
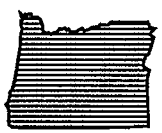
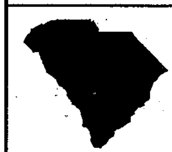
[1] Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops (Page 6 of 10)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Nevada	*Spray irrigation:* • Secondary treatment • Disinfection required when buffer zone <800 ft. • With buffer zone of 400 ft. - Fecal coliform 200/100 ml (median) 400/100 ml (single sample) • No buffer zone - Fecal coliform 2.2/100 ml (median) 23/100 ml (single sample) *Surface irrigation:* • Secondary treatment	• Samples taken prior to application point and after final treatment					*Spray irrigation:* • None, 100 ft., 400 ft., or 800 ft. depending on disinfection level *Surface irrigation:* • None required	
 New Jersey	• Determined on case-by-case basis			• Required	• Site specific, however < 4 in/wk	• Required • Minimum of 3 wells • At least 1 well upgradient to monitor background conditions	• 100 ft. from any surface water body or wetlands • 200 ft. from adjacent property lines • 400 ft. from inhabited dwelling	Requires New Jersey Pollutant Discharge Elimination Permit
 New Mexico	• Primary except for pastures for milking cows • Pastures for milking cows requires disinfection with fecal coliform ≤100 organisms/100 ml	• Fecal coliform sample taken at point of diversion to irrigation						

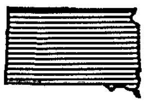
[1] Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops (Page 7 of 10)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 New York	• Secondary treatment and disinfection			• Two weeks plus any flow generated in prohibited time period (includes rainfall events)	• Hydraulic - 3 in/wk • Organic - 600 lbs/BOD/ac/day • Maximum salinity - 1,000 mg/l			• Spray irrigation should be practiced only from May 1 - Nov. 30 and only during daylight
 North Dakota	If waste stabilization ponds are used: • Minimum 180 days capacity • Representative sample of reclaimed water must be submitted to determine suitability for irrigation				• Site-specific • Based on soils type and type of vegetation			• Areas readily accessible to humans or animals should not be irrigated.
 Oklahoma	• Waste stabilization pond effluent limitations as defined by the Oklahoma State Department of Health Design Requirements OR • Minimum of primary treatment		• Emergency storage should be considered in case of system failure • Reliability features including factors of safety, back-up systems, and contingency plans should be considered	• Based on water balance using 90 percentile annual rainfall isopleths • Must also consider cessation of irrigation operation during winter months	• Based on nutrient, organic, and water balance assessments	• Network of monitoring wells may be necessary and should be evaluated for systems with deep percolation rates	• Spray irrigation may require buffer zones to ensure that aerosols are contained on the site	• Dairy cattle should not have access to application area
 Oregon	• Biological treatment and disinfection • Total coliform - 240/100 ml (2 consecutive samples) 23/100 ml (median)	• Total coliform - 1/week	• Standby power for all essential treatment processes • Multiple treatment units and monitoring equipment to insure required levels of treatment				• 10 ft. buffer with surface irrigation • 70 ft. buffer with spray irrigation	• No animals on pasture during irrigation • No irrigation of effluent 3 days prior to harvesting
 South Carolina	• Secondary treatment and disinfection • Total coliform - 200/100 ml			• Minimum of 7 days • Water balance required as documented in EPA manual 625/1-81-013	• Hydraulic - ≤2 in/wk (Coastal Plain area) ≤1 in/wk (Piedmont area)	• Required • 1 well upgradient • 2 wells downgradient	• 200 ft. to residences, surface waters, and public potable wells • 100 ft. to property lines and roads • 50 ft. to stormwater ditches	

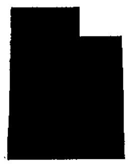
(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops
(Page 8 of 10)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 South Dakota	• Secondary treatment			• Minimum of 210 days	• Hydraulic - ≤2 in/acre/wk ≤24in/acre/yr	• Shallow wells in all directions of groundwater flow from site and not more than 200 ft. outside of site	• 1 mile from municipal water supply • 1/4 mile from private domestic water supply, lakes, and human habitation • 1/4 mile from state parks and recreation areas unless disinfected • 100 ft. from neighboring property	• Does not include pastures for dairy grazing
 Tennessee	• Lagoon treatment • Disinfection generally not required, however can be required when deemed necessary	• Site specific		• Based on water balance using five-year return monthly precipitation	• Nitrogen - Percolate nitrate-nitrogen not to exceed 10 mg/l • Hydraulic - Based on water balance using five-year return monthly precipitation	• Required	*Surface Irrigation:* • 100 ft. to site boundary • 50 ft. to on-site streams, ponds & roads *Spray Irrigation:* [1] Open Fields • 300 ft. to site boundary • 150 ft. to onsite streams, ponds & roads [2] Forested • 150 ft. to site boundary • 75 ft. to onsite streams, ponds & roads	
 Texas	*Fodder, fiber & seed:* • 30 mg/l BOD *Pastures for milking cows:* • 30 mg/l BOD with treatment using pond system (30 day ad.) • 20 mg/l BOD with treatment other than pond system (30 day ad.) • Fecal coliform not to exceed 800/100 ml	*Fodder, fiber & seed:* • Sampling and analysis 1/month *Pastures for milking cows:* • Once/2 weeks		• Based on water balance using average monthly precipitation records	• Site-specific based on water balances			

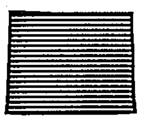
(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops (Page 9 of 10)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Utah	• Secondary treatment • pH 6.5 - 9.0 • 25 mg/l BOD (30 day mean) • 25 mg/l TSS (30 day mean) • Total coliform - 2000/100 ml • Fecal coliform - 200/100 ml (30 day mean)						• 1000 ft. from any place of human or dairy occupation if spray irrigation used	• Application area must be fenced • No dairy animals permitted on irrigation site
 Vermont	• Secondary treatment • BOD ≤30 mg/l at any time • TSS ≤30 mg/l at any time • Disinfection with 20 min. chlorine contact time immediately prior to spraying • 1.0 ppm free chlorine residual or 4.0 ppm total chlorine residual at the spray nozzle		• For mechanical treatment facilities all unit processes shall have a minimum of two independent units as a back-up unit of equal capacity	• Minimum of 45 days	• Hydraulic - 2.0 in/wk with secondary treatment 2.5 in/wk with tertiary treated effluent		• 100 ft. to edge of any surface water • 200 ft. to any water supply, habitation, property lines or roads	
 Washington	• Primary treatment and disinfection • BOD reduction of 35% • TSS reduction of 55% • Total coliform - 230/100 ml		• Warning alarms • Back-up power source • Emergency storage: short-term, 1 day; long term, 20 days • Multiple treatment unit processes or storage or disposal provisions • Personnel available or on call at all times the irrigation system is operating	• Storage required • Volume of storage based on site conditions		• Required • Minimum of one well in each direction of groundwater movement from site and one well upgradient of site		• Pasture irrigation for cows and goats shall receive secondary treated disinfected reclaimed water with the mean total coliform not to exceed 23/100 ml

[1] Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops (Page 10 of 10)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 West Virginia	• Secondary treatment and disinfection • 30 mg/l BOD • 30 mg/l TSS	• Analysis of crop required if used for animal consumption		• Minimum of 90 days	• Hydraulic - maximum of 0.25 in/hr 0.50 in/day 2.0 in/wk	• Minimum of one well between project site and public well(s) or high capacity private wells	• Fence shall be placed at least 50 ft. beyond spray area • 350 ft. from fence to adjacent property lines or highways unless low trajectory spray and/or physical buffers are provided	
 Wisconsin	• Biological, physical, or chemical treatment • BOD ≤50 mg/l • Total nitrogen and fecal coliform determined on case-by-case basis	• Determined on case-by-case basis			• Determined on case-by-case basis	• Required for design flows >0.015mgd	• 200 ft. from private water supply well • 1000 ft. from public water supply well and any residence	
 Wyoming	*Subsurface irrigation:* • Primary treatment *Spray irrigation:* • Fecal coliforms - 1000/100 ml (mean)				• Hydraulic - < 4.0 in/wk recommended		• 100 ft. buffer zone around spray site with secondary treatment • 150 ft. buffer zone around spray site with primary treatment	Reclaimed water quality criteria pertain to irrigation on agricultural lands supporting indirect food chain crops

[1] Distances are from edge of wetted perimeter unless otherwise noted.

Table A-5. Unrestricted Recreational Reuse (Page 1 of 2)

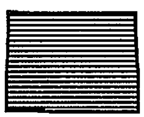
State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
 Arizona	• pH - 6.5 - 9.0 • Fecal coliform - 200/100 ml (mean) 800/100 ml (single sample) • Turbidity - 1 NTU	• pH - 1/month • Fecal coliform - 1/day • Turbidity - continuous						• Have limit on certain pathogenic organisms and trace substances
 California	• Disinfected, oxidized, coagulated, clarified, & filtered • Total coliform - 2.2/100 ml (median) 23/100 ml (single sample) • Turbidity - 2 NTU	• Total coliform - 1/day • Turbidity - continuous	• Warning alarms • Back-up power source • Emergency storage: short-term, 1 day; long term, 20 days • Multiple treatment unit processes or storage or disposal options					
 Colorado	• Disinfected, oxidized, coagulated, clarified, & filtered • Total coliform - 2.2/100 ml (median) 23/100 ml (single sample)						• 500 ft. from impoundment to domestic supply well • 100 ft. from impoundment to any irrigation well	
 Nevada	• Secondary treatment with disinfection • Fecal coliform 2.2/100 ml (mean) 23/100 ml (single sample) • Turbidity - 2 NTU (single sample)	• Samples taken after final treatment and prior to application						

Table A-5. Unrestricted Recreational Reuse (Page 2 of 2)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
 Oregon	• Biological treatment, disinfection, coagulation and filtration • Total coliform - 2.2/100 ml (mean) 23/100 ml (single sample) • Turbidity - 2 NTU (24 hr. mean) 5 NTU (5% of time during 24 hrs.)	• Total coliform - 1/day • Turbidity - hourly	• Standby power for all essential treatment processes • Multiple treatment units and monitoring equipment to insure required levels of treatment					

Table A-6. Restricted Recreational Reuse
(Page 1 of 2)

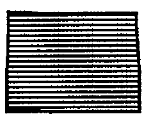
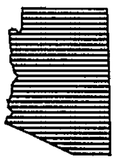
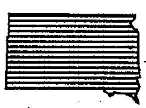
State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
 Arizona	• pH - 6.5 - 9.0 • Fecal coliform - 1000/100 ml (median) 4000/100 ml (single sample) • Turbidity - 5 NTU	• pH - 1/month ∘ Fecal coliform - 1/wk. ∘ Turbidity - continuous		• Minimum of five days when only surface irrigation available				• Have limit on certain pathogenic organisms and trace substances
 California	• Disinfected and oxidized • Total coliform - 2.2/100 ml (median)	∘ Total coliform - 1/day	• Warning alarms • Back-up power source • Emergency storage: short-term, 1 day; long term, 20 days • Multiple treatment unit processes or storage or disposal options					
 Colorado	• Disinfected and oxidized • Total coliform - 2.2/100 ml (median)					∘ 500 ft. from impoundment to domestic supply well • 100 ft. from impoundment to any irrigation well		
 Hawaii	• Disinfected and oxidized • Total coliform - 23/100 ml (7 day mean) 240/100 ml (2 consecutive samples)	• Total coliform - 1/day	• Reliability features to insure necessary treatment levels required • Minimum of 1 day reject storage unless another reuse or disposal system provided.					

Table A-6. Restricted Recreational Reuse (Page 2 of 2)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
 Nevada	• Secondary treatment with disinfection • Fecal coliform 2.2/100 ml (mean) 23/100 ml (single sample) • Turbidity - 3 NTU (single sample)	• Samples taken after final treatment and prior to application						
 Oregon	• Biological treatment and disinfection • Total coliform - 2.2/100 ml (mean) 23/100 ml (single sample)	• Total coliform - 3/wk.	• Standby power for all essential treatment processes • Multiple treatment units and monitoring equipment to insure required levels of treatment					
 Texas	• 10 mg/l BOD • Turbidity - 3 NTU • Fecal coliform not to exceed 75/100 ml	• Sampling and analysis 1/wk.						

Table A-7. Environmental – Wetlands

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
 Arizona	• pH - 6.5 - 8.6 with maximum pH change of 0.5 units/day in receiving waters • DO. - receiving waters not lowered below 6 mgd/l • Fecal coliform - 1000/100 ml (mean) 4000/100 ml (single sample) • Temperature shall not interfere with aquatic life and wildlife	• pH - 1/wk. • DO. - 2/wk. • Fecal coliform - 5/month < 1 mgd 10/month ≥ 1 mgd • Temperature - 2/wk.						
 Florida	• Comprehensive requirements for treatment, disinfection, monitoring, and site controls are established for treatment or receiving wetlands							• Only wetland restoration projects considered reuse
 South Dakota	• Pretreatment with stabilization ponds			• Minimum of 180 days in stabilization pond and artificial wetlands • Minimum of 150 days in stabilization pond	• Hydraulic - ≤ 25,000 gal/ac/day			• Regulations apply to artificial wetlands

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse (Page 1 of 3)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Arizona	• Determined on case-by-case basis							
 Hawaii	*Cooling Water:* • Oxidized, coagulated, filtered and disinfected • Total coliform - 2.2/100 ml (7 day mean) 23/100 ml (single sample) • Detectable enteric animal viruses - <1 PFU per 40 liters • Shall be treated with biocide or other disinfection agent to prevent viability of Legionella and Klebsiella *Industrial Processes Not Involving Food and Drink for Humans:* • Oxidized and disinfected • Total coliform - 23/100 ml (7 day mean) 240/100 ml (2 consecutive samples)	Total coliform - 1/day	• Reliability features to ensure necessary treatment levels required • Minimum of 1 day reject storage unless another reuse or disposal system provided					

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse (Page 2 of 3)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
 Nevada	• Secondary treatment with disinfection • Fecal coliform - 200/100 ml (mean) 400/100 ml (single sample)							
 Oregon	• Biological treatment and disinfection • Total coliform - 240/100 ml (2 consecutive samples) 23/100 ml (median)	• Total coliform - 1/wk	• Standby power for all essential treatment processes • Multiple treatment units and monitoring equipment to insure required levels of treatment					
 Texas	• 30 mg/l BOD with treatment using pond system • 20 mg/l BOD with treatment other than pond system • Fecal coliform not to exceed 200/100 ml	• Sampling and analysis 1/mo.						

[1] Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse (Page 3 of 3)

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
 Utah	• Advanced treatment • BOD ≤ 10 mg/l at any time • TSS ≤ 5 mg/l at any time • Total coliform - ≤ 3/100 ml at any time							

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Appendix B

Abbreviations and Acronyms

Table B-1. Abbreviations for Units of Measure

acre	ac
British thermal unit	Btu
cubic meter	m^3
cubic meters per day	m^3/d
cubic meters per second	m^3/s
Curie	Ci
cycles per second	cps
degrees Celsius	°C
degrees Fahrenheit	°F
feet (foot)	ft
gallon	g
hectare	ha
horsepower	hp
hour	hr
inch	in
kilogram	kg
kilometer	km
kiloPascal	kPa
kilowatt	kW
kilowatt hour	kWh
liter	L or l
meter	m
microgram	µg
micrograms per liter	µg/L
micrometer	µm
mile	mi
mile per hour	mph
milligram	mg
milliliter	mL or ml
millimeter	mm
million gallons per day	mgd
milliquivalent per liter	meq/L
minute	min
megawatt	mW
most probable number	MPN
pascal	Pa
plaque forming unit	pfu
pound	lb
pounds per square inch	psi
roentgen	R
second	s
square meter	m^2
year	yr

Table B-2. **Acronyms/Abbreviations**

AID	U.S. Agency for International Development
ANSI	American National Standards Institute
AWT	advanced wastewater treatment
AWWA	American Water Works Association
BNR	biological nutrient removal
BOD	biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
CFU	colony forming units
COD	chemical oxygen demand
COE	U.S. Army Corps of Engineers
CWA	Clean Water Act
DO	dissolved oxygen
EC	electrical conductivity
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ESA	external support agency
ET	evapotranspiration
FC	fecal coliform
FmHA	Farmers Home Administration
GAC	granular activated carbon
GC/MS	gas chromatography/mass spectroscopy
HPLC	high pressure liquid chromatography
IAWPRC	International Association on Water Pollution Research and Control
ICP	inductively coupled plasmography
I/I	infiltration/inflow
IOC	inorganic chemicals
IRCWD	International Reference Centre for Waste Disposal
IRWD	Irvine Ranch Water District
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MDL	method detection limit
MPN	most probable number
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
NPDWR	National Primary Drinking Water Regulations
NRC	National Research Council
NTU	nephelometric turbidity units
O&M	operations and maintenance
OM&R	operations, maintenance and replacement
OWRT	Office of Water Research and Technology
PAC	powder activated carbon
PCB	polychlorinated biphenyls
POTW	publicly owned treatment works
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
RAS	return activated sludge
RBC	rotating biological contactor
RO	reverse osmosis
SAR	sodium adsorption ratio
SAT	soil aquifer treatment
SBA	Small Business Administration
SDWA	Safe Drinking Water Act
SOC	synthetic organic chemical
SRF	State Revolving Fund
SS	suspended solids
TCE	trichloroethylene
TDS	total dissolved solids
THM	trihalomethane
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
TOH	total organic hydrocarbons
TOX	total organic halides
TP	total phosphorus
TPH	total petroleum hydrocarbon
TSS	total suspended solids
UN	United Nations
USDA	U.S. Department of Agriculture
UV	ultraviolet
VOC	volatile organic chemicals
WAS	waste activated sludge
WASH	Water and Sanitation for Health
WHO	World Health Organization
WPCF	Water Pollution Control Federation
WRF	water reclamation facility
WWTF	wastewater treatment facility

*U.S. Government Printing Office: 1996 - 750-001/41012