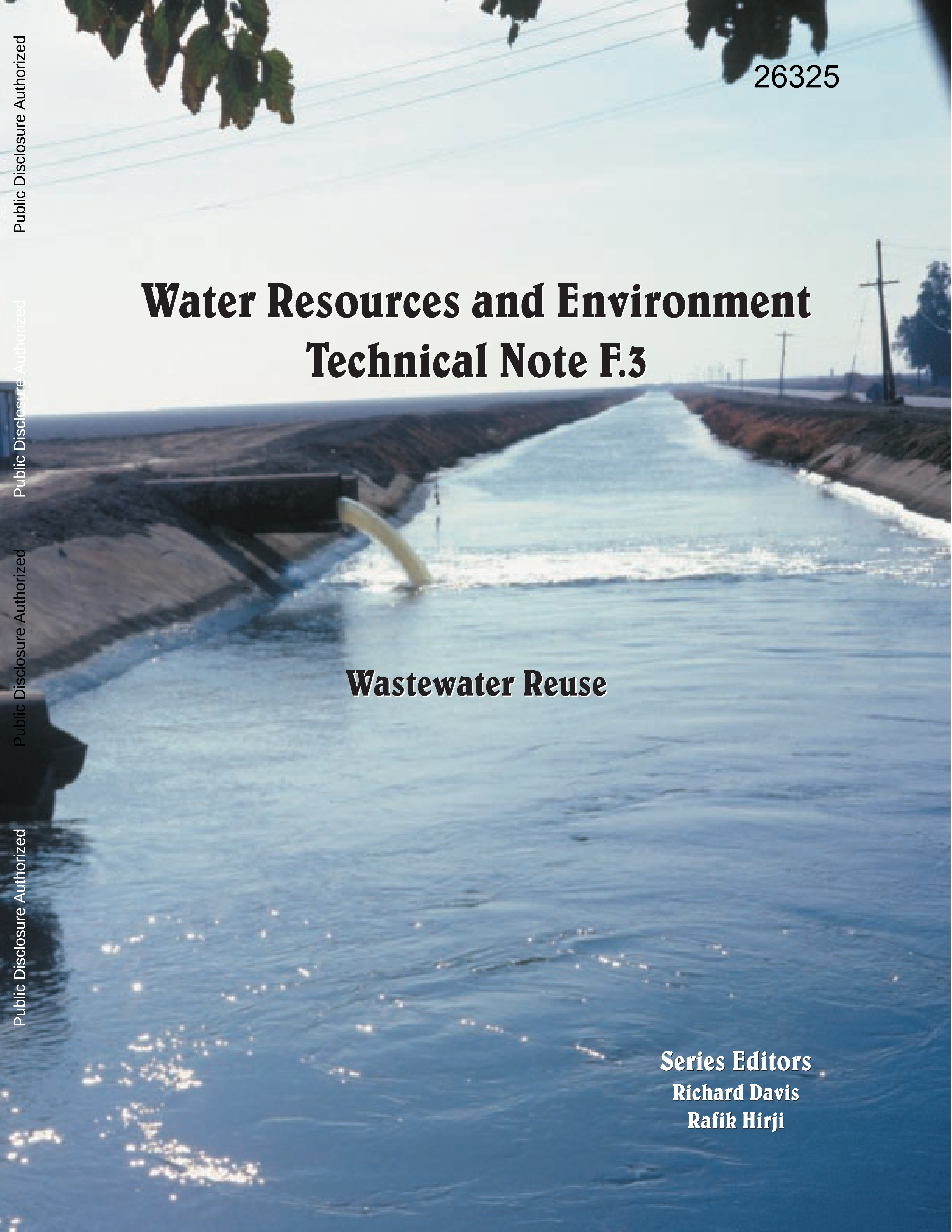

Water Resources and Environment
Technical Note F.3

Wastewater Reuse

Series Editors
Richard Davis
Rafik Hirji

WATER RESOURCES AND ENVIRONMENT

TECHNICAL NOTE F.3

Wastewater Reuse

SERIES EDITORS
RICHARD DAVIS, RAFIK HIRJI

The World Bank
Washington, D.C.

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To be effective any legal regime should be accompanied by appropriate standards and enforcement mechanisms, including financial incentives, sanctions, and ultimately possibilities of criminal prosecution.

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Reuse of drainage water,
near Fresno, California

This series also is available on the
World Bank website
(www.worldbank.org).

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FOREWORD

The environmentally sustainable development and management of water resources is a critical and complex issue for both rich and poor countries. It is technically challenging and often entails difficult trade-offs among social, economic, and political considerations. Typically, the environment is treated as a marginal issue when it is actually key to sustainable water management.

According to the World Bank's recently approved Water Resources Sector Strategy, "the environment is a special 'water-using sector' in that most environmental concerns are a central part of overall water resources management, and not just a part of a distinct water-using sector" (World Bank 2003: 28). Being integral to overall water resources management, the environment is "voiceless" when other water using sectors have distinct voices. As a consequence, representatives of these other water using sectors need to be fully aware of the importance of environmental aspects of water resources management for the development of their sectoral interests.

For us in the World Bank, water resources management–including the development of surface and groundwater resources for urban, rural, agriculture, energy, mining, and industrial uses, as well as the protection of surface and groundwater sources, pollution control, watershed management, control of water weeds, and restoration of degraded ecosystems such as lakes and wetlands–is an important element of our lending, supporting one of the essential building blocks for sustaining livelihoods and for social and economic development in general. Prior to 1993, environmental considerations of such investments were addressed reactively and primarily through the Bank's safeguard policies. The 1993 Water Resources Management Policy Paper broadened the development focus to include the protection and management of water resources in an environmentally sustainable, socially acceptable, and economically efficient manner as an emerging priority in Bank lending. Many lessons have been learned, and these have contributed to changing attitudes and practices in World Bank operations.

Water resources management is also a critical development issue because of its many links to poverty reduction, including health, agricultural productivity, industrial and energy development, and sustainable growth in downstream communities. But strategies to reduce poverty should not lead to further degradation of water resources or ecological services. Finding a balance between these objectives is an important aspect of the Bank's interest in sustainable development. The 2001 Environment Strategy underscores the linkages among water resources management, environmental sustainability, and poverty, and shows how the 2003 Water Resources Sector Strategy's call for using water as a vehicle for increasing growth and reducing poverty can be carried out in a socially and environmentally responsible manner.

Over the past few decades, many nations have been subjected to the ravages of either droughts or floods. Unsustainable land and water use practices have contributed to the degradation of the water resources base and are undermining the primary investments in water supply, energy and irrigation infrastructure, often also contributing to loss of biodiversity. In response, new policy and institutional reforms are being developed to ensure responsible and sustainable practices are put in place, and new predictive and forecasting techniques are being developed that can help to reduce the impacts and manage the consequences of such events. The Environment and Water Resources Sector Strategies make it clear that water must be treated as a resource that spans multiple uses in a river basin, particularly to maintain sufficient flows of sufficient quality at the appropriate times to offset upstream abstraction and pollution and sustain the downstream social, ecological, and hydrological functions of watersheds and wetlands.

With the support of the Government of the Netherlands, the Environment Department has prepared an initial series of Water Resources and Environment Technical Notes to improve the knowledge base about applying environmental management principles to water resources management. The Technical Note series supports the implementation of the World Bank 1993 Water Resources Management Policy, 2001 Environment Strategy, and 2003 Water Resources Sector Strategy, as well as the implementation of the Bank's safeguard policies. The Notes are also consistent with the Millennium Development Goal objectives related to environmental sustainability of water resources.

The Notes are intended for use by those without specific training in water resources management such as technical specialists, policymakers and managers working on water sector related investments within the Bank; practitioners from bilateral, multilateral, and nongovernmental organizations; and public and private sector specialists interested in environmentally sustainable water resources management. These people may have been trained as environmental, municipal, water resources, irrigation, power, or mining engineers; or as economists, lawyers, sociologists, natural resources specialists, urban planners, environmental planners, or ecologists.

The Notes are in eight categories: environmental issues and lessons; institutional and regulatory issues; environmental flow assessment; water quality management; irrigation and drainage; water conservation (demand management); waterbody management; and selected topics. The series may be expanded in the future to include other relevant categories or topics. Not all topics will be of interest to all specialists. Some will find the review of past environmental practices in the water sector useful for learning and improving their performance; others may find their suggestions for further, more detailed information to be valuable; while still others will find them useful as a reference on emerging topics such as environmental flow assessment, environmental regulations for private water utilities, inter-basin water transfers, and climate variability and climate change. The latter topics are likely to be of increasing importance as the World Bank implements its environment and water resources sector strategies and supports the next generation of water resources and environmental policy and institutional reforms.

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INTRODUCTION

As the demand for water increases and new sources of supply become more expensive to develop, there is an increasing need to use water more than once during the hydrological cycle. Wastewater from point sources–such as sewage treatment plants, industries, and thermal power stations–can provide an excellent source of reusable water because this water is usually available on a reliable basis, can be accessed at a single point, and has a known quality. These sources can be reused within the same industry or for completely different purposes. Wastewater reuse can not only help maintain upstream environmental quality by reducing the demand for new water sources, but can also offer communities an opportunity for pollution abatement by reducing effluent discharge to surface waters.

In many parts of the world, wastewater has long been used in an unplanned way for agriculture. The planned reuse of wastewater is less common but increasing, particularly in water-short regions. However, there are financial and social impediments to both planned and unplanned reuse. Treatment to a desired quality and transport of the water to the reuse location can make the project uneconomic; lack of social acceptance, particularly of reused sewage flows, can also limit the adoption of reuse technologies in countries where these technologies have not been traditionally applied.

The World Bank supports water reuse where it is an appropriate strategy. The potential of water reuse strategies for promoting water conservation was recognized in the Bank's 1993 Water Resources Management Policy and is a feature of the new Rural Development Strategy. Technical issues associated with wastewater reuse are explored in a number of World Bank publications, such as Technical Papers 51 and 64. The Bank has invested in projects that contain a water reuse component, and will continue to support socially and environmentally acceptable and economically efficient reuse projects.

This document is one in a series of Water Resources and Environment Technical Notes that have been prepared by the Environment Department to apply environmental management principles to water resources management.

This Note provides an overview of water reuse applications, the planning of water reuse projects, the development of public education programs, and the economics of reuse schemes. However, every individual country has its own legislation, cultural restrictions, and financial opportunities, so this general information needs to be customized for each circumstance.

This Note begins with a definition of terms used in water reuse management and an overview of reclaimed wastewater quality criteria and standards. It then discusses possible reuse applications, including irrigation, industrial use, groundwater recharge, and potable use. It describes a planning process for wastewater reuse and discusses public awareness and education programs. The Note concludes with discussions about the economics of wastewater reuse and some legal aspects.


Photo by International Water Management Institute, Sri Lanka

Wastewater irrigation fields, Hanoi, VietNam

RECLAIMED WASTEWATER QUALITY

Wastewater reuse (see Box 1 for terminology) is accepted in principle in most industrialized and developing countries, as well as in urban and rural areas. In developing countries, almost all wastewater reuse is applied to agricultural purposes. In general, planned reuse of municipal or industrial wastewater occurs in regions where the demand for water is high and the supply is limited because of either limited rainfall or environmental or health restrictions on development of further water resources. The best-known regions are the Middle East, the southwestern United States, Namibia, northern Africa, and Australia. In large, dense urban areas where space is precious, wastewater is reused for nonpotable purposes such as toilet-flushing, and stormwater is stored and used later for irrigation of lawns and parks. This occurs in Japanese cities such as Tokyo and in several counties in the greater Los Angeles area.

Wastewater has been reused in an unplanned way in many parts of the world for centuries. For example, wastewater that is discharged to streams or infiltrates groundwater systems without deliberate management activities is often reused for other purposes. There are many examples of river water being used for municipal purposes, discharged (often treated to some extent) back to the river, and later withdrawn for water supply for cities further down the same river. There are also many places, particularly in Asia, where wastewater is used to irrigate crops for human consumption without any treatment or administrative oversight. All these occurrences are termed unplanned reuse. In this Note, we will primarily be concerned with planned wastewater reuse, where the water is diverted to a specific use in a controlled way, including management of water quality.

Unplanned reuse can sometimes act as an impediment to planned reuse because water managers argue that there is no need to invest in wastewater treatment and management when unplanned reuse is already occurring. However, the unplanned uses may not be the most efficient uses of the discharged water, particularly when environmental impacts are considered. There can also be obvious health and environmental implications from unplanned activities.

Wastewater reuse is closely related to water conservation. Both approaches aim at making maximum use of existing water supplies in order to reduce the need to tap new sources of high-quality water for both financial and environmental reasons. Municipal and agricultural water conservation are described in Notes F.1 and F.2.

Many countries have developed guidelines and standards to establish an appropriate level of treatment

BOX 1.
DEFINITIONS

Wastewater reuse. Use of reclaimed wastewater for a beneficial use such as agricultural irrigation or industrial cooling.

Planned reuse. Direct or indirect use of reclaimed wastewater without losing control over the water during delivery.

Unplanned reuse. Use of wastewater after surrendering control of the water after discharge (including incidental use of water from a river downstream of a treated wastewater discharge point).

Wastewater reclamation. Treatment or processing of wastewater to make it reusable.

Direct reuse. Use of reclaimed wastewater without intervening discharge to a natural body of water.

Indirect reuse. Use of reclaimed wastewater with intervening discharge to a natural body of water.

Wastewater recycling. Use of wastewater that is captured and redirected back to the water-use scheme from which it originates. This technique is applied particularly in industry.

TABLE 1.
MICROBIOLOGICAL CRITERIA FOR DIFFERENT APPLICATIONS OF WASTEWATER RECLAMATION

Application	Fecal coliforms (geometric mean; no. per 100 ml)
Irrigation (restricted)	No standards recommended
Irrigation (unrestricted)	≤ 1000*
Aquaculture	≤ 1000* (measured in the fish ponds)
Landscape irrigation	≤ 200*
Groundwater recharge	23**
Non-potable urban use	3-1000**
Recreation	2.2-1000**
Drinking water	Must not be detectable*

** WHO standards*
*** USA-EPA standards*

for wastewater reuse. In developing countries, where wastewater is often reused without treatment, any treatment of untreated wastewater represents a significant health improvement. Applications range from irrigation of crops not intended for human consumption (for which the criteria are absence of gross solids and significant removal of parasite eggs) to potable reuse. In the latter application, secondary treatment followed by filtration, nitrification, denitrification, chemical clarification, carbon adsorption, ion exchange or membrane filtration, and disinfection is recommended. Many countries base their standards on those published by the World Health Organization (WHO).

The WHO guidelines emphasize microbiological safety because more than half of the world population is still exposed to waters that contain pathogenic organisms to some degree. Chemical contaminants normally cause health effects after prolonged periods of exposure. Of particular concern are chemicals that have cumulative toxic properties, like heavy metals and carcinogenic substances, for which several countries have developed their own standards.

Table 1 summarizes some microbiological criteria for different wastewater reuse applications according to the WHO guidelines. Apart from health concerns, use of wastewater for irrigation of crops can lead to the buildup of toxicants-such as heavy metals-in the soil, eventually rendering it unsuitable for crop use. Table 2 provides an overview of some national standards for selected chemical and microbial parameters for wastewater reused for irrigation of food crops for human consumption.

TABLE 2.
AN OVERVIEW OF VARIOUS NATIONAL STANDARDS FOR WASTEWATER REUSED FOR IRRIGATION OF FOOD CROPS FOR HUMAN CONSUMPTION

Parameter	Unit	Saudi Arabia 1989	Jordan 1985	USA	WHO
Chemical					
BOD	mg/l	10	150	30	na
COD	mg/l	—	500	na	na
TSS	mg/l	10	200	30	na
Oil and grease	mg/l	absent	8	na	na
pH		6.0 - 8.1	na	6 – 9	6 – 9
Chlorine residual	mg/l	na	0.5	1	na
Health					
Fecal coliforms	MPN/100ml	2.2	1,000	200	1,000
Nematodes	eggs/l	1	< 1	na	< 1

Saudi Arabia: Draft Standard, MAW 1989
Jordan: Jordan Standard 893/95
USA: EPA recommendations

na = not available

REUSE APPLICATIONS

Wastewater can be reused in many different ways. Table 3 provides a summary of the most common possibilities.

IRRIGATION

Worldwide, crop and landscape irrigation is the major reuse purpose for domestic and municipal wastewater. Health risks and soil damage are minimal if the wastewater is treated and the necessary precautions are taken (see Box 2). However, inadequate funding for operations and maintenance (O&M) in treatment plants in developing countries means that irrigation with ostensibly treated wastewater carries many of the same risks as irrigation with untreated effluent. In these circumstances, wastewater quality can be highly variable, and agricultural workers and nearby communities can be exposed to pathogens and other contaminants when they believe they are safe.

The WHO guidelines for viable intestinal nematode eggs are set at less than 1 per liter for restricted and unrestricted irrigation (arithmetic mean), and at less than 1,000 per 100 ml (geometric mean) for fecal coliform bacteria for unrestricted irrigation. A more stringent guideline–less than 200 fecal coliforms per 100 ml–is appropriate for landscape irrigation such as public lawns or school grounds, where frequent direct contact by the public is expected.

Treatment in wastewater stabilization ponds will produce effluent complying with the WHO microbiological guidelines with high reliability and at low cost, although a relatively large area of land is required. Another possibility is disinfection such as chlorination, although this will leave most helminth eggs unharmed and is costly. If the WHO guidelines are not fully met, it may still be possible to grow selected crops without risks to the consumer, but protection for field workers is needed.

BOX 2.
AGRICULTURAL USE OF TREATED WASTEWATER IN JORDAN

In Jordan, the demand for water is high and sources are limited. Consequently, wastewater reuse is a central part of national water policy. The use of wastewater has grown rapidly from 4 percent of total water supply in 1990 to 6.5 percent in 1995, and was projected to increase to 9 percent in 2000 and 16 percent in 2020. Groundwater abstractions will be reduced during this period to eliminate over-abstraction and protect highland aquifers from salinization.

Treated wastewater has been used for agricultural irrigation in the Jordan River Valley since 1968. If current plans are fulfilled, the share of treated wastewater in the valley is projected to increase from 18 percent in 1998 to 34 percent in 2020. This water is used to produce an additional winter crop and contributes to the irrigation of perennial crops. In addition, treated effluent—about 18,000 m^3 per day from the Mafraq, Aqaba, Ramtha, Al-Samra, and Kufranja treatment plants—is used to irrigate 600 ha of forage crops, forests, olives, and palm trees.

Health and environmental standards are a critical part of this program. Existing water quality standards have been reassessed and N and BOD targets have been made more stringent. Wastewater treatment plants are being upgraded as part of the reuse activities. Water quality is now monitored independently of the treatment facilities by the Royal Scientific Society. Laboratories have been upgraded and an early warning system has been instituted. In addition, treated effluent is mixed with freshwater from the Talal dam before delivery to the irrigation districts to help mange water quality.

There is widespread public support for wastewater reuse, although debate continues about the best agricultural uses for the wastewater.

Sources: UNDP/FAP/World Bank/WHO. 1998. *Wastewater treatment and reuse in the Middle East and North Africa Region: Unlocking the potential*. Report of a Joint mission to the Middle East Region. Subramanian, A. 2001. *The Hashemite Kingdom of Jordan Water Sector Review Update*. World Bank Report 21946-JO. Washington: The World Bank.

TABLE 3.
CATEGORIES OF MUNICIPAL WASTEWATER REUSE AND POTENTIAL CONSTRAINTS

Wastewater reuse categories	Potential constraints
Agriculture and landscape irrigation Crop irrigation Commercial nurseries Park/School yards Freeways (median strips) Golf courses Cemeteries Greenbelts Residential areas	Surface- and groundwater pollution, if not properly managed Marketability of crops and public acceptance Effect of water quality, particularly salts, on soils, grasses, and crops Public health concerns related to pathogens (bacteria, viruses, and parasites)
Industrial recycling and reuse Cooling Boiler feed Process water Heavy construction	Constituents in reclaimed wastewater cause scaling, corrosion, biological growth, and fouling Public health concerns, particularly aerosol transmission of pathogens in cooling water
Groundwater recharge Groundwater replenishment Salt water intrusion control Subsidence control	Organic chemicals in reclaimed wastewater and their toxicological effects Total dissolved solids, nitrates, and pathogens in reclaimed wastewater
Recreational/environmental uses Lakes and ponds Marsh enhancement Streamflow augmentation Fisheries Snowmaking	Health concerns from bacteria and viruses Eutrophication due to nitrogen and phosphorus in receiving waters Toxicity to aquatic life
Nonpotable urban uses Fire protection Air conditioning Toilet flushing	Public health concerns on pathogens transmitted by aerosols Effects of water quality on scaling, corrosion, biological growth, and fouling
Potable uses Blending in water supply reservoirs Pipe-to-pipe water supply	Constituents in reclaimed wastewater, especially trace organic chemicals and their toxicological effects Aesthetics and public acceptance Health concerns about pathogen transmission, particularly viruses

Source: Metcalf & Eddy, Inc. (1991)

Irrigation with wastewater can result in soil and groundwater pollution. The quality of irrigation water is of particular importance in arid zones with high rates of evaporation because of the accumulation of salts in the soil profile. The salinity of the wastewater must be low enough to maintain favorable osmotic pressures for plants to take up water (different crops have different salt tolerances).

Nutrients—such as nitrogen and phosphorus—in wastewater are beneficial to the plants and reduce the need for artificial fertilizers. However, most nonindustrial wastewater streams contain nutrients in excess of plant needs. Environmental problems, such as eutrophication of surface waterbodies (see Note G.4) from agricultural run-off and infiltration of nitrate to groundwater (see Note G.1), can occur

Photo by Manuel Marino, World Bank

Wastewater ponds

if these sources are not diluted with other, lower-nutrient sources of water.

Heavy metals, persistent organics, and ions such as boron, chloride, and sodium can harm crops and soils. Heavy metals pose the greatest long-term environmental risk because they accumulate in the upper soil. If a soil is highly permeable or if the groundwater table is close to the surface, pollution of groundwater can also occur. Many heavy metals and pollutants such as chlorinated hydrocarbons may accumulate in sufficient concentrations in crops to pose a serious hazard to the health of livestock and humans. In most cases, harmful levels of chemicals can be prevented by avoiding the use of untreated wastewater and by pre-treatment of industrial discharges to the wastewater reclamation system. References providing guidance on managing harmful chemical constituents are provided in the Further Information section of this Note.

The health risk depends on the method of applying the irrigation water. Flooding involves the least investment, but the greatest risk to field workers if the wastewater is not fully treated. Sprinkler irrigation should be avoided if the WHO guidelines are not fully met. Even with treated wastewater, sprinkler irrigation may promote aerosol transmission of viruses, although this is likely to be rare. Subsurface irrigation gives the greatest degree of health protection, more efficient water use, and often higher production yields. However, it is expensive, requires prevention of clogging, and may cause soil salinization in arid climates unless sufficient freshwater is added to leach the salts below the root zone (see Note E.1). This leachate fraction can be intercepted in sub-surface drains. Health protection requires regular monitoring of wastewater quality, crop quality, and medical surveillance of farm workers.

Although the above discussion focuses on the planned reuse of wastewater for agriculture, the reality is that in many parts of Asia, Central America, and Africa wastewater is used in an unplanned way for raising crops. These crops, which are central to the livelihoods of farmers and of considerable importance to local communities, could not be grown without this source of water and nutrients. It is unrealistic to expect that these wastewaters will receive treatment, so the issue is to understand how to continue to apply the effluent at minimal risk to both human health and soil productivity. Although research is under way in this area, there are currently no well-founded guidelines for these practices.

AQUACULTURE

About two-thirds of the world yield of farmed fish is produced from ponds fertilized with wastewater. These fish represent a cheap source of animal protein for poor people. Box 3 describes an economically successful and safe example of wastewater reuse for fish production. With a few exceptions, health aspects, treatment processes, and monitoring are comparable to those for irrigation. Some substances may accumulate in the fish or aquatic plants more readily than in agricultural plants. However, few standards have been set for chemical contaminants in wastewater reused for aquaculture.[1] Keeping fish in clean water for at least 2 to 3 weeks before harvest will remove residual odors and reduce con-

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[1] Zweig, R.D., J.D. Morton and M.M. Stewart. 1999. *Source water quality for aquaculture: A guide for assessment.* Washington: World Bank.

BOX 3.
AQUACULTURE IN SAN JUAN, LIMA, PERU

Between 1985 and 1990, CEPIS (Centro Panamericano de Ingeniería Sanitaria y Sciencias del Ambiente, a research centre of WHO) ran a test program on the use of effluent from the San Juan wastewater treatment plant, 15 km south of Lima, for aquaculture. The effluent had a coliform concentration between 1,000 and 10,000 per 100 ml. It was used to grow tilapia (*Oreochromis niloticus*) in tanks designed for aquaculture.

No pathogenic bacteria or viruses could be detected in the fish as long as the concentration of coliforms in the aquaculture tanks was less than 10,000 per 100 ml. Production of tilapia is influenced strongly by temperature. In the warmest four months of the year, tilapia could be produced with a final commercial weight of 250 g, at a density of 2 fishes/m^2, from an initial weight of 60 g. In this way, an initial fish biomass of 1,000 kg/ha could be increased to 4,400 kg/ha during four warm months.

The revenues from the tilapia production were such that the investment in the aquaculture tanks proved to be an economically viable operation. Much of the cost of wastewater treatment could be recovered by this reuse option.

tamination from fecal microorganisms. When planning or managing aquaculture, consideration should be given to the effects of the discharge from the ponds on surface waterbodies and on groundwater.

INDUSTRIAL REUSE

Wastewater reuse is increasingly used to supplement or replace freshwater demands from industry. Industrial reuse has the twin advantages of a generally continuous demand and the ability to utilize secondary treated wastewater. The major factors that influence industrial wastewater reuse include availability and reliability of the water source, the industry's discharge requirement, and the required water quality and quantity. Membrane technologies (ultra filtration and reverse osmosis) are being used increasingly, opening the possibility of producing high quality water from conventionally treated wastewater.

Major uses in industry are cooling system augmentation, once-through cooling systems, process water, boiler feedwater, washdown water, and miscellaneous applications such as fire protection and dust control. Reclaimed water for industrial use may be derived from recycling within the plant itself (Box 4) or from secondary effluent from municipal wastewater treatment plants (Box 5).

Quality requirements for cooling towers are set by the build-up of impurities in these closed-loop systems as water is evaporated from the cooling tower. If concentrations of impurities are too high, scale deposits will form on heat exchanger surfaces, lowering the heat transfer capacity. Excessive impu-

BOX 4.
RECYCLING OF INDUSTRIAL EFFLUENTS, JAMAICA

Bauxite/alumina companies have spearheaded the recycling of industrial effluent in Jamaica. The bauxite/alumina industry produces a waste product known locally as "red mud," which consists of over 70 percent water enriched with caustic soda and organics. The waste is thickened to 28 percent solids and sprayed on a sloping drying bed. The drying beds are sealed to prevent infiltration of effluent to the groundwater. The liquid fraction is collected at the toe of the drying bed and is channeled to a sealed holding pond. Pumps move the effluent from the holding pond back to the plant via a pipeline, where it is recycled through the process. The technology is now used at four bauxite/alumina plants in Jamaica.

The system is very effective at reducing contamination of groundwater resources. Moreover, the project reduces annual freshwater consumption by 4 to 5 million cubic meters. The main disadvantage is the large area required for the drying beds.

BOX 5.
RECLAIMED CITY SEWAGE AS INDUSTRIAL WATER IN CHENNAI, INDIA

The Chennai Metropolitan area, with scant rainfall, no river sources, and no major nearby watersheds, has long been chronically short of water. Demand is increasing substantially due to increases in population and industrial development. Lately, water shortages have resulted in several stoppages of water supplies to industries, leading to cessation of production and related financial losses to industries. As a result, a fertilizer company has explored alternative sources, including the use of desalinated seawater and treated wastewater to provide process and cooling water for its operations. The company has decided to reclaim water from city sewage using advanced wastewater treatment followed by reverse osmosis (RO) as an additional purification step. Wastewater used by the plant is treated to tertiary standards using an activated sludge process, with the treated water being further reclaimed through excess lime addition, ammonia stripping, recarbonation, chlorination, multimedia filtration, activated carbon filtration, cartridge filtration, and reverse osmosis.

The capital cost of the entire project is estimated at $18 million. Due to the sewage reclamation project, 13,700 m^3/day of potable water, previously supplied to the fertilizer company, has been redirected to domestic use in the city.

rity concentrations may cause accelerated corrosion, sliming, or clogging. Chemical additives are used to control these problems. Control of *Legionella* bacteria is an increasingly important issue in cooling systems. These bacteria are not introduced specifically by the reuse of wastewater, but may be promoted by, for example, nutrients from reclaimed water, which may accelerate the growth of the *Legionella* bacteria.

Once-through cooling involves substantial water volumes, but does not require as stringent quality requirements as does cooling tower augmentation. The primary water quality concerns are slime and suspended solids. Scaling and corrosion are usually not a problem. Discharge water quality is essentially unchanged, except for a temperature increase.

Boiler feedwater has similar but more stringent quality requirements to cooling tower augmentation. Removal of hardness is required to prevent scale formation and deposits in boilers.

Process water quality requirements are highly dependent on the particular industry involved. Generally it is desirable to minimize the suspended solids concentration, water turbidity, and color. Other concerns are silica, aluminium, hardness, microorganisms and pH. Generally, the water quality must meet near-potable water standards. If the wastewater stream is used for food processing, water quality must also meet potable water standards.


Photo by International Water Management Institute, Sri Lanka

Spinach fields, wastewater irrigation

GROUNDWATER RECHARGE

Groundwater recharge is used to preserve groundwater levels, to prevent land subsidence, to protect coastal aquifers against saltwater intrusion, and to store reclaimed wastewater and surface runoff for future use (called aquifer storage and recovery, or ASR). Recharge methods commonly used are surface spreading in basins, direct injection into groundwater aquifers, and riverbank infiltration (Box 6).

A problem with recharge is that boundaries between potable and nonpotable aquifers are rarely well-defined (see Note G.1). Recharging "nonpotable" aquifers carries the risk of contaminating high-quality potable groundwater sources. Therefore, the health effects from prolonged exposure to low levels of contaminants must be considered, as well as the acute health effects from pathogens or toxic substances. The lack of knowledge about the fate and long-term health effects of contaminants found in reclaimed water–together with the extreme difficulty of rectifying water quality problems once the groundwater has been contaminated–means that a conservative approach should be taken when recharging a nonpotable aquifer.

Because recharged water may be an eventual source of potable water, pre-treatment is necessary before groundwater recharge. Particular attention has to be paid to contamination by pathogenic microorganisms. If the reclaimed wastewater is being introduced through soil infiltration, many constituents will be removed during their passage through the soil, although very soluble contaminants such as nitrate will still enter the groundwater. The effectiveness of this treatment is affected by temperature, rainfall characteristics, and the physical and mechanical characteristics of the soil. In special cases, some soils–such as those with high arsenic concentrations–may contribute contaminants to the leachate. Direct injection to groundwater bypasses this "natural soil treatment," but there is evidence that contaminants are removed from wastewater in the aquifer matrix.

There are several advantages to ASR. The cost of artificial recharge may be less than the cost of using surface reservoirs; the aquifer serves as an eventual distribution system, reducing the need for pipelines and canals; and the aquifer is not subjected to evaporation, to taste and odor problems, or to ambient pollution. The physical transition between reclaimed wastewater and the water's later emergence as groundwater also provides an important psychological and aesthetic barrier for eventual potable uses. However, ASR is sensitive to leakage or poor placement of injection wells. Frequent monitoring of groundwater quality is essential, because it takes as much as 100 years for soil and groundwater to recover once it has been contaminated.

RECREATION AND ENVIRONMENT

There are three broad uses of reclaimed water for recreational purposes, each with their own specific quality requirements: primary body-contact such as swimming and water-skiing; secondary body-

BOX 6.
GROUNDWATER RECHARGE IN ISRAEL

Partially treated effluent has been used to recharge aquifers in the Dan region (Greater Tel Aviv) of Israel for almost 20 years. The effluent is discharged into spreading basins, from which it percolates through the unsaturated zone until it reaches the groundwater system. Most of the remaining contaminants are removed from the effluent during this Soil-Aquifer Treatment (SAT) process. The water then moves laterally until it reaches a series of recovery wells that surround the recharge area. The recovered effluent is pumped to the Negev Desert and used for irrigation. With proper design, the zone between the recharge area and the recovery wells can be separated hydrologically from the rest of the aquifer, which can then continue to be used for potable supply.

Source: UNDP/FAP/World Bank/WHO. 1998. *Wastewater treatment and reuse in the Middle East and North Africa Region: Unlocking the potential*. Report, Joint mission to Middle East region.

contact such as boating and fishing; and noncontact such as ornamental fountains and aquaculture.

The water quality criteria for primary body-contact are the most stringent. The water has to be aesthetically attractive, and have acceptable physical parameters such as color, taste, and odor. Most importantly, the water must be free of toxic compounds and hygienically and microbiologically safe. Most national standards range from 100 to 1,000 fecal coliforms per 100 ml. Water quality requirements are less strict for secondary body-contact. The requirements for non-contact recreational water are a reasonable temperature to sustain aquatic life, a suitable concentration of dissolved oxygen, a suitable chemical quality, the absence of nutrients to avoid eutrophication, and reasonable microbiological quality. The fundamental concern is public health, but the biological health of receiving water must also be considered in recreational/aesthetic reuse. Cyprus illustrates a special case where the sensitivity of tourists to wastewater reuse had to be considered (Box 7).

NONPOTABLE URBAN USES

Wastewater has long been used for nonpotable urban reuse in Japan. For example, treated wastewater is used in 19 buildings in a development in the Shinjuku District of Tokyo for toilet flushing. Not only does this reduce the need for water supply for this high-density urban renewal, but it reduces the pressure on existing sewerage and wastewater treatment facilities, which were not designed to handle the increased flow of wastewater.

Similar uses of wastewater are being investigated in several pilot projects in Europe and China, mostly as locally treated "grey" water (that is, all household wastewater except that from toilets) for toilet flushing and washing machines. Special attention is given to the possibility of biological contamination through aerosols, with tentative microbiological standards being established for *Cryptosporidium* (< 2 organisms per 10 litres), *Giardia* (< 5 organisms per 10 litres), and entero-viruses (< 1 organisms per 10 litres).

POTABLE WATER

Potable water can be reused directly or indirectly. Direct potable water reuse is a "pipe to pipe" connection between the reclaimed water treatment facility and the potable water distribution system. In indirect potable water reuse, the highly treated reclaimed water is introduced to a surface water or groundwater system that is ultimately used as a potable water supply. The reclaimed water is blended with water from the natural system, and there may be a significant delay between the point of reclaimed water discharge and the point of withdrawal into the potable water treatment facility. The choice of direct or indirect potable reuse is based

BOX 7.
WASTEWATER REUSE IN CYPRUS

By 2010, the Republic of Cyprus expects to have developed all readily available ground and surface water resources. The government has ambitious plans to use wastewater for agricultural production, particularly around Limassol, Nicosia, Larnaca, and AyiaNapa/Paralimni. However, the country's economy is heavily dependent on tourism, an industry where reuse is also widely practiced. More than 250 package treatment plants service hotels and tourist sites. About 75 percent of these use tertiary treatment and reuse the water for landscaping around the tourist sites. Tourists are particularly sensitive to health and aesthetic issues, and great care is taken to make sure that wastewater is used safely and with minimal environmental impact around the tourist sites.

For this reason, the tourist industry opposed the introduction of the discharge of treated wastewater in coastal areas. This opposition led to the delay and eventual cancellation of a proposed treatment plant and ocean outfall for wastewater from Larnaca. The wastewater was eventually collected, treated, and reused for nonpotable uses around tourist areas

Source: UNDP/FAP/World Bank/WHO. 1998. *Wastewater treatment and reuse in the Middle East and North Africa Region: Unlocking the potential*. Report, Joint mission to Middle East region. See also World Bank. 1996. *Environmental Assessment Sourcebook Update 13*. Washington: World Bank.

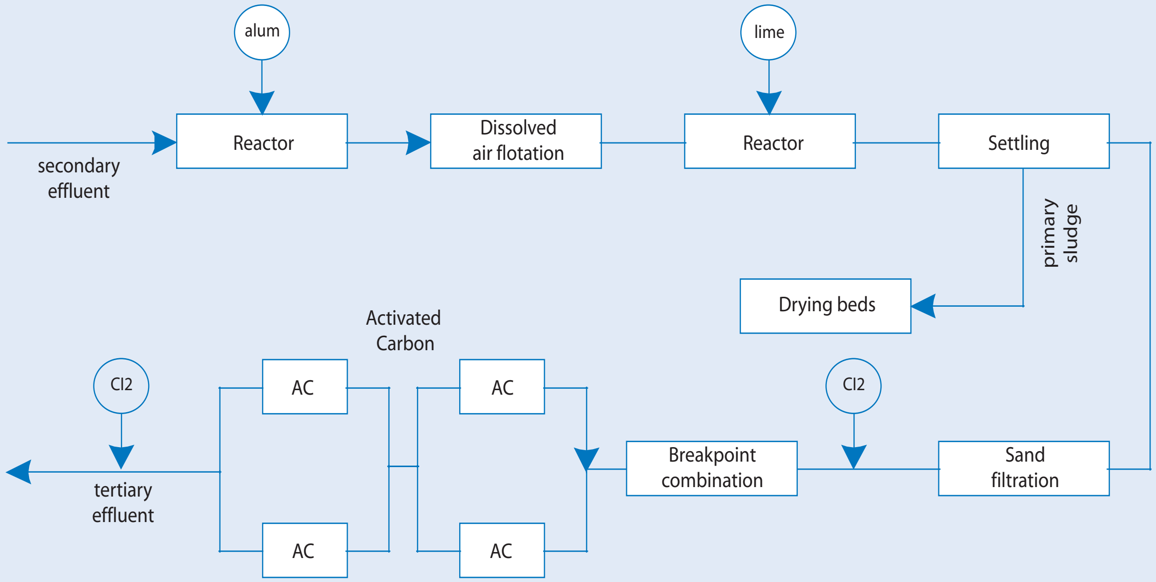
on technical factors–such as quality criteria, costs, distribution requirements, treatment technologies, and necessary reliability–and nontechnical factors such as public acceptance, and legal requirements.

The most serious problem of direct potable reuse is public acceptance of water with a wastewater origin, particularly chronic health effects that might result from ingesting the mixture of inorganic and organic (bacteria, viruses, protozoa, and helminths) contaminants that remain in the water, even after the most advanced treatment methods. Box 8 provides an example of direct reclamation in a water-deficient environment.

There are several means for indirect, reclaimed water to be introduced into water supplies. The most common are ASR (as discussed earlier), and sur-

BOX 8.
WASTEWATER RECLAMATION FOR DRINKING WATER PURPOSES IN WINDHOEK, NAMIBIA

In the 1960s, the city of Windhoek was approaching the limit of its conventional drinking water sources (groundwater and surface water) and was forced to implement direct reclamation of wastewater for potable use in 1968. Twenty-five years later, the existing capacity of 4,800 m^3/d was exceeded by the demand, and the existing plant was extended to 21,000 m^3/d in 1998. From the start, it was clear that reclamation could only be successful if three important matters could be controlled: diversion of industrial and potentially toxic wastewater; wastewater treatment to produce an adequate and consistent effluent quality; and effluent treatment to produce acceptable potable water. As a safeguard against pathogens, a maturation pond and multiple chlorination steps were applied. As shown in the schematic below, the wastewater is treated in two separate treatment plants—a conventional biological wastewater treatment plant (activated sludge) and a wastewater reclamation plant.



Wastewater reclamation plant in Windhoek, Namibia

The cost of reclaimed potable water is high compared to potable water from conventional sources due to the high costs of chemical dosage. For this reason, the reclamation plant was operated on an intermittent basis. For the 1968-91 period, the average production was 27.3 percent of the plant capacity, contributing only 4 percent to the total water supply in Windhoek. In 1982, after a series of dry years, the plant ran at 80 percent of its capacity.

From the start of the project, an extensive monitoring program, representing 20 percent of the total production cost, was conducted. Samples were taken at different points—varying from the treatment plant to consumer taps—and epidemiological research on the health effects of the consumption of water focused on diarrheal disease and hepatitis A. The study showed that a marginally lower incidence of diarrheal disease was found in the population receiving direct potable reuse water. The hepatitis study concluded that consumption of direct potable reuse water did not result in the occurrence of hepatitis A infections.

face water augmentation by direct discharge to a raw water storage reservoir or an intervening stream followed by withdrawal for use. Surface water augmentation with reclaimed wastewater must be done carefully and with thorough evaluation of several important considerations, such as the proximity of a reclaimed water discharge point to the supply intake. The attenuation of pollutant concentrations from biological degradation, adsorption, sedimentation, and exchange of contaminants needs to be assessed between these two points, preferably through water quality models. Short-circuiting of reclaimed water to the water supply intake should be avoided. The amount of effluent relative to the ambient water flows has to be considered for both average and extreme conditions, such as those that occur during drought periods.

THE PLANNING PROCESS FOR WASTEWATER REUSE

Wastewater reuse plans, programs, and projects not only include technical implications, but can have important environmental, economic, social and public health impacts. Planning water reuse projects should be integrated, involving a number of disciplines, institutions, and beneficiaries. Special emphasis should be given to market assessment for reuse options, and to public acceptance of the reuse project.

Because of the complexity and sensitivity of wastewater reuse, the planning process should occur in a number of phases from a broad "rough-sketch" stage to the technical design and construction:

- Scope, objectives and area boundaries of the project
- Preliminary investigations
- Screening of potential markets
- Detailed evaluation of selected alternatives
- Implementation plan for most feasible alternative(s)
- Agreements with users and institutions
- Design
- Construction
- Operation and evaluation.

The first four phases define the feasibility of the reuse project. The remaining five phases cover the actual implementation of the project, following more or less the normal process of technical facilities planning. This section of the Note includes guidelines for the first four phases. Table 4 summarizes the elements to be addressed in these phases; Box 9 provides an example of the operation of these steps.

SCOPE, OBJECTIVES, AND BOUNDARIES OF THE PROJECT

Reuse projects can be incorporated in national masterplans, basinwide programs, to locally defined projects. Every project should start with a definition of its scope and objectives. This should include a sketch of the present and desired future situation in order to clarify the priorities of the objectives. In principle, a water reuse project is multi-purpose, because it is at least both a pollution control project and a water supply project (potable or nonpotable). However, one objective may be more important than the others. For example, public health will be the dominating issue with reuse of raw sewage in and around many cities in developing countries. A clear definition of the main objectives simplifies the screening and evaluation phases. Nevertheless, to enable a broad perspective in the following phases, it is recommended that secondary effects be identified in the first phase as much as possible, including possible effects outside the project area.

PRELIMINARY INVESTIGATIONS

This phase is dedicated to gathering background information, gaining insight into the present situation, and listing all potential wastewater sources for reuse and all potential markets for the reclaimed water. Typically the following elements need to be addressed in a general way:

TABLE 4.
SUMMARY OF KEY ELEMENTS IN THE PLANNING OF WASTEWATER REUSE

Planning phase	Technical	Institutional	Social	Environmental	Market assessment
Scope and objectives	■ Main objectives ■ Project area		■ Positive effects	■ Positive effects	
Preliminary investigations	■ Present situation ■ Wastewater sources suitable for reuse	■ Laws and regulations ■ Institutions and their level of involvement	■ Survey of attitudes of the public	■ Potential impacts	■ Potential markets for reclaimed water
Screening of potential markets	■ Estimation and comparison of costs		■ Public information program ■ Stakeholders and their level of involvement		■ Requirements of user groups matching with reclaimed water
Detailed evaluation	■ Optimization of alternatives	■ Ownership and management	■ Start of public education	■ Environmental impact assessment	■ Requirements and interest of each user group

- Local sources of (treated) wastewater suitable for reuse
- Potential local markets for reclaimed water
- Present uses of other (fresh) water resources in the area
- Present and future water costs of freshwater in the area
- Public health considerations associated with reuse
- Potential environmental impacts of reuse
- Laws, regulations, and legal liabilities affecting reuse options
- Identification of local and national institutions, involved in regulation, permits and/or advice
- Sources of funding available to support the reuse program
- General survey of attitudes, (potential) support and opposition of the public, as well as cultural and religious concerns.

The information gathered should support the screening of alternatives in the following phases, for which specific technical, social, legal and environmental data are all necessary. This phase is also used to establish contact with relevant institutions, define the level of involvement of the different institutions (partnership, influence on decisions, advisory, to be informed only), and draft a plan for public participation and communication. In some developing countries, this phase may also include the development of specific institutions or a regulatory framework.

SCREENING OF POTENTIAL MARKETS

In this phase, the options identified in the preceding phase are reduced to a limited number, preferably between two and four, to reduce the cost of the detailed evaluation in the following phase. If the number of options identified is large (greater than 10), a first quick screening should be done by a team of experts, based on their evaluation of the general information gathered in the preceding phase. The next screening should be based primarily on a comparison between the cost of freshwater delivery to a market and the cost of reclaimed water to the same market, for which the following steps have to be made:

- Estimation of the water quality and quantity required for each type of application
- Expectation of the regulatory requirements for each type of application
- Estimation regarding probable reclaimed water quality that would be available in the future with various levels of treatment, and comparison with regulatory and user requirements
- Estimation of the quantity of reclaimed water available and the ability to meet fluctuating demand for each type of application
- Estimation of the present and future cost of freshwater for each user or group of users
- Estimation of the cost of reclaimed water treatment and distribution for each type of application.

Apart from the comparison of costs, other criteria derived from the technical, social, and environmental data gathered in the preceding phases can be used in the screening process (for example, the possibility for future expansion, technical and/or institutional complexity, reliability, use of energy, production of wastes, and expected user acceptance).

A public participation and information program has to be defined, based on the survey information from the preceding phase (Box 9). This is discussed extensively later in this Note.

DETAILED EVALUATION OF SELECTED ALTERNATIVES

The most promising alternatives from the preceding phase are evaluated in more detail, including a detailed survey of potential users, technical optimization, more refined calculation of investments and operational costs, and a more refined comparison between costs of reclaimed water and costs of freshwater systems. As far as possible, the following information should be obtained from each potential user:

BOX 9.
PUBLIC EVALUATION OF REUSE ALTERNATIVES IN SAN DIEGO, CALIFORNIA

Planning of a wastewater reclamation and reuse project in the San Diego Clean Water Program included public involvement from the early stages of assessing the system options to 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 to represent the area's residents, were interviewed to assess attitudes toward various forms of reuse, assess the seven alternatives and their associated costs, and obtain an assessment and ranking of each alternative.

Concurrent with the interview process, technical planners performed a comprehensive analysis of 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 Clean Water Program proceeded with development of plans and specifications for the preferred 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 involved in the planning process in a substantial way from an early stage, it is more likely that funding will be obtained for the project.

- Interest in using reclaimed water
- Potential uses of reclaimed water (e.g. type of crops, type of process)
- Present and future quantity needs
- Timing and reliability of needs
- Quality needs and constraints on specific uses
- Modifications to on-site facilities necessary to convert to reclaimed water, and estimate of associated costs
- Fraction of current demand that could be replaced by reclaimed water.

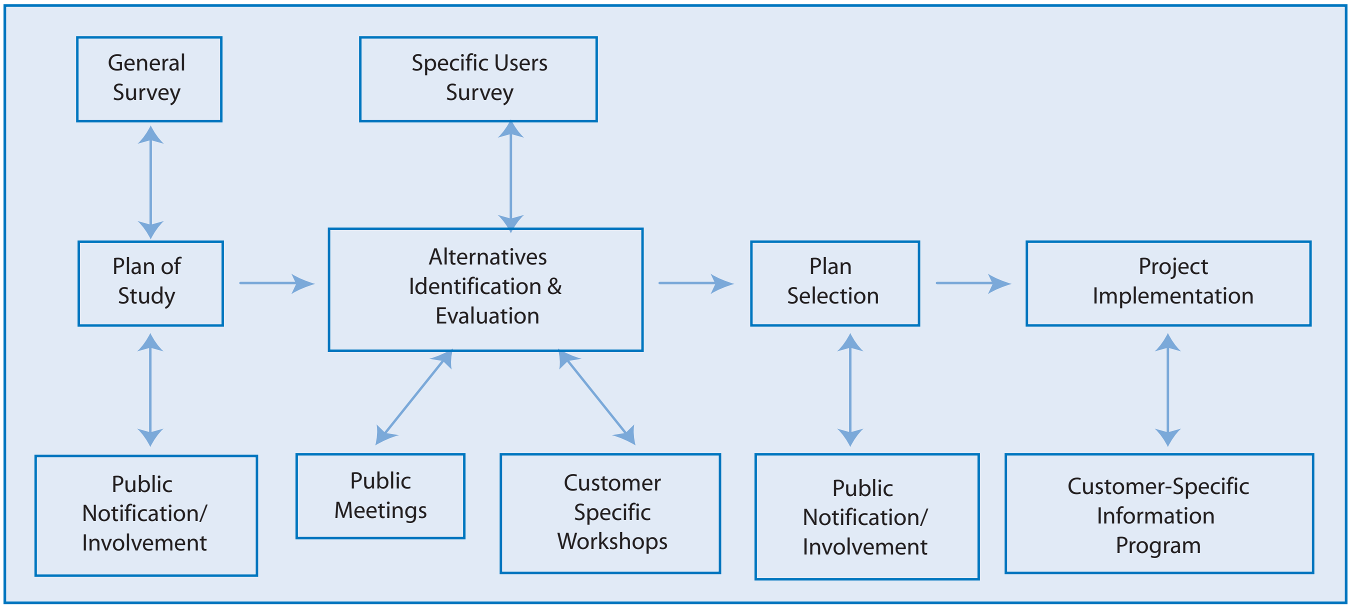
This detailed information is used in the basic design and technical optimization of the alternatives. The technical aspects should include reliability of systems, application of multiple barriers in the removal of substances, and functioning during emergencies. During this phase, ownership and management of installations, sale of reclaimed water, and competition elements have to be discussed by the institutions involved. The public information program starts implementation with the first steps of targeted education activities for the general public. Also, the process of environmental and/or public health impact assessment is identified, which may be necessary for obtaining permits. A first outline of the elements to be discussed in the impact assessment process can be used in the evaluation of alternatives and the final assessment of the feasibility of the reuse project.

AWARENESS AND EDUCATION

Public awareness and education programs are a particularly important aspect of water reuse projects in both industrialized and developing countries. There is a close association in the public's mind between water quality and health, while there is a general lack of knowledge of wastewater treatment processes. Modern public information, education, and participation programs should be designed to meet direct and obvious needs of the public. Moreover, accountability and transparency of agencies and agency activities instills public trust and improves public perceptions; this is essential to overcome major social and cultural barriers.

Figure 1 shows a flowchart of a general public participation program. Education and information is

FIGURE 1.
PUBLIC PARTICIPATION PROGRAM FOR WATER REUSE



not a single intervention, but an ongoing process that runs through all stages of the project. Public meetings and workshops provide a way to educate the public about a project, obtain information, and ascertain the level of support. A general survey may be helpful in identifying the level of interest, potential customers, and any initial concerns that the population might have. Specific surveys can serve to confirm earlier results and monitor the effectiveness of the ongoing education program. After a project is completed and is technically successful, the goal of education activities is to influence the users to maximize benefits by making full use of the facilities (Box 10).

Surveys in the United States over the last two decades indicate a high degree of public support for water reuse programs, although the public's reluctance to support reuse increases as the degree of human contact with the reclaimed water increases. Several 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. Table 5 provides an overview of average responses from the different surveys.

The results from San Diego, described above in Box 9, have been found to be true elsewhere. Water reuse projects show that the best results are obtained when communities are involved early in the planning and execution of projects and are encouraged to play an active and decisive role. Since social, economic, educational, and other conditions differ from one community to another, the form and degree of people's involvement may vary. Nevertheless, it is important to encourage all relevant groups within a community to participate, irrespective of ethnic origin, religion, social or economical status, or gender.

In many countries, it will require significant changes in policy, together with the reorganization and reorientation of agency staff, to switch from centrally managed projects to community-based projects. It also requires considerable effort and funding to

BOX 10.
REUSE OF WASTEWATER IN THE GULF REGION

In the arid countries of the Middle East, where water demand outstrips supply, conserving existing water resources and using innovative technologies to tap new sources is a priority. Although desalination has long been accepted as a new source of potable water, the reuse of treated wastewater for agriculture and industry has met with regulatory and cultural resistance.

Stringent water quality standards have been established, which many suppliers feel are so restrictive they discourage the reuse of treated effluent. Even when wastewater reuse has been permitted, problems have arisen. Inadvertent or unintended uses of wastewater have occurred, sometimes when the public is unaware of the meaning of signs indicating wastewater transport and points of discharge. Also, the hot dry climate encourages the aerosol transmission of viruses and disease when inadequately treated wastewater is used for sprinkler irrigation. These health hazards are a particular concern during pilgrimage times, when the Holy Shrines of Mecca and Medina are visited by millions of worshippers,.

Islamic religious beliefs, which require cleanliness and "purity" of water, also affect attitudes toward wastewater reuse. Since the introduction of wastewater reuse programs, the fulfillment of religious requirements for water purity has been an issue of debate among religious scholars in the Islamic world. After a thorough investigation, including both scientists and specialists, the Council of Leading Islamic Scholars of Saudi Arabia expressed its approval in 1978 of wastewater reuse, after proper treatment, for all purposes. However, they stated that they preferred to avoid using treated wastewater for drinking purposes.

Faced with the extent of the water shortage and reassured by this ruling, wastewater is now used for a wide range of purposes in Saudi Arabia. For example, 9,000 ha of date palms and forage crops near Riyadh and municipal parks in Jeddah, Jubail, Riyadh, and Taif are now irrigated with treated wastewater

Source: Abderrahman, W.A. 2001. "Water demand management in Saudi Arabia," in Faruqui, N.I., A. K. Biswas, and M. J. Bino, eds., *Water Management in Islam*. Tokyo: UN University Press.

TABLE 5.
PERCENTAGE OF RESPONDENTS OPPOSED TO VARIOUS TYPES OF WATER REUSE (USA)

Type of reuse	percent opposed to reuse
Drinking water	55
Food preparation	50
Bathing at home	35
Swimming	21
Laundry	21
Irrigation of vegetable crops, vineyards etc.	12
Toilet flushing	5
Irrigation of lawns, parks, golf courses etc.	4

engage the community in a participatory approach, and to support them so they are able to participate effectively. It is clear that political commitment at the highest level is required to make such important changes in project approach. Early community participation will provide an insight into community attitudes regarding a water reuse project and, if necessary, allow time for education to increase awareness of the benefits of the project.

Some communities participate only in advisory committees, while others may make a financial contribution or contribute labor to the implementation of a project. A citizen advisory or participation committee may help ensure that a project's technical staff has not neglected an aspect of the project that could build public confidence.

Media coverage may be important to a project, depending on the degree of development of a country. Background information should be provided to the media. It is important that community leaders are made aware of a proposed reuse project and its benefits prior to the media being informed. Stakeholder briefings may be a useful strategy to accomplish this objective, especially for those who may be contacted by the media for comments about the proposed project. Further, in a stakeholder interview other individuals in the community who have a logical interest in the project can be identified.

THE IMPORTANCE OF TERMINOLOGY

It is important to use water reuse terminology carefully with the public. For example, "water" and "wastewater" suggest radically different properties and are perceived differently by the general public. One should not hide the fact that recycled water is

BOX 11.
WATER EDUCATION PROGRAM, QUEENSLAND, AUSTRALIA

The Australian Water & Wastewater Association, together with the Sunshine Coast Environment Council, has developed a Water Education Program. The program will try to improve public knowledge of wastewater, including what is in it, and how it can be treated and monitored. It will not "market" the concept of reuse as potable water, but rather provide people with knowledge and understanding, so they have an informed opinion.

The program will avoid describing the quality of effluent by the amount of treatment it receives; its quality is what matters, not its history. It will be aimed at all ages and groups in the community and recognize all learning styles. Only a small proportion of residents are sufficiently motivated to come to meetings; all others have to be reached in more subtle ways. Two of the problems that will need to be addressed are the reluctance of water managers to consult with the community about future water supplies, which results in the community being unaware of the need for reuse, and gaps in knowledge about some of the health issues.

Terminology is of critical importance. In the past, the water industry seems to have had a penchant for negative terminology. Now, the word "disposal" has almost disappeared from the vocabulary. Water is now discharged if it can't be reused.

produced from wastewater (Box 11), but public discussions should carefully distinguish between "wastewater reuse" and "treated wastewater reuse." Omission of the latter term could give rise to the impression that raw sewage will be used, when in fact the wastewater will be treated to a high standard, making it comparable to freshwater.

In general, professionals implementing water reuse schemes need to be aware of the perceptions of their target audience. Technical people often play it safe by using conservative, worst-case scenarios with likely risks couched as deaths-per-million. This can give a wrong impression to many people, because they wonder if that one case could apply to them. Personal control over risks is an important factor. People are willing to assume more risk if they perceive that they have control, such as when driving an automobile. Risks that are outside an individual's control are met with considerably greater resistance, even if the risks are much lower in comparison with voluntary risks.

ECONOMIC AND LEGAL ASPECTS OF WASTEWATER REUSE

BENEFITS AND COST FACTORS

Wastewater reuse projects are diverse and can involve improvements in sanitation such as wastewater collection, water pollution control such as reduction of waste discharges in streams, alternative water production, and social or economic improvements such as the development of an agricultural area. The benefits to be included in an economic analysis will depend on the purpose of the project. For example, in a project where no wastewater infrastructure is present and where the goal is to use the wastewater for agricultural production in an area where freshwater sources are scarce, the cost of the wastewater reuse system would include all elements of the wastewater collection system, wastewater treatment, transport, and distribution to the users. The benefits would include health improvements (for example, reduction of medical costs), environmental benefits such as reduction of oxygen depletion in streams, social/economic benefits, an increase in agricultural production, and a reduction in the cost of fertilizer.

In developing countries, part of the wastewater collection system may often be present, but wastewater treatment typically is absent or inoperative due to lack of funds. Wastewater treatment may not be felt by the government to be a priority, if direct short-term benefits are not obvious. However, if the wastewater can be reused for agriculture or aquaculture, then the costs of wastewater treatment can be included as part of irrigation/aquaculture costs (see Box 2). The complete wastewater treatment plant can be defined as a production unit for irrigation water, and can be designed and built to meet the standards for the proposed use rather than for discharge into receiving waters. In most other cases (for example, wastewater reuse as potable or non-potable urban water, or for industrial purposes), alternative freshwater sources will be present or planned, and so the evaluation of costs and benefits will involve a comparison of alternatives. To prevent overestimation of the cost of the wastewater reuse alternative, the following costs should be included when assessing the alternative:

- Wastewater treatment and discharge
- Collection and transport of wastewater to the wastewater treatment plant
- Wastewater treatment to standards for disposal to receiving waters
- Transport of effluent to discharge location
- Cost of effluent discharge (pollution taxes should be set by government).

The following should be included when assessing the reuse scheme:

- Wastewater reuse alternative
- Wastewater treatment to reclaimed water standards
- Transport and distribution to the users.

In this way, any savings on effluent transport to the receiving waters, in discharge taxes, and in (additional) treatment to meet increasingly stringent discharge limits are measured as benefits. An example is the use of advanced wastewater treatment to remove nutrients before discharge into surface water susceptible to eutrophication. Such advanced treatment can be avoided if effluent is reused, especially for agriculture or aquaculture, where the nutrients are beneficial. If the treated water is intended for potable use and drinking water or other freshwater infrastructure is already present, then the cost of the reuse system should be compared to the cost of the expected increase in capacity of the present water system if the reuse system is not implemented.

Increasingly, the role of governments is seen as coordinating and regulating water infrastructure projects; private sector finance is sought to build and operate these schemes. This is also true with wastewater reuse schemes. However, even when there appears to be a commercially acceptable rate of return on the investment, there are large risks associated with water reuse schemes, partly because of their novelty and partly because of public wariness of wastewater reuse. Where the treated wastewater is intended for agriculture, there is the additional risk because of the inter-annual variability in demand from agricultural users. In these cases, the government may need to accept part of the risk in order to attract private investment. Box 12 provides an example of public-private sector cooperation in a wastewater reuse scheme.

ECONOMIC AND FINANCIAL ANALYSES

The economic evaluation of wastewater reuse projects seeks to determine the net benefit to society of the proposed investment. The tools commonly used are:

- *Net-Present Value* (NPV). If all or most of the benefits can be expressed in financial terms (as described in the preceding paragraph), the net present value represents the present value of the benefits minus the present value of the costs. If NPV is greater than zero, the activity has a net economic value. It is also possible to compare the NPVs of different alternatives (Maxi-

Box 12.
Managing the risks in the Virginia Pipeline Scheme, South Australia.

The Virginia area near Adelaide, Australia, has used groundwater for horticulture for over 50 years. In recent years, water yields have been dropping and salinity has been increasing. At the same time, the operators of the major wastewater treatment plant for the nearby city of Adelaide (1 million people) were required by the Environmental Protection Authority to reduce nitrogen concentrations in their discharges to coastal waters. They decided that the most cost-effective solution was to sell their wastewater to the horticulturalists at Virginia, 120 km away.

The government took the roles of promoting and demonstrating large-scale wastewater recycling and providing start-up finance. A private sector operator, who was granted the rights to build and operate the project, supplied the capital investment. The operator, Euratech, a pipe manufacturer, was selected early in the project to give them the opportunity to negotiate agreements with all parties from the beginning. Euratech assumed the construction, financing, and operations risks. The horticulturalists faced risks from the unknown effects of the wastewater quality on their crops. Both operator and horticulturalist risks were reduced by the government, which provided some of the project development costs, assisted with the necessary approvals, and undertook research into the suitability of the water for horticulture. The wastewater plant operators faced the risk that, if the reuse scheme did not achieve its targets, they would have to incur the additional expense of constructing nitrogen removal facilities. The contracts between the parties specified the water quality standards for pathogens, metals, and salinity, and the responsibilities for maintaining the standards.

Once the scheme was operational, the horticulturalists were able to obtain contracts with the major Australian supermarket chains to accept produce grown with recycled wastewater. They are also selling their produce to Asia.

Source: Croke, G., B. Kracman, and C. Wright. 1999. "The Virginia Pipeline scheme, Adelaide South Australia - Commercial solutions to environmental problems," in Medina, J. A., *Proceedings of the 17th International Congress on Irrigation and Drainage*, Granada, Spain, pp. 93-106.

mum Net-Present Value Criterion).

- *Cost-Effectiveness Analysis.* Cost-effectiveness analysis can be used if it is difficult to express the benefits in financial terms. It is a systematic method to compare the costs of alternatives that produce the same result. This technique requires a single base criterion for the evaluation.
- *Impact Analyses or Multi-Criteria Analysis.* If benefits are difficult to express in financial terms and impacts and results of projects are diverse and difficult to express as a single base criterion, impact analysis or multi-criteria analysis can be used. A number of positive and negative impacts are compared qualitatively, including costs, and weighed in a more or less subjective manner.

Financial analysis refers to the cost and benefits for a specific user or participant, and determines the feasible price of the product. Even if the reuse project proves to be economically feasible, compared to the cost of developing new freshwater sources, it may be necessary to set the price of the water lower than the price needed to cover costs. In most instances, the price should be set lower than the (sometimes subsidized) drinking water price in order to make the reuse water attractive for the potential users, particularly during the first few years of operation. Grants, subsidies, and support from national or international organizations can be employed. For long-term sustainability, however, prices should eventually be raised to ensure that capital and operating costs are covered.

ESTIMATION OF COSTS

The estimated costs for reclaimed wastewater and reuse projects can be divided into capital costs (Table 6) and operation and maintenance costs (Table 7), and include the following costs:

- Additional treatment required to meet reuse standards
- Conveyance and distribution of the treated wastewater

TABLE 6.
EXAMPLES OF PARAMETERS FOR ESTIMATING CONSTRUCTION COSTS OF WATER SUPPLY AND RECLAIMED WASTEWATER SYSTEMS

Item	Main factors influencing cost	Key parameters of cost functions
Water pipes	Diameter, material, class of pipe	Diameter of pipe, length
Ground storage reservoir	Storage capacity, construction materials, shape and structure of reservoir, soil conditions	Storage capacity
Elevated storage reservoir	Storage capacity, height, construction materials, shape and structure, wind and earthquake loadings, soil conditions	Storage capacity and height of reservoir above ground level
Pumping station	Pump capacity, pump head, no. and type of pumps used, construction material for station, class and material for pressure pipe	Pump capacity and pumping head
Water treatment	Plant capacity, type of process and treatment facilities, construction materials, topography of plant site, soil conditions, raw water intake	Plant capacity
Sewers	Diameter of sewer, depth of sewer, materials, shape of trench, type of soil, water table level, static and dynamic loading on sewer	Diameter of sewer, mean sewer invert depth, length
Wastewater treatment	Type of treatment, construction material, area, plant capacity, influent	Area, population equivalent, BOD standard

TABLE 7.
EXAMPLES OF PARAMETERS FOR ESTIMATING OPERATION AND MAINTENANCE COSTS OF WATER SUPPLY AND RECLAIMED WASTEWATER SYSTEMS

Item	Main factors influencing cost	Key parameters of cost functions
Water pipes	Total length of pipes, material and quality of construction, topography of area, pressure in pipes	Total length of pipes, or percentage of construction cost
Sewers	Total length of pipes, materials and quality of construction, topography of area	Total length of sewers, or percentage of construction cost
Storage tank	Quality of construction, size of structure	Percentage of construction cost
Water treatment	Plant capacity, type of process and facilities, quality of raw water	Plant capacity
Wastewater treatment	Plant capacity, designed efficiency of plant type of process and facilities, quality of construction	Population equivalent, or BOD of influent wastewater
Pumping station	Pump capacity, pumping head, no. and type of pumps, pump efficiency, quality of construction, energy cost	Percentage of construction cost and pumping head

- Storage to accommodate diurnal and/or seasonal fluctuations
- Connection, additional on-site treatment and use
- Operation, maintenance, and replacement
- Monitoring reclaimed water quality and health and environmental impacts
- Customer billing, administration, and overhead.

Normally capital cost is a large part (50-80 percent) of total costs. The capital cost is directly related to the transport, distribution, and storage of the reclaimed water. Strong seasonal fluctuation in demand for, or production of, reclaimed water necessitates very large storage reservoirs. The cost of constructing these facilities may render the reuse scheme economically less feasible. Economical feasibility can be expected to be high if a few large continuous users can be identified close to the origin of the wastewater, such as an existing wastewater treatment plant.

It is difficult to provide general guidelines for wastewater reuse costs. Total costs vary greatly, because they strongly depend on the local physical and economic situation, local reuse options, and abundance of alternatives. Nevertheless, the following examples provide indicative costs of wastewater treatment:

- In The Netherlands, the cost for wastewater collection is around \$0.50 per m^3. The cost for transport to the wastewater treatment plant and advanced biological treatment (including nutrient removal) amounts to another \$0.50 per m^3 (2000).
- In Egypt, the costs for wastewater collection and wastewater treatment were reported at \$0.40 per m^3 (1990).
- In Middle Eastern countries, the cost of advanced wastewater treatment was reported between \$0.20 and \$0.50 per m^3 (1997).

Indications for the cost of wastewater reuse schemes:

- In the Middle East, the use of treated wastewater as a source for drinking water (high level treatment by reverse osmosis) was calculated at \$0.40 to \$1.00 per m^3. This was cheaper than reverse osmosis of seawater at \$1.50 to \$2.00 per m^3 (1980).

- CEPIS (see Box 3) reported the cost of wastewater treatment by a series of disinfection lagoons, followed by fish breeding lagoons in Peru, at \$0.10 to \$0.20 per m^3. The cost was more than balanced by the revenues from the production of fish (1985).
- A large chemical industry in the Netherlands studied the production of demineralized water from effluent from their own biological wastewater treatment plant, instead of producing it from drinking water. Drinking water cost was \$1.00 per m^3, and demineralized water from drinking water cost \$0.50 per m^3, resulting in a total cost of \$1.50 per m^3. Demineralized water from effluent by ultra-filtration followed by reversed osmosis cost \$1.00 per m^3 (1998).
- In India, a petrochemical company decided to reuse secondary treated municipal effluent for cooling water (15,000 m^3/d). Additional treatment included coagulation by iron, sedimentation, filtration, ion-exchange, and chlorination. Total cost of the additional treatment was \$0.15 per m^3 (1990).
- In Japan, secondary treated municipal effluent was used for toilet flushing in a business area with high-rise buildings (4,000 m^3/d). Additional treatment included filtration and chlorination. Total cost was \$3.00 per m^3, with a large part of the cost attributed to the extensive distribution system.
- In Clayton County (USA), secondary treatment of municipal wastewater was reported to cost \$0.25 per m^3. The effluent was then reused in a nature conservation area at a cost of \$0.10 per m^3. Via groundwater flow and streams, the water finally reaches the area where potable water is abstracted (1987).

LEGAL ASPECTS

Legislation for wastewater management usually consists of a water management component and a public and environmental health component. Consequently, different departments of government may be involved, so water supply planners and managers must address the legal aspects of water reuse in a coordinated way. Depending on the legal requirements of different countries and states, the following items may need to be regulated:

- Protection and creation of water rights and allocation of water among competing users. Water abstraction from a system may result in net loss of water as a consequence of return flows not reaching the water system. As a result, the rights of legitimate users who rely on such return flows need to be protected.
- Ensuring adequate protection of public health and the environment from changes in flows as well as changes in water quality.
- A permit system for authorizing wastewater discharges.
- Controls over land uses and activities in the catchment area (see Box 13).
- Water quality standards appropriate to various uses.

To be effective, any legal regime should be accompanied by appropriate standards and enforcement mechanisms, including financial incentives, sanctions, and ultimately possibilities of criminal prosecution (see Note B.2).

Box 13.
Collection of urban stormwater for potable water supply, Singapore

Singapore has reached a point where around half its total land area is harnessed for water resources. The recent Lower Seletar / Bedok Water Scheme utilizes runoff from residential areas as the main source of raw water. The scheme collects surface runoff and transfers it to two new raw water storage reservoirs. The reservoirs are connected by pipeline to the Bedok waterworks, where there are extensive pre-treatment and treatment processes. The design and operation of the stormwater collection systems also ensures that only the cleaner part of the stormwater is abstracted and pumped into the reservoir. This prevents the low-quality dry weather flow and the first flush during storms from entering the reservoirs.

Since its commissioning in 1986, the scheme has delivered raw water comparable in quality to raw water obtained from an upland reservoir with a largely forested catchment.

The use of urban stormwater as a raw water source for potable water supply implies that the runoff should not contain excessive concentrations of organic matter and other urban pollutants. Consequently, pollution control measures are incorporated into the spatial planning of the urban area, especially regarding potentially polluting industries. Pollution control measures are imposed where necessary as a condition for planning approval. This is made possible by close and continuous consultations between government agencies to ensure that all new developments in the catchment are non-polluting and that suitable measures are implemented to prevent pollution of the stormwater.

CONCLUSION

Reuse of wastewater is one of a number of water conservation measures that are increasingly being implemented in water-scarce regions. Reuse of contaminated effluent can also provide the additional benefit of protecting sensitive downstream environments from damage. The source of the wastewater can vary-from industrial discharges to urban effluent to thermal power stations. The treated wastewater can be used for a range of purposes, from such high-quality uses as potable supply to lower-quality requirements such as toilet flushing and cooling water. However, reuse is not a pancea; costs of treatment can be high, adequate sources of water may be remote from the needs, and the volumes required may not match the supply. Nevertheless, there are enough economically successful examples of reuse schemes to show that it is a viable option that should be considered in water supply projects.

FURTHER INFORMATION

General information on wastewater reuse can be found in:

U.S. Environmental Protection Agency/Agency for International Development. 1992. *Guidelines for Water Reuse*. Washington: U.S. Environmental Protection Agency/Agency for International Development.

Water Pollution Control Federation. 1989. *Water Reuse, Manual of Practice SM-3*. Alexandria, VA: Water Pollution Control Federation.

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Khouri, N., J.M. Kalbermatten, and C.R. Bartone. 1994. *The reuse of wastewater in agriculture: a guide for planners*. Water and Sanitation Report No. 6. UNDP-World Bank Water and Sanitation Program. Washington: World Bank.

Information on handling harmful chemical contaminants in wastewater can be found in:

Chang, A.C., A.L. Page, T. Asano, and I. Hespanhol. 1996. "Developing Human Health-related Chemical Guidelines for Reclaimed Wastewater Irrigation." *Water Science & Technology* 33 (10–11): 463–472

Mara, D. and S. Cairncross. 1989. *Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture*. Geneva: World Health Organisation (WHO).

León, G. and J.M. Cavallini. 1996. *Curso de tratamiento y uso de aguas residuales*. Lima: Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente (CEPIS)/Organización Panamericana de la Salud (OPS/PAHO/WHO).

Some case studies of reuse schemes are described in:

Rosenblum, E. 1999. "Selection and implementation of non potable water recycling in "Silicon Valley" (San Jose area) California." *Water Science & Technology* 40 (4–5): 51–57.

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Asano, T., M. Maeda, and M. Takaki. "Wastewater reclamation and reuse in Japan: Overview and implementation examples." *Water Science and Technology* 34 (11): 219–226.

Mansour, M. and F.J. McNeill. 1998. "Wastewater reuse is key to solving Jordan's water problems." *Water Environment & Technology* 10 (11): 44–48.

The International Water Management Institute (IWMI) maintains contact information on wastewater reuse at the following address:

Citations: http://www.iwmi.org/library/dbsearches/wwcitations.htm

Contacts: http://www.iwmi.org/library/dbsearches/wwcontacts.htm

Organizations: http://www.iwmi.org/library/dbsearches/wworganizations.htm

Projects: http://www.iwmi.org/library/dbsearches/wwprojects.htm