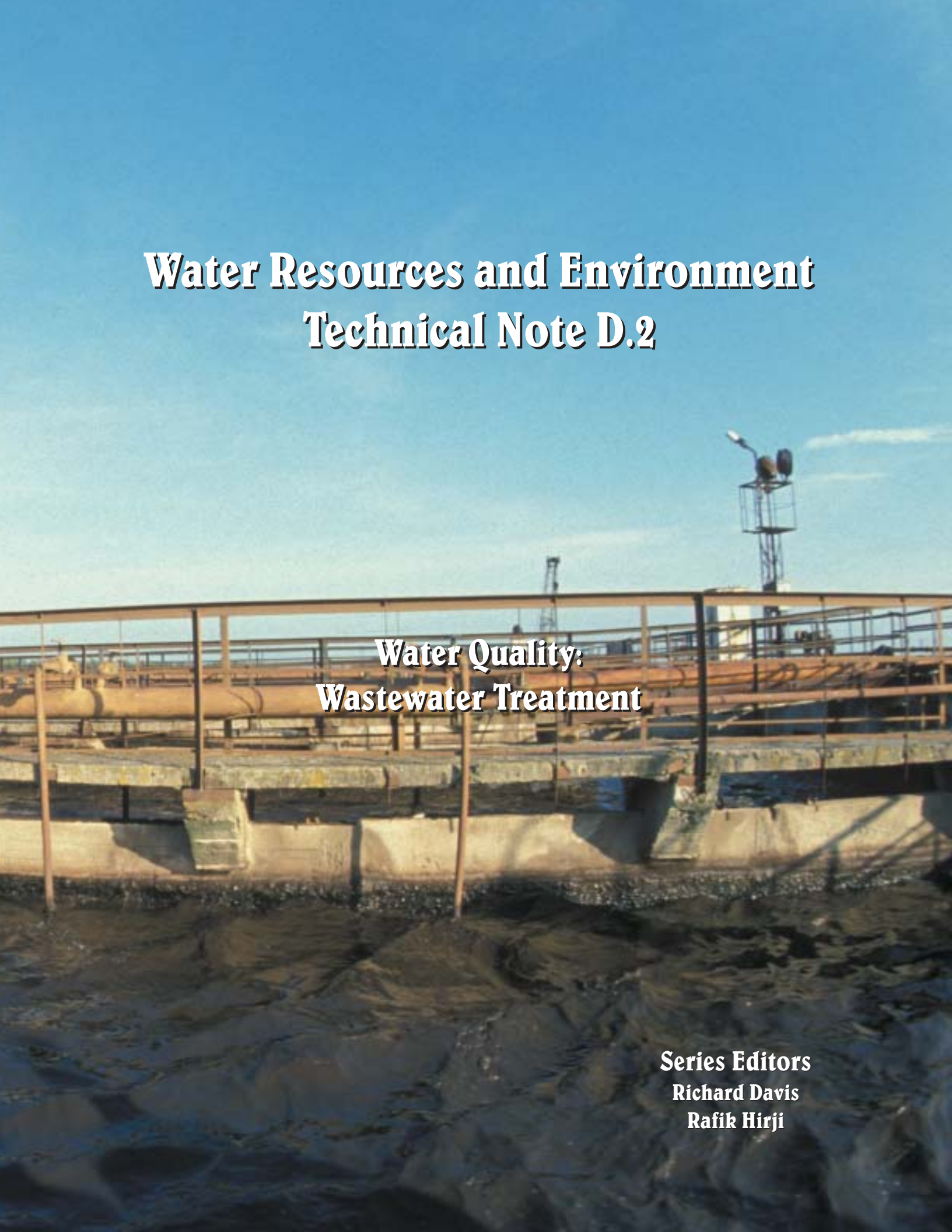

Water Resources and Environment Technical Note D.2

Water Quality: Wastewater Treatment

Series Editors
Richard Davis
Rafik Hirji

Water Resources and Environment

Technical Note D.2

Water Quality: Wastewater Treatment

Series Editors
Richard Davis, Rafik Hirji

The World Bank
Washington, D.C.

Water Resources and Environment Technical Notes

First printing March 2003

Contents

Author
Gary Wolff

Technical Adviser
Stephen Lintner

Editor
Robert Livernash

Production Staff
Cover Design: Cathe Fadel

Design and Production:
The Word Express, Inc.

Notes
Unless otherwise stated,
all dollars = U.S. dollars.
All tons are metric tons.

Cover photo by
Curt Carnemark, World Bank
Wastewater treatment
plant, Latvia

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

Boxes

Tables

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.

Kristalina Georgieva
Director
Environment Department

ACKNOWLEDGMENTS

The Bank is deeply grateful to the Government of the Netherlands for financing the production of this Technical Note.

Technical Note D.2 was drafted by Gary Wolff of the Pacific Institute for Studies in Development, Environment, and Security, building on an earlier version by Random Dubois of the United Nation's Food and Agriculture Organization.

This Technical Note was reviewed by David Hanrahan, Peter Kolsky, and Sumter Lee Travers of the World Bank.

INTRODUCTION

Urban water services can include any or all of the following: (a) provision of water for domestic and industrial uses; (b) sanitation to remove human wastes from possible contact with humans; and (c) treatment of wastes to remove contaminants. Whereas the removal of wastes–sanitation–confers well-established and obvious health benefits on urban residents, the treatment of the wastes provides benefits for downstream communities. These benefits emerge primarily as environmental improvements, which support the environmental services that these communities rely on, although there can be health benefits too, particularly if disinfection is included in the treatment to remove pathogens.

Sanitation sources can be provided either using water as a carrier (e.g., sewerage systems) or not (e.g., pit latrines). Whether waterborne sanitation technologies are used or not, it is important to make sure that the wastes are treated before they get to waterbodies in order to protect downstream communities. Thus, poorly sited or maintained latrines can contaminate waterbodies because the usual soil processes are not able to remove nutrients and disable pathogens before the wastes emerge into the environment.

This Note does not deal with water supply or sanitation services.[1] Its focus is on the treatment of wastes, principally waterborne effluent streams, because they discharge directly into waterbodies and consequently can degrade water quality if not properly designed and managed.

Photo by Michael Mertaugh, World Bank

Naretwa River at Mostar, Bosnia-Herzegovina

The importance of clean water supplies and sanitation led the international community to designate the 1980s as the "International Drinking Water Supply and Sanitation Decade." The percentage of global population with access to sanitation services rose from 20 to 31 percent during the decade. However, there are no figures available on the extent to which wastewater treatment accompanied these improvements in sanitation services.

Pollutants can be stabilized, diluted, degraded, or removed through natural processes within the receiving waters. Microbial action can covert different forms of nitrogen to nitrogen gas, which then escapes to the atmosphere. Many waterbodies respond to increases in pollutant loads by increasing these assimilation processes, and so can manage a certain level of increased pollution. The ability of the receiving waters to manage these pollutants is termed its assimilative capacity. However, if the pollution load increases too much, then these natural processes either become overwhelmed or are compromised because toxicants in the pollution poison vital microbial processes.

In its most recent strategy–*Water and Sanitation Services for the Poor: Innovating through Field Experience*–the World Bank Water and Sanitation Program states that the strategy will address the end use of wastewater, including "water conservation, wastewater treatment and re-use, and the protection of water sources." More broadly, the 1993 Water Resources Management Policy of the Bank supports the collection and treatment of wastewater in order to protect aquatic environments and public health. Some Bank documents examining the effects of wastewater discharges on receiving waters are cited at the end of this Note.

[1] Information on water supply and sanitation can be found at http://www.worldbank.org/html/fpd/water/urban.html.

This Note on wastewater treatment is one of three that focus on water quality issues. Note D.1 discusses issues related to assessment and protection of water quality. This Note covers issues of establishing water quality objectives for point source discharges into receiving waters from wastewater treatment plants, different treatment technologies, and the financial issues arising from provision of different levels of wastewater treatment. It does not deal with environmental issues that can arise from disposal of solid wastes or on-site disposal of effluent in pit latrines, etc. Note D.3 discusses nonpoint-source water pollution.

THE NEED FOR WASTEWATER TREATMENT

BENEFITS AND COSTS

Wastewater treatment is almost always funded as part of a larger project involving sanitation services, and sometimes water supply. Consequently, many aspects of wastewater planning and management have to be discussed in the context of water supply and sanitation improvements.

Expansion of water supplies without simultaneous wastewater facilities can lead to wastewater-related environmental and public health problems. In both Manila and Jakarta, for example, the provision of reticulated water without the construction of sewers in large parts of these metropolitan areas has led to the installation of septic tanks by home owners. In essence, people have personally invested in a minimal treatment of their wastewater that is poorly suited to dense urban areas.

Nearly 3 billion people worldwide do not have sanitation services at present. Sanitation services create healthier homes and streets, a direct use value for those who live in newly served neighborhoods. But waterborne sanitation systems may also create a loss of welfare for downstream users of river water. The principal downstream impacts are environmental; potential health impacts can arise when the effluent stream is insufficiently mixed in the receiving waters or where the water is used for drinking immediately below the discharge point. Both upstream and downstream impacts are significant, and both should be accounted for in assessing new investments.

Cost-benefit analysis does not distinguish between recipients of costs and benefits. If health impacts and financial costs are the only concerns, sewer projects often have net benefits for those living in the service area, and net costs for those living downstream. Total benefits to all affected parties may exceed total costs, justifying the project on economic grounds, but there are clearly distributional effects. Those who lose a fishery due to an upstream sewer project are, in effect, subsidizing those receiving the new service. In recognition of the wider impacts of water and sanitation provision, there is now an acceptance of the need to include upstream and downstream water users in decisionmaking.

Identifying the parties affected by wastewater discharges is not simple, since the benefits and costs can be distributed over long time periods and large geographical areas. Even after the affected parties are defined, it is difficult to know if total benefits exceed total costs because many benefits and costs are intangible. For example, the cost of lost biodiversity downstream is difficult to quantify because future income from ecotourism or new pharmaceuticals is highly uncertain.

Nonetheless, all benefits and costs should at least be identified in an economic assessment (Table 1). A discussion of intangible costs and benefits will allow these effects to be included in the decisions at least qualitatively. Omitting intangible costs and benefits from the initial evaluation often leads to costly investments at a later time to correct problems that could have been avoided by thoughtful and comprehensive analysis of the initial project.

TABLE 1.
EXAMPLES OF REASONABLY QUANTIFIABLE BENEFITS OF WASTEWATER TREATMENT PROJECTS

Benefit (or cost if wastewater service is not provided)	Examples
Avoided water supply protection or replacement expenses	Relocation of the water supply intake for Shanghai, China at a cost of $300 million
Avoided water supply costs when reuse is implemented	Cyprus and San Jose, California (see Box 10)
Protection of income from fisheries	Prawn and shellfish harvests in the coastal waters of China
Protection of income from agriculture	Cholera in Peru in 1991 cost $1 billion in lost agricultural exports
Protection of income from tourism	Lake Tata, Hungary (see Box 9)

LESSONS FROM BANK EXPERIENCE

The lessons from Bank experience with wastewater treatment plants are consistent with the key principles in a draft municipal wastewater guidance document prepared by the United Nations Environment Program (Box 1).

These lessons can be synthesized into six broad topics: (1) assessing environmental issues from the beginning; (2) using regional and multisectoral planning; (3) creating extensive stakeholder involvement; (4) using a demand-oriented approach; (5) engaging the private sector; and (6) providing sufficient funds for operation and maintenance (O&M).

Assessing environmental issues from the beginning. Concentrated discharges of untreated or poorly treated wastewater into rivers or coastal zones, or uncontrolled spreading of sewage sludge on agricultural land, can create environmental, health, and economic problems as severe as those that are being solved by the sewage scheme. For example, a Bank-funded sewer project in 1974 in Abidjan, Cote d'Ivoire, constructed an outfall for untreated sewage into the shallow Ebrie lagoon (mean depth of 3 meters). EAs were not required in 1974. In this region between Cote d'Ivoire and eastern Nigeria, coastal lagoons are highly productive components of marine and freshwater fisheries, and this lagoon was one of the country's most attractive coastal features. A treatment facility and ocean outfall had to be constructed in 1989 for the previously untreated sewage at considerable cost.

In some cases, environmental assessments can reduce the immediate costs of a project by determining that some facilities are unneeded or won't lead to the expected environmental benefits. For example, the EA for the Bombay sewage disposal project analyzed not just the direct environmental impacts of the project, but also whether the project would attain environmental goals for the receiving waters. Using hydrodynamic and water quality modeling, the EA demonstrated that the impact of the project would be highly dependent on pollution control in upstream areas outside the legal boundaries of Bombay. Consequently, it recommended that a system of aerated lagoons be dropped from the design, since the water quality objective in the receiving waterbody could not be achieved without addressing upstream pollution that was reaching the waterbody directly.

Nevertheless, EAs are not fully effective in mitigating environmental impacts. A review[2] of EAs for Bank-funded projects found that EAs had been

[2] Green, K.M., and A. Raphael. 2002. *Third Environmental Assessment Review* (FY96-00).Washington: World Bank Environment Department.

BOX 1.
KEY PRINCIPLES FOR MUNICIPAL WASTEWATER MANAGEMENT

1. ***Political will and financial affordability are prerequisites for adequate wastewater management.*** Success without these two prerequisites is difficult if not impossible. First, political will is fundamental for assigning a high priority to wastewater management among other pressing public investment needs. Second, the chosen wastewater management approach must be financially affordable.

2. ***Environment, health, and economy are important indicators for action.*** All three indicators are driving forces for adequate wastewater management. The non-action alternative imposes great costs on current and future generations.

3. ***Stepwise implementation of measures is essential to reach long-term management goals***. Wastewater management is not an isolated problem, but integrated with water supply, urban and rural planning, and other development sectors.

4. ***Demand-driven analyses and prognoses ensure effective investments.*** Demand-driven approaches give greater "value for money" than do supply-driven investments. Demand-driven approaches need proper analysis of the societal demands now and in the near future.

5. ***National and local governments are responsible for creating an enabling environment for sustainable solutions.*** All branches of government have a responsibility in creating solutions. A country's central government, for example, plays a significant role as facilitator and initiator even when primary governance of wastewater management issues is at the local government level.

6. ***Commitment and involvement of all stakeholders are assured from the start.*** Investment in awareness creation, demonstration of win-win situations, and development of commitment and catchment solidarity are essential for success in wastewater management.

7. ***"Water User Pays" and "Polluter Pays" are basic principles to consider.*** These principles are essential and can be applied in a way that sustains equitable sharing of costs by the rich and poor.

8. ***Public- private partnerships and other new financial mechanisms should be explored.*** New partnerships are important options and potentially useful tools, if the governing regulatory system is strong enough or can be strengthened enough to avoid the negative consequences that can result from private participation in management of public goods.

9. ***Linking municipal wastewater management systems to other sectors, for example water supply or tourism, ensures better opportunities for adequate cost recovery.*** Sustainable wastewater management may involve high initial investments and long-term contracts to cover financial risks and to recover costs. As profits–or "net benefits"–are likely to be higher in other sectors, linking these to wastewater management can reduce the risks involved and enhance the feasibility of new partnerships.

10. ***Sustainable solutions for wastewater management build upon pollution prevention at the source, efficient water use and best available technologies, and address economic aspects and low-cost alternatives when appropriate***. Wastewater management need not always involve high initial investments. A very careful search for low-cost–and thus more sustainable–technologies and approaches that target waste prevention, pretreatment, water conservation, efficient use of water, and natural systems for wastewater treatment is essential.

11. ***Innovative alternatives and integrated solutions are to be fully explored before final decisions on action are taken.*** Because innovative and integrated solutions are challenging to develop, they tend to be neglected unless full exploration of them is required as part of every wastewater management decision process.

Source: UNEP. 2001. "Guidance on Municipal Wastewater: Practical Guidance for Implementing the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA) on Sewage." Working Document Version 2.0, 21 October 2001. The Hague: UNEP/GPA Coordination Office.

"highly effective" during the project implementation phase in only 25 percent of Category A (significant adverse impact) projects and "partially effective" in a further 60 percent. There is a need to move the EA process further upstream before the project becomes too far advanced.

Using regional and multisectoral planning. Wastewater treatment and water quality planning need to be approached from a regional, multisectoral perspective. Regulations, treatment requirements, and pollution prevention policies or interventions should compare estimated benefits with estimated costs across the region and across sectors. Otherwise, a saving in one sector (e.g. limited wastewater treatment) may result in an even larger loss in another sector (e.g. downstream water users). Note F.3 provides examples where cross-sectoral approaches led to re-use of wastewater at considerable savings to both the municipality generating the wastewater and water-scarce agricultural users.

Wastewater reuse is also an example of an innovative solution to wastewater management (UNEP Principle 11). Similarly, demand management of water supply (Note F.1) can lead to lower volumes of effluent (although the loads of pollutants will be unchanged), thereby extending the life of wastewater treatment plants, lowering treatment costs and, to some extent, reducing the occurrence of treatment plant bypass during high-flow events.

Unfortunately, sector-specific projects often precede regional multisector plans because administrative authority cuts across the water cycle. When this occurs, the possibilities for joint control of different water pollution sources are often not recognized; and, if recognized, such trade-offs are outside the task assigned to project staff and consultants. This can lead to less environmental protection at greater cost, as illustrated in Box 2. However, the importance of undertaking strategic plans before commencing individual projects is more widely recognized both within the Bank and in borrowing countries. The increasing use of Country Environmental Analyses and Sector Environmental Strategies move in this direction.

Creating extensive stakeholder involvement. A wastewater management project affects numerous people. It creates construction, operation, maintenance, and system administration jobs; improves water quality or habitat for downstream water users; potentially affects neighboring communities through disposal of sewage sludge; and can potentially supply a source of water for other activities (see Note F.3). Early and comprehensive involvement of these stakeholders, along with the decisionmakers, ensures that everyone understands the project's costs and benefits. Neglect of one affected group or one issue can generate sufficient opposition to delay the project and, in extreme cases, lead to failure.

BOX 2.
IMPROVING MEXICAN WASTEWATER MANAGEMENT WITH REGIONAL MULTISECTOR PLANNING

Water resources management in Mexico is the responsibility of the federal National Water Commission (CNA). However, wastewater management is normally managed at the municipal level. Lack of resources and other local priorities have resulted in treatment of only 20 percent of municipal discharges and 10-15 percent of industrial discharges. Unaffordable operation and maintenance costs have also plagued many treatment plants. Less than 10 percent of the existing plants in Mexico are now estimated to be operating satisfactorily.

To address this problem and the growing demand for improved water quality, a River Basin Council was established in the Lerma-Chapala river basin in 1989. The results to date suggest that the integrated water pollution approach has improved financial sustainability, increased state and local involvement in the planning and implementation of pollution control problems, and improved compliance with industrial effluent standards. CNA is currently extending the Lerma-Chapala approach to other river basins and is developing a simplified procedure for adapting effluent standards and pollution charges to the specific pollution levels of each river basin.

Source: Marino, M., and J. Boland (1999). *An integrated approach to wastewater management*. Washington: The World Bank.

Even when stakeholder participation does not change the choice of facilities, stakeholder involvement helps ensure their commitment to the decision. Knowing what is planned reduces the likelihood that there will be opposition because of a sense of exclusion. It is essential that governments are included in these stakeholder groups so that high-level political support is maintained because of their role in financing and regulating wastewater discharges. The French system of river basin agencies is a successful, historical example of this approach. Seven river basin agencies were created in 1964. In each basin, all aspects of water policy and planning are referred to a basin committee, which represents all stakeholders–including national, regional, and local governments; industrial and agricultural interests; and citizens. The committee guides the activities of the technical staff of the basin agency (see Note B.2).

Identifying the stakeholders and quantifying the costs and benefits to them is more difficult with wastewater treatment facilities than it is with, say, water supply or sanitation investments. Downstream beneficiaries are likely to be dispersed, poor, and often lack the political influence of urban communities. In addition, it may take a scientific study to quantify the links between pollution removal, environmental benefit, and the dependence of communities on these environmental services.

Photo by Curt Carnemark, World Bank

Delivering water, Indonesia

The groups benefiting from sanitation services are not usually the ones bearing the greatest costs from wastewater discharges. Consequently, users of a sewer project may be relatively unconcerned about wastewater treatment. To include the voices of those facing the costs from effluent discharges requires that a wider constituency be formed in sanitation planning and implementation. The downstream benefits will occur, at least partly, as costs avoided if the wastewater treatment plant is planned as part of a sanitation project, and this may be difficult for downstream communities to accept. That is, they may feel that there is no benefit to them if the investment in a wastewater treatment plant merely maintains the quality of the receiving water at its present level.

There is no simple solution to obtaining meaningful stakeholder involvement in projects that include municipal wastewater discharges. It will take persistence, considerable time, and money in many cases. However, the benefits of more trouble-free project implementation and better long-term sustainability usually make this up-front investment worthwhile.

Using a demand-oriented approach. Water demand studies conducted by the World Bank in the 1980s concluded that sustainable provision of water and sanitation service depended on the extent to which consumers' preferences and willingness to pay were incorporated in the investment planning and implementation process. Box 3 describes a successful application of this approach to both sanitation and wastewater projects, although those making the decisions about the level of investment in Indonesia did not include the downstream communities dependent on the receiving waters.

The demand-oriented approach should include the needs of all those affected by sanitation services, including those bearing downstream costs such as effluent discharges and sludge disposal. This lesson is consistent with a multi-sectoral approach and the early involvement of all stakehold-

BOX 3.
SUCCESSFUL, DEMAND-ORIENTED WASTEWATER PROJECTS

The demand-oriented approach allows community members to take responsibility for their sanitation and wastewater treatment needs. Wastewater professionals provide technical assistance, but community members decide on the level of treatment to be constructed (within a budget) and may participate in construction, operation, and maintenance.

Trunk sewers and treatment facilities in urban areas are usually still constructed and operated by a central authority. However, treatment facilities have also been constructed and operated by organizations of service users in rural areas in the Lao PDR and in Indonesia. For example, residents of five communities on the Malang Penninsula, Indonesia, have constructed community sewer systems with treatment in communal septic tanks preceded by simple screening and grit removal facilities. More than half the influent organic materials are removed by this treatment. Effluent still does not meet Indonesian standards for discharge into waters that support fisheries and livestock watering in most communities. However, these standards were met in one community, and better construction techniques and more knowledgeable operation at the other facilities would probably allow them to meet the standard.

Source: Wright, Albert M. 1997. *Toward a strategic sanitation approach.* Washington: UNDP-World Bank Water and Sanitation Program

ers in a forum where these needs can be explored. Under this approach, public agencies become facilitators and organizers, taking on tasks only when they have a clear comparative advantage. They become "lead agencies" in a broad search for solutions, rather than physical suppliers of solutions. This approach expands participation opportunities for the private sector, nongovernmental organizations, and individuals.

Engaging the private sector. Government-funded agencies have traditionally built and operated water, sanitation, and wastewater systems and the possibility of using local, private sector expertise has often been neglected. Not only does the latter approach relieve the government of debt burden, but it can create local employment and provide a profit motive for success.

For example, the Government of Lesotho trained bricklayers to build improved pit latrines. Government banks provided unsubsidized credit to finance the latrines. The program has been very successful, in large part due to the marketing efforts of the bricklayers. The latrines operate more effectively, reducing the potencial for off-site contamination.

However, transferring responsibility to the private sector can lead to increased environmental pollution unless there are adequate regulatory controls and the political and financial backing to enforce them. The development of private sector involvement in sanitation and wastewater treatment should be part of a package that involves clarification of institutional roles, strengthening regulatory and enforcement procedures, and operation of reliable monitoring programs (see Note B.3).

Providing sufficient funds for O&M. There are numerous examples where wastewater treatment plants are operating at below their design capacity or have failed completely because of inadequate O&M funding. The benefits from proper treatment are not as apparent as, say, the benefits from the treatment of drinking water and the beneficiaries of proper wastewater treatment are usually not a powerful lobby. Consequently, governments are often reluctant to enforce the collection of fees for wastewater treatment. When these plants fail, the resulting pollution can threaten the ecological health of receiving waterbodies and the livelihoods of those dependent on the waterbodies. Box 4 provides an example where inadequate capital funding is possibly threatening an internationally renowned lake.

BOX 4.
PREVENTING POLLUTION IN LAKE NAKURU, KENYA

Lake Nakuru in Kenya is famous for the diversity of its wildlife, including two species of pink flamingo. The lake is on the Ramsar list of internationally important wetlands and is the basis of a valuable tourism industry. However, there were serious concerns about pollution of the lake from the discharge of minimally treated sewage from the rapidly growing town of Nakuru. In 1987, the Japanese Bank for International Cooperation agreed to rehabilitate and expand the town's two sewage treatment plants–the Town plant and the Njoro plant. The upgrades were completed in 1997.

A recent review has found that, while the Town plant is generally operating to design standards, the Njoro plant is receiving so little influent that it does not discharge through its drainage channel to the lake. This is because the plant was not fully connected to the parts of Nakuru town that it was designed to serve. This includes the town's industrial operations. The plant's effluent either evaporates or leaches into groundwater. There is no evidence that either plant is adding nutrients, industrial pollutants, chemicals, or pathogens to the lake, and the plants appear to be fulfilling their role. However, the lack of funding to connect large parts of the town to the Njoro plant means that effluent and industrial wastes are almost certainly being transferred through stormwater runoff to the lake instead of being treated.

Source: Special Assistance for Project Sustainability Team. 2002. *Special assistance for project sustainability for Greater Nakuru water supply project in the Republic of Kenya*. Final Report. SAPS team for Japan Bank for International Cooperation.

ESTABLISHING WATER QUALITY OBJECTIVES

AMBIENT AND EFFLUENT WATER QUALITY INDICATORS

Some of the more important ambient water quality indicators (see Note D.1) for wastewater discharges are:

- Dissolved oxygen and biological and chemical oxygen demands
- Fecal coliform as an indicator of pathogens
- Suspended solids
- Nutrients such as nitrogen and phosphorus
- Chlorophyll
- Potentially toxic substances, such as metals or organochlorine pesticides.

Dissolved oxygen (DO). Fish and other aquatic life require oxygen to survive. The necessary concentration depends on the species, although most fish species require at least 4 ppm. Consequently, a minimum concentration of dissolved oxygen is a common ambient water quality objective. The maximum dissolved oxygen in water decreases as temperature increases. For this reason, warm ambient waters, all other factors equal, are more susceptible to oxygen depletion than cold ambient waters.

Biological oxygen demand (BOD). BOD is a measure of the oxygen consumed by microorganisms over time as they degrade organic matter in a water body. When the BOD of an effluent depletes the dissolved oxygen in the receiving water below the minimum level required to support the most sensitive aquatic species, it has the potential to cause harm to aquatic life. Given the typically high organic content of discharged effluent, BOD is the most commonly used measure of effluent quality. Because wastes discharged to surface waters mostly biodegrade within five days, BOD_5 is the parameter usually used.

Chemical oxygen demand (COD). COD is a measure of the oxygen required to chemically degrade organic materials in a water sample. COD includes BOD, because materials that can be biologically degraded can be chemically degraded. COD should be measured when industrial sewage is discharged because, in these circumstances, COD can be much higher than BOD. In addition, physical or chemical treatment processes are often required when COD greatly exceeds BOD, because biological treatment cannot remove materials that microbes don't degrade.

Fecal coliforms. Fecal coliforms are an indicator of contamination with human wastes and, consequently, the potential for pathogens to be present. However, fecal coliforms can also arise from livestock wastes. In either case, water from sources with elevated fecal coliform is a potential source of pathogens and should be handled with care. Fecal coliforms should be monitored in waste streams from sewage treatment plants, but often are not. It is essential that they are monitored when the waste stream is being reused (Note F.3).

Suspended solids. Suspended solids are a measure of the small particles that remain in suspension in a water sample. Suspended solids are a common measure of effluent water quality because they can affect water clarity, which can be detrimental to fisheries, recreational uses of water, and other beneficial uses.

Nutrients. Nutrients such as nitrogen and phosphorus can cause eutrophication, which usually manifests itself as an increase in phytoplankton concentrations to nuisance levels (see Note G.4). Both nitrogen and phosphorus are found in high concentrations in discharges of wastewater. The nitrogen originates from human waste, breakdown of organic matter, and industrial sources, while the phosphorus comes from organic matter, detergents, and human wastes. In fresh waters, phytoplankton are often limited in their growth by access to phosphorus, so measurements of these nutrients, particularly phosphorus, provide an indication of the potential eutrophication of the waterbody. Note D.3 provides more details of the different measures of nitrogen and phosphorus.

Chlorophyll a and secchi disks. Eutrophication can be measured more directly than through the nutrient loads being discharged. Algae are the primary form of phytoplankton in most instances and chlorophyll *a* is, on average, 1.5 percent of the dry weight of algal cells. Consequently, chlorophyll *a* is a good proxy for the amount of algal biomass present in a sample. Chlorophyll has the property of fluorescing in response to a flash of bright light, so the chlorophyll concentration can be easily measured with a fluorometer.

Secchi disks are an even simpler way to estimate eutrophication. A specially marked disk is attached to a pole and lowered into the water from a boat. The depth at which the markings can no longer be seen, the Secchi depth, is a measure of the water's turbidity. The euphotic zone (the depth beyond which only 1 percent of the incident light penetrates) is 5 times this depth. However, turbidity can also be caused by suspended soil particles (the Yellow River is a classic example), and so Secchi disks only indicate eutrophication when algal growth is the dominant cause of the turbidity.

Toxicants. Potentially toxic substances in wastewater discharges include heavy metals, synthetic organic compounds, and some inorganic compounds such as cyanides and sulfides. In the United States, the following metals are listed as "priority pollutants," and monitored in municipal wastewater discharges: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Analysis for these metals can be expensive, and is most critical when industrial effluents are included in the waste stream.

There are numerous synthetic organic compounds that are potentially toxic. Bio-accumulative substances such as DDT, PCBs, and organochlorine pesticides are an important group. Many of these compounds accumulate in the fatty tissues of living organisms, and tend to increase in concentration within those tissues as one moves up the food chain. This im-

Photo by Manuel Marino, World Bank.

Sewage treatment plant, Podgorica, Serbia and Montenegro

plies that discharges of bio-accumulative substances at very low levels can later show up at much higher levels in humans or top level predators. Because these material accumulate, there is often no safe level of discharge. Two other environmentally sensitive groups of synthetic organics are phenols and polyaromatic hydrocarbons (PAHs). Phenols are present in many wastewaters, and PAHs are often present in combined wastewater and storm water discharges.

AMBIENT WATER QUALITY OBJECTIVES

Wastewater discharges can harm those who use the receiving water. Ambient water quality objectives are intended to protect these users by establishing acceptable levels of contaminants after the effluent stream mixes with the receiving waters. Ambient water quality objectives need to be established before a wastewater treatment facility is designed. It is not possible to design the necessary wastewater treatment processes rationally unless these objectives are well-established.

There are many beneficial uses of waterways, and so ambient water quality objectives differ from place to place (see Note D.1). For example, waters from which shellfish are harvested are very sensitive to bacteriological and toxic pollutants because many shellfish are filter feeders, leading to accumulation of contaminants in their flesh. Because these fish are often consumed raw by humans, the potential for transmission of disease is very high. Consequently, the water quality objectives for such a waterbody would need to include fecal coliform concentrations.

Civil society should be included in the setting of ambient water quality objectives because of the financial implications. Stringent objectives will inevitably lead to significant wastewater treatment costs. There is a tendency in some developing countries to adopt water quality objectives that have been established in the developed world when, in fact, there is a limited technical capability to meet those standards and little desire or ability on the part of citizens to pay for the treatment.

EFFLUENT QUALITY OBJECTIVES

If the objectives are expressed as concentrations, effluent needs to be treated to be below the ambient water quality objectives after dilution in a small zone around the point of discharge. If ambient quality objectives are stated in terms of total mass (loads) of pollutants, then different design issues may be important.

For example, discharges of some heavy metals in the San Francisco Bay in California are believed to be toxic to aquatic life. Concentrations of some of these heavy metals in the effluent stream are not of much concern (except very high concentrations), but the total loading of each metal to the Bay and the ability of natural processes to assimilate these loads is a concern. For this reason, discharge permits for petroleum refineries in the San Francisco Bay region usually restrict the total mass of discharged selenium, but have no restrictions on the concentration of selenium in effluent.

In part because past regional efforts to determine effluent discharge objectives proved uneven, uniform effluent discharge objectives have now been established in the United States, the European Union, and other developed countries. U.S. and European Community requirements for wastewater that has been treated to secondary level are summarized in Table 2. According to Marino and Boland (1999), the improvements in water quality achieved by these national approaches have come at the expense of increased costs, reduced regional ownership of effluent treatment programs, and reduced innovation.

THE INTERACTION OF AMBIENT AND EFFLUENT OBJECTIVES

Ambient water quality objectives are best established with the regional, multi-sector approach discussed previously using cost-benefit analysis. An example of (partial) cost-benefit analysis for the Nitra River Basin in the Slovak Republic illustrates how this

TABLE 2.
U.S. SECONDARY TREATMENT AND EUROPEAN COMMUNITY URBAN EFFLUENT STANDARDS

Parameter	U.S. Secondary Treatment Standard	European Community Directive
BOD_5	30 mg/l (30 day average) 45 mg/l (7 day average)	25 mg/l
COD	None	125 mg/l
TSS	30 mg/l (30 day average) 45 mg/l (45 day average)	35 mg/l (optional)
pH (Acidity)	6-9	None

approach can be used to help choose ambient water quality objectives (Box 5).

The ambient water quality objectives can usually be achieved with different combinations of effluent objectives for various pollution sources, because the most cost-effective wastewater investments in each city or area often depend on investments made in other cities or areas within the watershed. The role of cost-effectiveness analysis in assessing the various combinations of effluent objectives, and an example from Eastern Europe, is described in Box 6.

As this example illustrates, there is an interaction between ambient and effluent objectives–and between cost-benefit and cost-effectiveness analysis–such that these objectives may have to be set iteratively.

WATER QUALITY MODELING

Uniform effluent objectives make the planning process relatively simple for individual treatment plants. However, when there are multiple treatment plants and other effluent discharges within a region, the

BOX 5.
COST-BENEFIT ANALYSIS IN THE NITRA BASIN, SLOVAK REPUBLIC

The Nitra is a tributary of the Vah River, which eventually enters the Danube. Its length is about 171 kilometers, and there are about 600,000 inhabitants in the Nitra River Basin. About 70 percent of BOD_5 pollutant load comes from municipal discharge sources. Some of the time, dissolved oxygen (DO) is depleted in the downstream reaches of the river. Satisfying the European Community objectives listed in Table 2 would require capital costs of about $65 million and would achieve a minimum DO of 7 mg/l. Achieving a minimum year-round DO objective of 6 mg/l would require capital investments of only $26 million; and achieving a year-round minimum DO objective of 4 mg/l would require capital investment of only $13 million.

Only capital costs were included in this analysis. Completing the cost-benefit analysis would require that operation and maintenance costs be summed with amortized capital costs for each of the three alternatives, and that the benefits to inhabitants of the basin of minimum DO of 4, 6, and 7 mg/l be included. In addition, it is important to ask if the costs of achieving these three DO levels represent the most cost effective investments possible. Nonetheless, the Nitra Basin example demonstrates how simple cost-benefit analysis can be used to select ambient water quality objectives.

Note, however, that cost-benefit analysis simply aggregates the benefits and the costs without considering the distributional impacts. For example, the 4 mg/l minimum DO level may lead to the discharge of wastewater that leads to downstream communities bearing the majority of the costs.

Source: Somlyody, L. and P. Shanahan. 1998. *Municipal Wastewater Treatment in Central and Eastern Europe*. Washington: The World Bank.

BOX 6.
COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis is not the same as cost/ benefit analysis. The former identifies the lowest cost way to achieve a specified objective, while the latter identifies the project alternative objective that maximizes net benefits (total benefits less total costs). For example, meeting ambient water quality requirements might require reducing BOD_5 discharge by 100 kilograms per day, based on cost/benefit analysis. If only one pollution source exists, cost-effectiveness analysis would be limited to picking the treatment technology that meets this ambient water quality objective. If multiple pollution sources exist, the lowest cost of treatment for each source should be compared. If the lowest cost of treatment is the same at each source, uniform effluent objectives would be the most cost-effective solution. But if BOD can be removed at lower cost from one source than another, the effluent objective at the lower-cost source should be lower than at a higher-cost source.

Cost-effectiveness analysis for pollution reduction in the Vistula River, Poland, found that the cost of reducing loads on the Baltic Sea varied by a factor of 2.5 between the most and the least cost-effective treatment plants. If Baltic Sea loads were the only ambient water quality objective guiding the selection of treatment facilities along the Vistula River, additional treatment at the lowest-cost facilities and less or no treatment at higher-cost facilities would significantly reduce the total cost of achieving the desired load reduction.

Cost-effectiveness analysis, however, is usually performed for more than one water quality parameter. In the Vistula River example, ambient water quality concerns also existed in parts of the River near each city. Consequently, some high-cost treatment plants might need to be upgraded to meet a local ambient water quality objective. The local objective acts as a constraint on the cost-effectiveness analysis for the region. Consequently, cost-effectiveness analysis should be performed at various scales–starting at local water quality or health objectives (for which pollution prevention may be less costly than collection and treatment), then at various watershed scales (for example, the Baltic Sea watershed, and perhaps subwatersheds within it).

Source: Somlyody, L. and P. Shanahan. 1998. *Municipal Wastewater Treatment in Central and Eastern Europe.* Washington: The World Bank.

planning process to determine the most cost-effective choice of treatment facilities may be much more complicated. Water quality modeling is essential to managing this complexity successfully.

As with the Bombay sewage disposal project mentioned previously, water quality modeling may uncover some unexpected results. In Gunabara Bay, Rio de Janeiro, a modeling study found that high levels of wastewater treatment could, at least in the short term, cause deterioration in ambient water quality. Cleaner water might lead to algal blooms that would be worse than the before-treatment ambient water conditions. This is because removal of organic wastes (but not nutrients) would initially increase dissolved oxygen in the receiving water; but the nutrient availability and increased water clarity would promote algal growth, which eventually depletes dissolved oxygen even more severely than before treatment. As a result of the modeling effort, the recommended approach assigned a higher priority to nutrient reduction than had originally been proposed.

Without the modeling of dissolved oxygen concentrations in the Nitra River Basin example (Box 5), the planning team could not have known what level of treatment would achieve the minimum DO level that would support aquatic life, and therefore could not calculate the additional cost of higher DO levels. A variation of the same modeling tool, used in the highly polluted Huangpo River at Shanghai, found that oxygen depletion in the tidal reaches of the river would still be a problem even after high levels of treatment of wastewater discharges. This was because incoming tides would cause treated water to be present in the tidal reaches for very long periods, resulting in much more oxygen depletion from discharged wastewater than in a free-flowing river.

Similarly, ocean outfalls for effluent are usually designed so that wastewater or fecal solids do not wash onto shore under most weather and ocean conditions. These designs rely on relatively simple water quality modeling that accounts for the quantity of discharge, the level of treatment prior to dis-

charge of wastewater, the depth of the discharge, the location of the discharge relative to prevailing ocean currents, and so forth.[3] In Barbados, an ocean outfall was designed that takes advantage of strong, unidirectional currents that sweep the coast. Modeling was used to determine that an outfall located 1 kilometer offshore would keep the wastewater-mixing zone (a small zone around the discharge point) at least 30 meters below the ocean surface, and would satisfy ambient water quality objectives for bathing waters and shellfish harvesting.

The *Pollution Prevention and Abatement Handbook* and a recent World Bank publication[4] describe some common water quality models and, in the case of the latter publication, the experience of applying them in India, China, and the Philippines. These models include ones that are designed for predicting the water quality impacts of catchment runoff, urban runoff, and discharges from point sources into rivers, lakes, and marine waters. However, some data required by these models may not be available in all settings. Where these data values are missing, they can often be estimated and uncertainty limits can be placed on the model predictions to account for these estimates.

Computer-based models are not a substitute for hand calculations by experts, logical thinking, and extensive stakeholder involvement. In fact, economic and water quality models can be developed with extensive review and input from stakeholders using, for example, the Adaptive Environmental Assessment and Management (AEAM) process (Box 7). In this way, the model itself becomes part of the consultation process, leading to the stakeholders having increased trust in the outputs of the model.

[3] Further information can be found in the Environmental Assessment Sourcebook Update 13.

[4] Palmer, M. D. (2001).

BOX 7.
THE ADAPTIVE ENVIRONMENTAL ASSESSMENT AND MANAGEMENT (AEAM) PROCESS

Originally developed by the ecologist C.S. Holling, AEAM is a workshop-based process for the exploration and evaluation of management options for complex systems. It is particularly applicable to environmental management issues, where there are complex interactions of social, economic, physical, and ecological systems.

Key phases of the methodology are to (a) identify stakeholders; (b) use a workshop environment (incorporating key players) to develop and define the stakeholders' understanding of the system; (c) identify key components of the system with ongoing stakeholder input; (d) develop algorithms for the representation of the key components and combine the algorithms into an interactive model, which should have the capacity to incorporate key geographic, economic, policy, and management components for the system; (e) use gaming workshops to test the model, obtain feedback from stakeholders, and develop initial management scenarios; (f) finalize model development and present the model through a workshop with stakeholders; and (g) report the project results to the wider community.

The interactive model produced by the AEAM methodology is formulated by the stakeholders and incorporates their expertise and understanding of the system. The model relies on available data and is made as simple or as complex as these data allow. The role of facilitators in the workshops is to provide skills that draw out and clarify the expertise and knowledge of the stakeholders.

Source: Holling, C. S. 1978. *Adaptive Environmental Assessment and Management.* London: John Wiley & Sons.

WASTEWATER TREATMENT TECHNOLOGY

LEVELS OF TREATMENT

This section discusses the levels of treatment required to meet the effluent objectives established during planning for ambient water quality in more detail, and some of the more common technology choices within each level of treatment. There is an enormous body of literature on wastewater treatment technologies (see Further Information).

Effluent treatment is conventionally divided into five levels: (1) pretreatment, (2) minimal treatment, (3) basic (primary) treatment, (4) full (secondary) treatment, and (5) advanced (tertiary) treatment. Processes to kill pathogens (disinfection) may be used following most levels of treatment.

Pretreatment. Industrial facilities or agricultural processing may create pollutants that can be most effectively treated at the point of generation, such as a factory or canning plant. Such treatment prior to discharge into a sanitary sewer is called pretreatment. In many countries, licenses for industrial discharges to sewers require that the influent meet certain water quality standards. When an influent concentration of some particular pollutant is unusually high, pretreatment is usually necessary and cost-effective.

For example, the wastewater treatment plant at Nove Zamky, in the Slovak Republic, is greatly overloaded. The capacity of the plant is about 3,500 kg of BOD removal per day, but the actual load is about twice as large. Sixty percent of influent is from industrial sources with high concentration of BOD, TSS, TN, and TP. Treatment plant upgrades are required, with capital costs in the range of $4 to$6 million or $11 to$14 million depending on the approach. Although the more expensive approach would reduce nitrogen levels in the influent more than the less expensive one, neither approach is capable of meeting ambient water quality objectives for nitrogen discharges. Consequently, the less expensive approach combined with an industrial pretreatment program was recommended.

Minimal treatment. Raw wastewater typically contains materials that clog or impair pumps or other equipment needed to discharge wastewater reliably and causes unsightly conditions in the receiving water. Solid waste inappropriately dumped in sewers is another common problem. Minimal treatment removes these materials and is used as a first step in nearly all wastewater treatment facilities.

Larger objects are usually removed by either mechanically cleaned screens or communitors that cut up larger objects. The quantity of screenings usually varies from 0.0035 to 0.0375 m^3 per m^3 of wastewater.

Septic tanks are a form of minimal treatment because they also remove grit and floatable objects from wastewater. If the tank is not overloaded, much of the organic content in grit and floatables will anaerobically degrade. Tank cleaning will be required every two to three years as inorganic grit (silt, sand, etc.) and refractory organic matter accumulates. Unfortunately, most septic tanks are overloaded in practice and require much more frequent cleaning. Often this is not done, and the tanks clog up and untreated sewage overflows onto the surface.

Disposal of screenings, grit, skimmings, and septage (septic tank sludge) are environmental and public health issues that should be addressed early in project development. Septage is usually collected by private contractors who often discharge it illegally to surface waters or storm drains. Also, subsurface discharges of seepage from the disposal fields of septic tanks often re-emerge in the stormwater and drainage channels. These practices can create ambient public health problems that are sometimes more severe than if on-site, waterless disposal such as pit latrines had been used for sanitary wastes.

Basic (primary) treatment. Primary treatment typically removes organic materials by physical settling, often assisted by the addition of flocculants (chemicals that cause particles to settle more rapidly). Well-operated primary treatment plants can reliably reduce both BOD and SS below 50 mg/l. Primary sedimentation tanks typically remove 50 to 70 percent of the suspended solids and from 25 to 40 percent of BOD_5. Effluent from pond systems may have higher levels of BOD_5 and SS than this, due to the algae that grow in these nutrient-enriched ponds, unless the algal biomass is removed by processes such as filtration or dissolved air flotation prior to discharge.

Basic treatment is appropriate when the receiving water has a high capacity to assimilate organic matter. For example, ocean waters that are high in dissolved oxygen may be able to degrade organic matter without causing dissolved oxygen levels to drop significantly. Increased algal biomass, due to nutrients in the wastewater, may be eaten by aquatic species so rapidly that algal blooms and eutrophication do not occur. Similarly, a small discharge into a large river may be sufficiently diluted that few adverse effects occur if only basic treatment is provided. For example, the city of Manaus[5] discharges primary treated wastewater into the Rio Negro just upstream of the Amazon. It is difficult to see the benefit of higher levels of treatment in these circumstances.

Full (secondary) treatment. This level of treatment removes more BOD_5 and SS and (usually) nutrients than does basic treatment. Regulatory standards for this level are provided in Table 2 for the United States and Europe.

The most common form of secondary treatment is referred to as "activated sludge." In this process, bacteria are used to biodegrade organic materials into gases (for example, carbon dioxide), water, and bacterial biomass. Activated sludge facilities usually include an aeration basin in which the biodegradation occurs and a sedimentation tank in which the microbe-laden solids settle. Activated sludge is sometimes referred to as a "suspended growth process" because bacteria are suspended in the water column within the aeration basin.

Pond or lagoon systems are also capable of providing secondary level treatment, although the wastewater needs to be retained much longer than in activated sludge basins, necessitating more land area for the treatment facility. Hydraulic retention times in pond systems vary from 4 to 40 days, with secondary effluent quality achievable at longer retention times and primary effluent quality achieved at shorter retention times. By comparison, wastewater is retained in activated sludge aeration and settling tanks for only 4 to 8 hours, and within the entire treatment plant for much less than 1 day. Pond/lagoon systems have the advantage of removing bacteria more effectively than conventional sewage treatment and are simple and cheap to operate.

Both aerobic and anaerobic bacteria may be present in pond systems. Aerobic bacteria require oxygen to degrade wastes, whereas anaerobic bacteria degrade wastes in the absence of oxygen though a different chemical pathway. Anaerobic treatment can be useful when wastewater has a high solids content, since establishing uniform aerobic conditions is difficult in this case. Anaerobic degradation also takes place in septic tanks, leach fields, other subsurface systems, and the bottoms of some treatment ponds.

There are many other systems that are capable of treating wastewater to the full (secondary) level. These include overland flow systems, slow and rapid infiltration land treatment systems, aquaculture (including floating aquatic plants such as duckweed), and wetlands (see Note G.3).

From an environmental perspective, constructed natural systems are often superior to conventional engineering treatments. They often use less energy, have fewer solid byproducts such as sludge, produce potentially useful biomass products, and usu-

[5] Margulis, S., et al. 2002. *Brazil: Managing Water Quality.* Tech Paper No. 532: Washington, World Bank.

ally have lower operation and maintenance costs. Like ponds and lagoons, however, these systems require more land than is usually available in urban areas. Even so, these systems might prove more cost-effective than conventional facilities in some urban settings if the intangible benefits (Table 1) could be quantified. Certainly, these systems are often found to be cost-effective in rural settings where land is inexpensive. Box 8 discusses one constructed natural system that will be used in rural Hungary and the Slovak Republic.

Advanced (tertiary) treatment. Advanced treatment is typically used to remove nutrients, particularly nitrogen and phosphorus, or to protect waters–for example, mountain lakes–with limited natural ability to degrade organics. The ambient water quality objectives for the receiving waters drive the need for advanced treatment. Protection of ambient water quality in the Black Sea, for example, may require advanced treatment in some Bulgarian treatment plants.

Nitrogen removal is often accomplished by a process referred to as "denitrification." The nitrogen is mostly in the nitrate form (NO_3) following secondary treatment. This is then reduced by bacteria to nitrogen gas (N_2) if dissolved oxygen concentrations are low. Denitrification can occur in constructed natural systems used to provide secondary and advanced treatment, or as a separate step after conventional secondary treatment ("effluent polishing").

Phosphorus is usually removed by the addition of chemicals that form a precipitate that can then be removed by gravity settling. Aluminum sulfate (alum), lime, and ferric chloride are commonly used for this purpose. Box 9 presents an example of phosphorus removal by precipitation in Hungary. It demonstrates that delay in implementation of advanced wastewater treatment, if required, can be very costly.

Phosphorus can also be removed by some constructed natural systems. Soil-based land treatment systems are very effective at phosphorus removal if soil has a significant clay content or if iron or aluminum are present. These elements bind strongly to the phosphorus, thus removing it from the effluent. Aquatic systems such as ponds and permanently flooded wetlands, however, are much less effective due to limited contact opportunities between wastewater and soil. Shallow wetland systems that incorporate soil filtration of wastewater usually provide more phosphorus removal than ponds, but less than land treatment.

BOX 8.
TREATMENT IN CONSTRUCTED NATURAL SYSTEMS IN RURAL SETTINGS

The village of Szugy, Hungary, with a population of 1,200 and residential area of 74 hectares, is typical of rural villages in many parts of the world. There is currently no piped water or sanitary sewers. Shallow groundwater is highly contaminated, with nitrates from improper on-site sewage disposal and fertilizer application. Shallow wells continue to be used for some purposes, but bottled water and usage of deep wells has become necessary to maintain public health. Bids received for construction of a conventional wastewater treatment facility ranged from $180,000 to $280,000 depending on whether a steel or concrete tank was specified for biological treatment. In contrast, the estimated construction cost of a 4-hectare root zone treatment system is $140,000. This type of system involves a bed of reeds planted over a 15-cm compacted clay layer. Wastewater moves through the system horizontally, and is simultaneously filtered by soil and biologically degraded. The design effluent quality is 10 to 30 mg/l for BOD_5 and 4 to 50 mg/l for SS. Effluent will be disinfected prior to discharge into a creek.

The feasibility of root zone treatment was also analyzed for six villages in a lowland region of the Slovak Republic. Village populations range from 400 to 2200. Four alternatives were studied: 1) individual conventional biological treatment plants for each village; 2) two conventional, regional, biological treatment plants; 3) one conventional, regional, biological treatment plant; and 4) root zone facilities for each village. Capital costs for the first three options ranged from $1.4 million to $2 million, while the six natural systems would require only $1.2 million.

Source: Somlyody, L. and P. Shanahan. 1998. *Municipal Wastewater Treatment in Central and Eastern Europe.* Washington: The World Bank.

Pathogen removal. Pathogen removal is an extremely important aspect of wastewater treatment. Bacteria, viruses, protozoa, and helminths may be present in treated wastewater. Pathogens can be destroyed by natural processes, such as the high pH levels that occur in the anaerobic parts of some pond treatment systems. Many pathogens are killed by prolonged contact with seawater. Pathogens also die off naturally, or are killed by predation. Longer retention times and higher temperatures in pond systems and other aquatic systems promote these processes.

Disinfection with chemicals–for example, chlorination–is used in most conventional treatment systems. Chlorination can be used following basic, full, or advanced treatment. Effectiveness at any given dose level depends on factors such as the length of time that wastewater is held in the chlorine contact chamber; the concentration of pathogens; and temperature. Since disinfection is hindered by higher levels of BOD and SS, equivalent levels of pathogen removal require higher disinfectant doses in more highly polluted wastewaters.

Reactions between the introduced chlorine and organic compounds in the wastewater produce trihalomethane compounds, many of which are toxic to humans and aquatic life. Even when acute toxicity (immediate death) does not occur, chronic toxicity (long-term effects such as cancer, reduced reproductive success, lower growth rates, etc.) often results from long-term exposure to these chlorinated compounds. While the presence of these toxic byproducts is a concern in developed countries where other health effects from wastewater discharges are now under control, the benefits from pathogen removal with chlorination in the developing world usually outweigh the possible health effects from such byproducts.

Dechlorination with sulfur dioxide is commonly used to remove residual chlorine and chlorinated compounds. Dechlorination is a very reliable process provided that the residual chlorine is monitored reliably. If not, toxic compounds will be released into the receiving water or the measured BOD and COD of the wastewater will be increased due to oxidation of excess sulfur dioxide. For this reason, alternatives to chlorination or chlorination/ dechlorination should be carefully considered during project development. Although ozone or other disinfection processes such as ultraviolet light may be significantly more expensive than chlorination or chlorination/ dechlorination, the beneficial uses of the receiving water might be protected more reliably by these other processes.

The potential for environmental or public health damage from chlorine and chlorinated compounds

BOX 9.
ADVANCED TREATMENT FOR PHOSPHORUS REMOVAL IN HUNGARY

Lake Tata, Hungary, is an artificial lake created by impounding the Alteler River, a tributary of the Danube. The lake and its watershed was a popular recreational area, but deteriorating water quality has reduced tourism income by half in the last decade. The lake is severely eutrophic and is no longer suitable for swimming. More than 90 percent of nitrogen and phosphorus loads in the lake originate from municipal discharges of two towns (Oroszlany and Tatabanya).

Phosphorus precipitation was added to the wastewater treatment plants at both towns in the early 1990s, removing about 90 percent of the phosphorus in the effluent. The lake, however, failed to show any improvement in water quality. Subsequent analysis has shown that due to historical nutrient loads, a significant amount of phosphorus has accumulated in lake sediment. This provides an internal phosphorus source that more than offsets phosphorus removed from wastewater. The lake's sediment must be treated for a successful rehabilitation, at a prohibitive cost of $10 million. This example shows that prompt action to control nutrient discharges may be advisable once a problem is apparent or expected.

Source: Somlyody, L. and P. Shanahan. 1998. *Municipal Wastewater Treatment in Central and Eastern Europe.* Washington: The World Bank.

is an example of why it is important to consider environmental issues early in the project development process. If the receiving water is sensitive to chlorine residuals for its intended beneficial uses, then using chlorination for pathogen removal is unlikely to be the favored technology during the design process.

MANAGEMENT OF SLUDGE AND RESIDUALS

Wastewater treatment creates solid residuals that need to managed in an environmentally sound manner. By far, the largest such residual streams are sludge from primary and secondary treatment, although residuals of grit, skimmings, and harvested aquatic vegetation from the pretreatment can be significant too. The environmental implications of managing these materials are rarely considered during project development.

Sludge management facilities may account for as much as one-third of both the capital and operating costs of conventional, secondary, activated sludge wastewater treatment plants. In addition, disposal of sludges will result in significant releases of methane and the costs of this greenhouse gas need to be factored into the decisions. Incremental process improvements that reduce the quantity of sludge by 10 percent or more would create significant savings. Treatment processes that produce little sludge (for example, some anaerobic ponds) would compete more effectively with conventional treatment if the avoided costs of sludge management are included.

Disposal in a sanitary landfill or incineration are the most common options for disposing of screenings, skimmings, and grit. If planned and managed correctly, either of these options can be environmentally appropriate. However, if disposal is not addressed explicitly during project development, it is likely that inappropriate disposal will occur, because operating and maintenance budgets are often inadequate in the first place. Additional demands, such as residuals disposal that were not explicitly budgeted from the beginning, will usually be handled in the simplest and lowest cost manner.

Activated sludge can be biologically digested after removal from the settling tanks, or left in a raw condition. Digestion reduces the volume of sludge requiring disposal, reduces its organic and pathogen content, and creates a sludge that is less odorous. Anaerobic digestion can be used to convert organics into biogas, which in turn can be used in gas-driven pumps within the treatment plant or to produce electricity that may be used within or outside the treatment plant. Although electricity production from biogas at treatment plants has received much attention in recent years, biogas-driven influent pumps are an older energy recovery technique that has been used successfully for many years.

Both raw and digested sludge are typically dewatered prior to disposal in order to save on transport costs. Sludge from septic tanks and pit latrines can be disposed of jointly with sewage sludge. Dewatering increases the solids content from 3-5 percent to 20-30 percent. Alternatively, digested sludge can be dried in shallow solar drying beds. Raw sludge is too odorous in most situations to be dried in open beds, and attracts flies, rodents, and other creatures that can transmit disease. An underdrain system is typically provided to assist the dewatering process, with the drained water being returned to the treatment plant. If an underdrain is not provided, the need to protect groundwater from wastewater infiltration should be evaluated and addressed. Solids content rises to 40 percent after the sludge has been in drying beds.

Digested sludge can be applied to land, composted to make a soil amendment, disposed of in a sanitary landfill, disposed of in the deep ocean, or incinerated. The first two techniques are environmentally preferable because they recycle organic materials and nutrients. However, they may also cause environmental and production problems in particular situations, for example when heavy metals are present in the sludge.

SLUDGE DISPOSAL

Land application. Sludges from domestic wastewater are often suitable for application to agricultural

land, but have also been used to restore degraded lands, such as exposed surfaces at open pit mining sites. Sludges that include residuals from industrial wastewater may be unsuitable due to the presence of metals, pathogens, or other potentially harmful substances. Trace metals can be absorbed into food crops or into vegetation consumed by grazing animals. Local standards should be more stringent when particularly sensitive waters adjoin or underlay the land application site.

Ocean disposal. Ocean disposal typically involves barging the sludge to a deepwater location. The environmental impact may be difficult to assess because it requires an understanding of ocean currents and biological processes, which may not be available at the proposed disposal location. At a minimum, potential impacts on ocean fisheries should be thoroughly investigated. Because of these uncertainties, it is not a preferred option.

Incineration. Incineration is suitable when supplemental energy sources are inexpensive and emissions from the incinerator can satisfy local air quality objectives. However, local operation and maintenance capacity should be considered carefully before incineration is selected. A poorly operated sludge incinerator will not combust the sludge completely, and may emit harmful or corrosive organic substances or ammonia. Even with complete combustion, the possibility exists that harmful substances, such as dioxins and metals such as mercury, will be emitted. Like ocean disposal, it is not a preferred option.

Landfill. Disposal to a sanitary landfill is appropriate when leachate can be contained at the landfill. Compacted clay or synthetic liners are best, but a landfill situated over relatively impermeable soils or rock is also acceptable. Sludge should always be dewatered prior to disposal in a sanitary landfill, unless the landfill is equipped with a leachate collection system (an underdrain). Over long periods of time, significant liquid accumulation at the base of fill can create enough hydraulic pressure to force leakage through even relatively impermeable soils or rock.

Liquid accumulation at the base of fill can also render fill slopes unstable, especially during earthquake events, threatening sudden release of liquids or damage to neighboring facilities. A slide at a landfill located over saturated, marshy terrain in Northern California in the 1970s caused an adjacent underground, 60-inch diameter, treatment plant outfall pipe to be displaced horizontally about 40 feet. Fortunately, the outfall was of the gravity type (not pressurized), and did not rupture.

SOME EMERGING TECHNOLOGIES AND TECHNIQUES

The previous section has described the most widely used wastewater treatment processes and techniques available. Research into wastewater treatment, alternative sewer systems, and on-site waste management techniques is resulting in the emergence of promising new technologies and techniques. Some references are given in the Further Information section. Here, we discuss two emerging technologies and two emerging management techniques that may lead to environmentally sound, relatively low-cost, sanitation services.

Demand management. Demand management of water supplies can potentially achieve very significant savings by reducing inflows to treatment plants and thereby reduce the need for sewer and treatment plant infrastructure. Techniques to achieve reduced water use are discussed in detail in Note F.1.

So-called “effluent sewage” systems that collect either septic tank discharges or only greywater (urine and fecal matter are managed separately) can reduce sewer construction costs by 20 percent and treatment costs significantly. Low flow plumbing fixtures save water and reduce hydraulic loads on sewers and treatment plants, again reducing capital costs.

Systems that reuse graywater on-site can reduce the environmental pressures on water resources in areas that are short of water. These systems need to

be built and operated in a manner that satisfies strict public health codes. Thus, the public health code in Santa Barbara County, California, now permits graywater systems that are designed in accordance with county guidelines.

Vermi-composting (worm composting). Some species of earthworms are well-suited for biological stabilization of wastewater sludges. Earthworms both aggregate loose materials into discrete, relatively dry, and odorless fecal pellets (castings), and create more surface area on which aerobic bacteria can feed. Anaerobic conditions are toxic to earthworms, so vermi-composting is not technically feasible for anaerobically digested sludge, unless it is thoroughly aerated prior to introduction of worms. Because earthworms both aerate and mix the compost pile, mechanical equipment costs are much lower for vermi-composting than conventional piles.

Vermi-composting can be applied to sludge either prior to or after dewatering. Investigations have shown that, for sludge treated with worms prior to de-watering, total solids vary from 14 to 24 percent; COD ranged from 606 to 730 grams per kilogram of total solids; organic nitrogen was in the range of 27 to 35 grams per kilogram of total solids; and pH was between 6.6 and 7.1. The type of sludge–primary or secondary–does not seem to affect the stabilized sludge quality very much.

Pathogen removal by vermi-composting is not yet fully understood although, in one test, the Texas Department of Health found no Salmonella in either the castings or the earthworms at a raw sludge facility. Earthworms may accumulate significant concentrations of cadmium, copper, and zinc, and therefore should not be used as a major food source for animals or fish. Testing for metals concentrations in castings and earthworm bodies, however, should be performed in a pilot project before harvesting is included in a facilities plan.

Capturing cross-sectoral benefits. Regional, multisector planning of wastewater management is one of the lessons from Bank experience. Economists describe these cross-sectoral benefits as "economies of scope," because a project that delivers two or more separate services–for example, wastewater treatment and irrigation water supply (see Note F.3)–is less expensive per recipient than supplying these services separately (Box 10). Thus, many U.S. cit-

BOX 10.
CAPTURING CROSS-SECTORAL BENEFITS

A 1984 Bank-sponsored study in Cyprus concluded that a wastewater treatment plant and ocean outfall was the least-cost solution to the groundwater and sea water pollution resulting from the on-site systems that serviced residents and high influxes of summer tourists. These facilities were not built, however, because hoteliers resisted the rate increases that were a condition of international Bank funding. After extensive stakeholder involvement, an update of the feasibility study was commissioned in 1990. The update concluded that a sea outfall was not necessary and recommended reuse of treated effluent for landscape irrigation.

The San Jose/ Santa Clara, California, regional water pollution control plant discharges tertiary treated effluent to near-shore waters of the south San Francisco Bay. In the mid-1990s, the permitting agency required the treatment plant to restrict dry season discharge to no more than 120 million gallons per day in order to protect a saltwater marsh from being converted to a freshwater marsh, a loss of habitat for the endangered clapper rail and salt marsh harvest mouse. All prior analysis of alternatives to near-shore discharge had identified a deep, offshore outfall as the least-cost solution.

When water supply and wastewater system needs were considered simultaneously, however, the lowest cost option was wastewater re-use for landscape irrigation. Subsequently, a 15 million gallon-per-day reuse system was put into operation, and plans are underway for up to 100 million gallons per day of reuse. The water district contributes around $100 per acre-foot to the cost of the reuse system, because it can avoid over $300 per acre-foot of expense for construction of new water supply reservoirs. With this contribution, reuse is a lower cost option for the treatment plant than construction of a deep ocean outfall. Both parties benefit financially, and the environment benefits as well.

Source: World Bank.1999. *Environmental Assessment Sourcebook Update No 13*. Washington: World Bank.

ies maintain their own sanitary sewers, but a regional plant treats the sewage. Sewer, water pipe, and street maintenance have an improved economy of scope by having one agency (typically the city) responsible for all three.

Identifying and capturing cross-sectoral economic and environmental benefits of wastewater investments is an emerging management approach that needs to be included in the early stages of project development. For example, the high organic and moisture content of municipal solid waste in less-developed countries is conducive to biogas production in specially designed landfill cells. Disposal of treatment plant sludge in such cells would be environmentally sound, provide a source of energy at the treatment plant site, and have lower cost than construction and operation of anerobic digesters.

Vertical and horizontal unbundling. Diseconomies of scope can also occur. One agency that provides all wastewater services may be more costly than multiple service providers, each specializing in one type of service. Similarly, facilities can be too large, creating diseconomies of scale. Transferring responsibility for different stages of wastewater management is termed vertical unbundling; the transfer of responsibility to smaller geographic entities is termed horizontal unbundling (Box 11). These techniques avoid diseconomies of scope and scale, thus reducing costs per service recipient and allowing more environmental protection at a lower cost.

In itself, unbundling is not a solution. The important point arising from successes in vertical and horizontal unbundling arises from the recognition of the possible economies and diseconomies of scale and scope when all costs, including environmental costs, are included. For example, horizontal unbundling was not environmentally or economically desirable in Chongquing, China, because there was sufficient slope throughout the city to gravity drain standard-depth sewers to a single treatment plant location. In addition, a horizontally unbundled approach involving numerous treatment plants would have discharged treated wastewater upstream from water intakes, necessitating treatment to the full (secondary) level. Discharge at a single, downstream plant requires treatment only to the basic (primary) level.

BOX 11.
THE EMERGING TECHNIQUES OF VERTICAL OR HORIZONTAL UNBUNDLING

Brazil was successful at lowering the cost of sewer service to the urban poor by changing the authority and responsibility for lateral sewers. As in other major cities, in-house plumbing and toilets had been traditionally owned by each household, and lateral sewers, trunk sewers, and treatment facilities had been traditionally owned and operated by a central agency. The transfer of responsibility for lateral sewers to community groups (vertical unbundling) allowed them to innovate and succeed where centralized agencies had failed.

Horizontal unbundling is the practice of breaking cities into districts with separate sewers and treatment facilities. For example, sewer systems in flat areas can become prohibitively expensive as they are enlarged, because pipes either need to become larger and deeper to carry wastewater by gravity flow or pumping stations are required. Bangkok has divided its collection and treatment services into separate districts for this reason. Sewer systems are also horizontally unbundled in many parts of the United States, including Los Angeles County and Alameda County in California.

Many of these horizontally unbundled sewer systems are also unbundled from the treatment plants that serve them. In other instances, separate facilities are based on history and political boundaries. In those cases, "bundling" existing districts and functions might improve cost-effectiveness.

Source: Serageldin, I. 1994. *Water supply, sanitation and environmental sustainability: The financing challenge*. Washington: The World Bank.

FINANCIAL ISSUES

COSTS FOR WASTEWATER TREATMENT

Wastewater treatment costs depend on the type and level of service provided and local conditions. Table 3 provides ranges of costs for conventional treatment options. The wide range of costs arises from differences in the level of service, local conditions, quality of data, and methods of calculation. None of the costs include environmental costs such as impacts on downstream users of water or water-based resources (e.g., fisheries).

Cost recovery. Utility services of all types have been, and continue to be, subsidized in many parts of the world. Extensive experience shows that widespread subsidies lead to overuse of water resources, discharge of contaminated wastewater, and subsequent environmental problems. User fees that recover the cost of delivering services, such as wastewater treatment, are an essential part of the solution to this problem.

Water users should be charged for at least the operation and maintenance cost of the water and sanitation system plus the costs that result from disposing of wastewater–such as downstream impacts of sewage discharges. As a practical matter, the cost of wastewater treatment is often included in water rates or tariffs since water use is easier to observe or meter than is wastewater discharge.

Cross-subsidies between user groups may be used to reduce the burden on poorer users of water or sanitation services. If designed properly and reviewed periodically, cross-subsidies can be consistent with full cost recovery and with price signals to users that lead to socially desirable results. For example, the capital recovery portion of the financial cost of a wastewater treatment system may be allocated exclusively to wealthier and middle-income customers without distorting the volumetric water-price signal. This is because capital recovery charges are often a separate part of the water/wastewater bill.

TABLE 3.
COST RANGES FOR ON-SITE AND SEWERED (CONVENTIONAL TREATMENT) OPTIONS

Economy	Option	Capital Cost[1] ($ / capita)	Capital Plus Operation and Maintenance Cost ($ / capita/ year)
Low-Income Economies	Treatment plant[2]	20–80	5–15
	Sewer + treatment[2]	200–400	10–40[3]
Middle-Income and Transitional Economies	Treatment plant[2]	30–50[2]	Not provided
	Sewer + treatment[2]	300–500[2]	30–60[3]
Industrialized Countries	Treatment plant[2]	150–300[1]	Not provided
	Sewer + treatment[2]	100–200[2]	100–150[3]

Notes:
[1] For primary plus secondary treatment, including land purchase and simple sludge treatment, for a capacity of 30,000 to 40,000 persons. Lower values pertain to low-cost options such as waste stabilization ponds; higher values pertain to mechanized treatment such as oxidation ditches and activated sludge plants.
[2] For plant capacity of 100,000 to 250,000 persons.
[3] For industrialized countries, this includes tertiary treatment and full sludge treatment; for other countries, this includes secondary treatment.

Source: UNEP, 2001

Historically, user fees are set (after technical analyses) without the involvement of those affected. However, willingness to pay is not a fixed item that experts can extract from historical data, but a complicated set of preferences and concerns that are only fully sorted out during a participatory process. Participation in setting charge rates can increase willingness to pay, because of an improved understanding of the benefits of wastewater treatment or an increased confidence that services will actually be delivered.

FURTHER INFORMATION

Good references to wastewater management are available in:

Marino, Manuel and John Boland. 1999. *An integrated approach to wastewater management*. Washington: The World Bank.

The World Bank. 1992. *World Development Report 1992: Development and the Environment*. New York: Oxford University Press.

UNEP 2001. "Guidance on Municipal Wastewater: Practical Guidance for Implementing the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA) on Sewage." Working Document Version 2.0, 21 October 2001. The Hague: UNEP/GPA Coordination Office.

Two World Bank publications discuss the provision of wastewater services by user groups:

Subramanian, Ashok, N.Vijay Jagannathan, and Ruth Meinzen-Dick. 1997. "User organizations for sustainable water services." World Bank Technical Paper No. 354. Washington: The World Bank.

Wright, Albert M. 1997. *Toward a strategic sanitation approach*. Washington: UNDP-World Bank Water and Sanitation Program.

The following reference provides overviews of the wide range of technologies available for wastewater management:

Tchobanoglous, George. 1991. *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd edition. New York: McGraw-Hill.

Natural wastewater disposal systems (constructed wetlands, etc) are described in:

Reed, Sherwood, E. Joe Middlebrooks, and Ronald W. Crites. 1988. *Natural Systems for Waste Management and Treatment*. New York: McGraw Hill.

Water Pollution Control Federation. 1990. *Natural systems for wastewater treatment*. Manual of Practice FD-16. Alexandria, VA: The Water Pollution Control Federation. (Note: the Water Pollution Control Federation is now called the Water Environment Federation.)

The following reference provides more information on effluent disposal to agricultural lands:

Khouri, Kalbermatten, and Carl Bartone. 1994. *Reuse of wastewater in agriculture: a guide for planners*. Water and Sanitation Report No. 6. Washington: UNDP-World Bank Water and Sanitation Program.

Models for predicting the water quality impacts of wastewater treatment discharges are described in:

World Bank, 1998. *Pollution Prevention and Abatement Handbook* 1998. Washington: The World Bank.

Palmer M.D. 2001. *Water Quality Modeling: A Guide to Effective Practice*. Washington: The World Bank.

The following website provides access to numerous documents on water supply and sanitation issues in the developing world, including municipal wastewater treatment:

http://www.irc.nl/products/documentation/reference.html