Optimizing Wastewater Treatment

Growing volumes of industrial and municipal wastewater are being discharged to surface waters. The treatment provided is frequently inadequate to protect the desired uses of the receiving waters. Limited institutional capacity and financial resources make for difficult choices as governments try to optimize their investments in municipal systems and establish practical requirements for industrial wastewater treatment. This chapter presents a framework for making coherent decisions on the level of wastewater treatment.

In many urban situations, both the municipal sewage system and industrial wastewater treatment are inadequate. A municipal sewage network may be in place, but coverage is usually incomplete, and the level of treatment provided is inadequate. Even where reasonable treatment facilities exist, poor maintenance and operation often result in failure to meet design effluent levels. In such circumstances, management of industrial wastewater discharges is also frequently poor, with uncontrolled discharges of untreated effluent to surface waters (through often drainage or stormwater channels) or to the sewer system. The result is high levels of water pollution. It is not uncommon for streams or water bodies to be almost or completely anaerobic and heavily polluted with organic compounds, pathogens, and heavy metals.

Objectives

There are several objectives that must be addressed in such a situation:

- The collection and removal of domestic and municipal wastewater to protect public health and to improve the immediate environment (particularly important where inadequate disposal is resulting in groundwater pollution)
- The establishment of an effective industrial pollution control system to reduce the loads and impacts of industrial discharges
- Provision of municipal and industrial treatment as necessary to protect the environment at the points of final discharge
- Efficient and cost-effective achievement of all these goals within the relevant social and political constraints.

Public and Private Involvement

The basic responsibility for municipal sewage lies with the government (at the appropriate level, preferably local). Industrial wastewater treatment is fundamentally the responsibility of the enterprise but in practice has to be driven by government action. The challenge for the government is to use the whole range of options and instruments available to achieve the objectives outlined above, combining physical and operational improvements in the municipal infrastructure with the controls and incentives necessary to induce improvements in the industrial sector. This chapter focuses on the management of industrial wastewater within this broader context.

Focus on Water Bodies

From the environmental (as distinguished from the sanitation) point of view, the focus must be on the receiving water bodies. The problems are typically diffuse, with hundreds or thousands of small discharges and with the problems concentrated to some extent where particularly polluted streams or poorly treated effluents discharge to major water bodies. Upgrading or extension of the wastewater collection system may reduce this diffuse pollution but may produce major point discharges that must receive adequate treatment.

A wastewater strategy must therefore be based on a water quality plan for all the receiving waters in the catchment, usually on the basis of water quality objectives.

Water Quality Objectives

It is necessary to have explicit medium- to long-term objectives for the quality of water in the various water bodies in the catchment under consideration. These objectives are often based on defined beneficial uses for the water bodies, typically including about a half dozen uses such as source of water supply, agricultural use, fisheries protection, and so on. A set of key numerical parameters can be defined for each use, and the water quality objectives can be developed in terms of uses for different sections of the water bodies and a strategy for achieving those standards. (See the related chapter on Integrated Wastewater Management.) The objectives then provide clearly defined goals for protection or improvement of each section of the system.

Development of the Strategy

Load Estimation

The first step in developing a wastewater strategy is to estimate the overall loads in the catchment over the time scale being considered, which is typically about 20 years. This will require, in addition to information on population growth and densities, estimates of industrial activity and of projected changes in industrial and population patterns.

In some cases, direct observations of industrial pollution loads are available, but more often, estimates are based on statistical information on economic activity (sectors, employment, turnover, and so on), using various coefficients for the unit loads of pollution. Overall planning requires estimates of both domestic and industrial loads on a geographic basis and over the time period under consideration. The estimates need to be developed for key parameters such as suspended solids, oxygen demand, nutrients, organic materials, and heavy metals, depending on the particular characteristics of the catchment and receiving waters.

Determination of the Reductions Necessary

Once load estimates are available, it is possible to determine the reductions in present and future loads needed to achieve the water quality objectives. In simple cases, a mass balance may suffice, but often it will be necessary to carry out water quality modeling (see the chapter on Water Quality Models).

The objective of the modeling is to estimate the impacts of the increasing loads on water quality and to identify where load reductions are required in order to achieve the water quality objectives. The sophistication required in the modeling will depend on conditions. In some cases, a simple one-dimensional model of oxygen depletion will be acceptable; in other cases, complex models will have to be developed to address water circulation and the degradation and interaction of several pollutants.

Development of Options for Load Reduction

After the desired degree of reduction in pollutant loads has been estimated, the next step is to develop options for achieving that reduction. If the most significant pollutants are those associated with industrial effluents—for example, complex organic compounds or heavy metals—the control efforts will clearly be concentrated on the industrial discharges. Often, however, oxygen depletion and nutrients are the critical issues, and the causes are typically a mixture of municipal and industrial sources. Then it is necessary to control both types of sources.

The costs of cleaning up a major industrialized urban area can be massive. The estimated costs of water pollution control in Shanghai in 1986 were US$1.4 billion. Preliminary estimates show that the Buenos Aires sewerage authority faces an investment program of nearly US$1 billion over the next decade. Clearly, such programs require decades for implementation, making it important to tackle them in an organized and cost-effective manner.

Components of an Urban Wastewater Program

An urban wastewater program comprises several distinct but interlocking components. Municipal system improvement is almost always a central feature, but the emphasis given to the industrial wastewater control component depends greatly on the extent of the industrial contribution to the overall problem, the types and sizes of industries involved, and the costs of enforcement and implementation. In some cases, or for some pollutants, small or nonpoint sources may be a significant problem, and one that is typically difficult to tackle.

Municipal System Upgrading

There are normally two imperatives behind municipal system upgrading:

- Expansion of the coverage and quality of sewerage provision
- Reduction of the impacts of final disposal of treatment plant effluents.

Detailed treatment of expansion of the coverage of the service is beyond the scope of this chapter. It should be noted, however, that because of limited funds, sewerage authorities often have to make tradeoffs between expanded coverage and higher levels of treatment, with consequent implications for the quality of the receiving water.

The impacts of final disposal depend, obviously, on the discharge location. In many cases, an existing system configuration more or less limits the choice of the discharge site, and therefore the emphasis is on improving the level of treatment provided.

Levels of Treatment

Municipal wastewater systems are normally designed to treat influents that are essentially domestic in nature. Such systems are ineffective in removing some industrial pollutants and may even be damaged by them.

Design of municipal wastewater treatment is a sophisticated operation. In general terms, however, there are three major types of process, in ascending order of removal effectiveness (and cost): physical, sometimes assisted by chemicals; biological; and "advanced," which includes further chemical or biological stages, filtration, or combinations of these methods. These systems can achieve high levels of removal of organic material and of suspended solids. The advanced systems can also remove nutrients to a high degree.

Municipal systems do not cope well with high concentrations of complex organic chemicals such as solvents and hydrocarbons or of heavy metals. The removal efficiencies are low, and biological treatment systems can be poisoned if incoming levels are too high. Other wastewater treatment processes that can be tailored to deal with such industrial effluents are available. Because of the limitations of municipal systems, and to protect the physical infrastructure and workers, it is normal practice to require pretreatment of industrial effluents that are discharged to a sewer system.

Control of Industrial Effluents

Treatment systems for industrial effluents can be designed to provide any required level of pollutant removal, although at increasing cost and sometimes with a resultant wastewater treatment sludge that presents its own disposal problems. Where effluent treatment costs are high, waste minimization programs become very worthwhile.

The degree of industrial effluent treatment required is established, in theory at least, in relation to relevant ambient quality or effluent standards. In practice, control of industrial effluents is frequently poor, and industry may be a major contributor to the overall pollution load.

Where practical controls exist, industry is typically faced with two choices: direct discharge to surface waters (licensed groundwater discharge is rare), or discharge to the sewer system, if one is available. Effluent standards will apply to both options. Sewer regulations will require pretreatment to remove toxic substances, but effluents that can be treated by normal municipal systems will be accepted, at a charge. Direct discharge standards will depend on the character and objectives of the receiving water but would normally be expected to be more stringent than sewer standards.

Because of economies of scale, sewer discharge of simple wastes such as BOD is often cheaper than industrial onsite treatment. However, there are often problems with the capacity of the municipal treatment system and with implementing correct charging procedures, and so this option may not always be available.

Clearly, where regulations are inadequate or enforcement is lax, there is a financial incentive for industry to avoid treating the effluents.

Optimizing the Program

Once the basic information on water quality, municipal and industrial loads and trends, and estimated control costs is available, it is possible to begin to optimize a wastewater management program.

A key decision variable is the time scale over which the required upgrading is to be implemented. The costs of major treatment systems are so high that upgrading almost always has to be staged. Moreover, high urban growth rates mean that significant investment is often required just to maintain present levels of service to the growing population. Implementation of effective industrial pollution control programs takes time, and a realistic approach to projecting load reductions must be adopted.

An iterative planning process is therefore required that examines a number of options for the scale and rate of wastewater treatment improvement, balancing the costs of the program against the time needed to achieve the water quality objectives. This process should involve an appropriate level of public discussion so that a practical program can be developed that will have the broad public and political support necessary for implementation.

Benefits and Costs

A set of agreed water quality objectives (WQOs) that has been adopted by the government can be taken as reflecting the value of improving the receiving water quality, assuming that it is based on evaluation of the economic benefits of the improved uses of the water resources and on the outcome of a public priority-setting process.

The major components of a wastewater management plan, which typically compete for investment funds, are:

- Upgrading of *sewer systems* in existing urban areas to remove pollution from neighborhoods and to reduce uncontrolled discharges to local watercourses and groundwater
- Upgrading of *municipal treatment systems* to reduce the impacts of the effluent discharges on the receiving waters
- Introduction of a system to identify and regulate *discharges from industry*
- Reduction of *current industrial pollution loads* through recycling, improved waste management, onsite treatment, or connection to sewer systems
- Adequate provision of sewerage and treatment for *new urban development*
- Effective control of effluent discharges from projected *new industrial development*
- Development of programs to quantify and tackle *nonpoint sources* of pollution, including combined sewer overflows.

Both the overall costs of these components and the distribution of costs must be taken into account in arriving at an estimate of the most cost-effective investments for achieving WQOs. In effect, a marginal cost curve can be developed for the water quality improvements, although there are always many uncertainties in the estimates.

Two practical problems have to be resolved in preparing realistic options: the actual costs of pollutant removal for each component and the impact of such removal on water quality.

Unit Costs of Pollutant Reduction

Each of the components outlined above will have a different effective cost of pollutant reduction, and the distribution of the burden of the costs will usually be different. For example, for BOD, which is usually one of the main parameters, the following general conclusions can be drawn.

Upgrading sewer systems can greatly reduce local pollution loads but will increase the loads at the treatment plant. It is reasonable and realistic to set domestic charge levels to cover at least this component of sewerage, since it provides direct benefits to households. Thus, it should be possible to cover investment costs out of increased revenue.

Upgrading municipal treatment addresses what is often the single largest point source of BOD in a system, and the costs of removal can be calculated quite accurately. Sludge handling and disposal costs can be a significant element and must be included in the estimates. BOD removal normally entails increasing marginal costs in moving from primary to secondary systems and on to advanced systems. The costs of treatment should, in principle, be borne by the system users (the polluters pay). It is often politically difficult, however, to raise surcharges enough to cover the higher treatment levels because the users do not see the benefits directly. In many projects, some component of the treatment costs is borne directly by the government.

Introducing industrial pollution controls is used to achieve reductions in industrial effluent discharges. To do this, a regulatory and permitting system has to be in place, whether it is based on standards or on charges. The cost of putting a system in place or reinforcing it is part of the investments that are necessary (but not sufficient) to achieve reductions in industrial discharges of BOD or other pollutants. The design of the system should specifically address how effective it can be in actually achieving certain levels of reductions. This effectiveness depends on a number of factors, but the number and size of polluters is clearly a key one: it is much quicker and more cost-effective to deal with a small number of large firms than with many different small ones.

Reducing industrial loads can often be done at little or no net cost to industry, even for significant reductions (see the chapter on Implementing Cleaner Production), but there are often transaction costs that are typically borne by the government. Estimates can be made of, for example, the volume of BOD generated by industrial sources and the costs of reduction, if an inventory of sources is available. Clear priority should be given to ways of inducing waste minimization as a first step in reducing overall loads.

In principle, the costs of treating BOD loads from industrial sources should be no more than the costs of municipal treatment because industry can, in the ideal case, choose to use the municipal sewers and pay the costs. Given the waste minimization opportunities that typically exist in industry, the marginal costs of pollution reduction should be no higher than the costs in the municipal system.

New urban developments should be provided with sewerage and treatment systems adequate for meeting the necessary discharge requirements. The costs should be borne by the users. In practice, however, fringe developments are often expensive to service and are occupied by poorer (often illegal) households. Projections of development should therefore include realistic estimates of the extent and net cost of control of expanding urban areas.

New industrial development presents a much easier task in enforcing effluent standards than does retrofitting older plants. The net cost of controlling new pollution loads can therefore be expected to be less. In this context, it is important, in setting water quality objectives, to take into account the growth of urban and industrial activity so that realistic discharge requirements can be placed on new projects.

Nonpoint sources account for a significant load of many pollutants, including BOD but particularly nutrients. This category typically includes runoff from urban and agricultural land but can be broadened to include small polluted urban drains and streams, where the precise sources of the pollution are too small and numerous to be readily identified. The costs of controlling these sources are typically high. Unfortunately, the loads may be also high, so that it is difficult to achieve water quality objectives by dealing with point sources only. It is therefore important to try to address the extent and control the costs of nonpoint sources.

From detailed analysis of the sources and the costs, it is possible to estimate marginal reduction costs for the major types and locations of pollutant loads. These load reductions must then be translated into real water quality improvements.

Optimizing Load Reduction

Most large water catchments are not uniform and fully mixed, and therefore not all load reductions will have the same impact on final water quality. In most cases, too, the WQOs vary across the catchment. It is therefore necessary to estimate (usually using a water quality model) the improvements that can be obtained with different levels and locations of load reduction. For some pollutants, such as heavy metals, the number and location of sources may be sufficiently limited that such modeling is not required.

The model makes it possible to identify, to an acceptable level of uncertainty, the most cost-effective investments for achieving the desired WQOs. Once an initial estimate has been prepared, one can examine the implications of adopting more or less ambitious objectives. On this basis it is possible to carry out an informed process of discussion and agree on a water quality plan and a wastewater management strategy and program.

The approach outlined here is standard when the problem is presented and tackled as a water quality management issue. Unfortunately, in sector projects, such as municipal services, industrial upgrading, and pollution reduction projects, the tradeoffs between the different water pollution sources are sometimes not recognized.

To illustrate: a major study of the impacts of the Vistula River in Poland on pollution of the Baltic Sea identified a wide range of regulatory and institutional measures and possible investments (Baltic Sea Environment Programme 1992). Priority investments were identified by a screening process, taking into account the size of the load, the cost-effectiveness of the actions, and the impacts of different types of pollution. Two perspectives were used to evaluate cost effectiveness: regional benefits at the level of the Baltic Sea, and benefits to the local population and environment directly affected. Most of the actions identified were cost- effective at both levels, but the priority ranking on cost-effectiveness differed. For example, the cost of reducing loads on the Baltic Sea varied from 8 European currency units per kilogram (ECU / kg) for the most cost-effective plant to 21 ECU / kg for the project ranked ninth. The recommended priority investments were based on a balance of local and regional rankings.

Monitoring and Feedback

A major improvement program addressing a complex natural system will have uncertainties in the initial analysis and design. Sensitivity analysis will indicate which assumptions are critical, and these should be reviewed and checked. However, the most critical management issue is to monitor the desired outcome (the ambient water quality) and to compare it with the projections used in the design. Any major variations from the design predictions will then be identified, and appropriate adjustments can be made.

The value of detailed information and analysis is demonstrated by two examples, both containing complexities that were identified early in the process and were taken into account in the detailed design.

Modeling of oxygen levels in the highly polluted Huangpo River at *Shanghai* demonstrated that oxygen depletion would be a problem, even after high levels of treatment of wastewater discharges. The treated wastes would have had very long detention times in the tidal section and would have continued to degrade and remove oxygen. The conclusion was that costly high levels of treatment would not result in correspondingly high levels of water quality improvement.

Detailed modeling of Guanabara Bay, *Rio de Janeiro*, uncovered the apparently perverse result that high levels of wastewater treatment could, in the short term, cause deterioration in overall water quality. Cleaner water would promote algal blooms, because of excess nutrients, leading to severe water quality problems. The recommended approach assigned a higher priority to nutrient reduction than had originally been proposed.

Reference

Baltic Sea Environment Programme. 1992. “Prefeasibility Study of the Vistula River and the Baltic Coast of Poland.” Copenhagen, Stockholm, and Warsaw.