# WASTEWATER RECYCLE, REUSE, AND RECLAMATION

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## Summary

Total supply of fresh water on the planet earth far exceeds human demand. However, scarcity of water currently faced in many regions of the world is caused by two reasons. First, its availability in time and space is not equally distributed. Thus there is problem of water in the wrong place, or at the wrong time and in wrong quantities. Second, while the population growth and expanded industrial activities are increasing demands on available water resources, they also jeopardize the availability of freshwater in adequate quantities by discharge of pollutants into freshwater sources. It is at times like these, when the rising curve of water demand intersects the fluctuating curve of water availability, that the recycling and reuse of wastewater is seriously considered. Wastewater recycling, reuse, and reclamation are now accepted as appropriate ways to conserve water resources as well as to contain polluted waters from contaminating other available clean water sources.

Though the very idea of drinking the water that someone else has already used is repugnant to most people, water reuse does not necessarily mean reusing only for drinking purposes. In water-scarce regions, unintentional recycling of domestic wastewater for non-potable and irrigation purposes has always been a common practice. The primary concern in the reintroduction of wastewater into the community is public health, as polluted water is largely unsafe for human health. A clear analysis and understanding of pollutants that make wastewater unsuitable for beneficial uses, is the

first step towards making intentional and planned wastewater reuse. By identifying opportunities for water quality requirements for large-scale water use activities, and assessing the possibilities for replacing such water needs with wastewater that is reclaimed to meet the quality requirements, increasing demands for fresh water can be minimized. Managing the quality and quantity of wastewater through various treatment processes, waste minimization, and cleaner industrial production concepts form parts of the efforts to achieve this end. Water quality management through natural treatment processes such as wetlands, and of quantity through artificial recharge of treated wastewater into groundwater systems are currently gaining in significance. Manufacturing industries contribute substantial organic and toxic pollutant loads to water systems. The emphasis on protecting water systems from these pollutants has substantially shifted from end-of-pipe waste treatment technologies to adopting production technologies that minimize generation of wastes, either through by-product recovery, raw materials change, better housekeeping, or through water conservation and recycling.

The foremost requirement of fresh water is for drinking purposes. There are many needy places in the world where the scarcity of water for drinking purpose is further aggravated by lack of sanitation. Such situations largely occur in rural and scattered (remote) settlements of developing countries. Only non-conventional systems can bring the basic amenities of drinking water and sanitation to these communities. The non-conventional systems mainly include reclamation of water from contaminated sources by adopting simple water treatment technologies, and also preventing future contamination by providing simple on-site sanitation technologies.

## 1. Introduction

Throughout human history, water has been a source of life as well as of death. Water is so common a natural resource that its availability is taken for granted. An adequate quantity of water for meeting basic human needs is a prerequisite for existence, health, and development. As development proceeds, the demand for water will invariably increase. Despite our understanding about the vitality of water for development, and its crucial role in meeting basic human needs, we continued with our extravagant water-use patterns as if the availability of fresh water on the planet is unlimited. Fortunately for the human race, the unsustainable nature of water-use patterns, despite modern technology and feats of engineering, has been dawning upon us for the last decade or so. Water planners in many corners of the world are projecting that within two decades, availability of freshwater sources will fall short of needs. Water is mostly taken from rivers or aquifers. Water that has been withdrawn, used for some purpose, and returned to the environment will be polluted, making it unfit for further beneficial uses. In many countries, a large proportion of such polluted water (i.e. wastewater), is discharged into the environment with little or no treatment. As water demands increase, not only must large quantities of freshwater be made available, but natural water sources are being relied upon to dilute the polluted water discharged, compounding further the limited availability of freshwater. In many parts of the world, there is a widespread scarcity, gradual destruction, and increased pollution of freshwater resources. In the developing world, one person in three lacks safe drinking water and sanitation: the basic requirement for health and dignity. In these nations, an estimated 80 percent of all diseases and over one-third of deaths are caused by consumption of contaminated water. The causes include inadequately treated wastewater of domestic and industrial origin, loss of natural water catchment areas, deforestation, and poor agricultural practices. Low water quality reduces the availability of water resources for specific uses, in particular, domestic needs.

Historically, water management has focused on building dams, reservoirs, and diversion canals, etc., to make available water wherever needed and in whatever amount desired. The growth of water development projects went unchecked, as availability of water was viewed as a key to economic growth and prosperity. Soaring demands due to rapidly expanding population, industrial expansion, and the need to expand irrigated agriculture, were met by ever larger dams and diversion projects. Future water needs were projected without considering whether available water resources could meet these needs in a sustainable manner. The conventional approach of continuously expanding supplies worked all right only as long as water was abundant. This was, however, not well suited in an era of growing scarcity, damage to the environment, and capital constraints. As a result, aquifer depletion, falling water tables, and diminishing flows, even in perennial rivers, to ecologically damaging levels have become increasingly widespread.

In the face of diminishing sources of freshwater, a truly secure and sustainable water future can be realized only by managing the ever-increasing and complex water demands of societies, rather than ceaselessly striving to meet it. Global understanding of the seriousness of an insecure water future, and its possible effects on sustainability of development efforts, has led to the inclusion of the conservation and management of freshwater as one of the major issues of *Agenda 21* adopted by the United Nations Conference on Environment and Development, popularly known as the “Earth Summit,” of Rio de Janeiro in 1992. Sustainable development is heavily dependent upon availability of water with suitable quality and in adequate quantities, for a variety of uses ranging from domestic to industrial supplies. Demands on water resources for household, commercial, industrial, and agricultural purposes are increasing greatly. The world population will have grown 1.5 times over the second half of the twenty-first century, but worldwide water usage has been growing at more than three times the population growth.

The need of a growing population in the new century for an increased provision of water is generally assumed, however, the question of where the extra water is to come from has led to a scrutiny of present water use strategies. A second look at these strategies has uncovered wide ranging possibilities for increasing the productivity of water (i.e. increasing the benefits from each liter of water used), which might allow us to increase water availability without resorting to increasing water supply: making rational use of already available water, which if used sensibly could provide enough water for all. This new look invariably points to the recycling and reuse of the wastewater that is being increasingly generated due to rapid growth of population and related developmental activities, including agriculture and industrial productions.

## 2. Wastewater Recycling and Reuse: The Concept

The term wastewater is defined, according to the Food and Agriculture Organization (FAO) of the United Nations, as “the spent or used water of a community or industry that contains dissolved and suspended matter.” About 99 percent of most wastewater is water, and only 1 percent is solid waste. Therefore, natural shortage of water can be overcome by reuse of wastewater. Wastewater is a preferable unconventional water source, since the supply is increasing because of population growth. Wastewater needs to be treated before disposal in order to safeguard the environment. Reuse of wastewater will help to maintain environmental quality, and, simultaneously, to relieve the unrelenting pressure on conventional, natural freshwater sources.

The basic drinking water need of a person is less than five liters per day. The water needs of society for various other needs, such as industrial and irrigation purposes, do not require water of the same quality as that needed for drinking. Therefore, much of the wastewater generated after first use can be used again in the same location (usually referred to as recycling), or collected from one or more utilities that generate wastewater for use elsewhere (referred to as reuse). By using water several times, societies can get more production out of each liter, thereby lessening the need to develop new water supplies and hence, conservation of water resources. Furthermore, the recycle and reuse of wastewater results in the containment of polluted waters, preventing their contamination of other freshwater sources, thus increasing the availability of these freshwater sources for more beneficial uses. By taking measures to improve the quality of water resources that have already been rendered useless due to pollution, the source can be reclaimed (called reclamation) to further supplement the availability of freshwater.

Managing water demand through recycle, reuse, and reclamation, therefore, requires a thorough understanding of the sources, types, and effects of water pollution, as well as the water and wastewater treatment practices needed to achieve the water quality requirements of recycle and reuse, and the technological and socio-economic considerations that affect these water demand management practices.

## 3. Sources of Water Pollution

Water pollution is caused by pollutants emanating from point sources or non-point sources. Point sources are identified as all dry weather pollutants that enter watercourses through pipes or channels. Point source pollution comes mainly from industrial facilities and municipal wastewater discharges, with or without adequate treatment. Storm drainage, and run-off from irrigation, construction sites, and other land disturbances constitute non-point sources of water pollution. Various types of sources under the point and non-point source category, and the pollution effects caused by them, are presented in Table 1.

| **Source** | | **Pollution** |
|---|---|---|
| Decaying vegetation | | Color, depletion of dissolved oxygen (DO), organic trihalomethane (THM) formation |
| Mine drainage | | Non-filterable residue; turbidity, metals, and acids |
| Erosion, construction, and land clearing | | Non-filterable residue, turbidity |
| Animal wastes | | Nutrients (such as nitrogen and phosphorus), depletion of DO, pathogens |
| Fertilizers and pesticides | | Nutrients, toxic chemicals |
| Irrigation return water | | Dissolved solids, nutrients, toxic chemicals |
| Sewage (treated and untreated) | | Depletion of DO, nutrients, pathogens, non-filterable residue |
| Commercial, light industrial areas | | Wide range of pollutants |
| Sanitary landfill leachate | | Toxic chemicals, putrescible organics, color, and nutrients |
| Urban stormwater | | Nutrients, non-filterable residue, turbidity, DO depletion, lead, oil, and grease |
| Industrial areas | | pH, metals, non-filterable residue, DO depletion |
| Thermal power plants | | Temperature increase of water bodies |
| Nuclear power stations, uranium mining, medical, and research establishments | | Radioactive wastes |
| Groundwater | | Odors, metals (such as iron and manganese), reduced (ammonia) nitrogen and sulfur, temperature |
| | | |

Table 1. Principal sources of water pollution

### 3.1. Types of Water Pollutants

Substances that cause deterioration of water quality by their presence (i.e., pollutants), can be divided into following seven major groups:

- Pathogens that cause water-borne diseases.
- Oxygen-demanding substances that deplete oxygen from water bodies.
- Nutrients that support unwanted plant and microbial growth in water bodies.
- Heat that reduces the oxygen-holding capacity of water.

- Non-toxic chemicals (such as salts) that reduce the beneficial uses of water.
- Toxic chemical compounds.
- Petroleum compounds (such as oil) that prevent aeration and light penetration into water bodies.

### 3.1.1. Pathogens

Pathogens are disease-causing organisms that grow and multiply within the host. The resulting growth of micro-organisms in a host is called an infection. It was not until the late nineteenth century that the role of pathogenic micro-organisms in causing diseases was understood. There are many ways that water contaminated with pathogens can associate with diseases. Most commonly used system of classification to describe and track diseases that involve water for their transmission is presented in Table 2. (For a detailed discussion on pathogenic organisms in polluted waters see also "Public health issues of on-site sanitation systems," EOLSS on-line, 2002).

| **Transmission mechanism** | **Description** | | **Examples of diseases** |
|---|---|---|---|
| Water-borne | Oral ingestion of water contaminated by pathogens from urine and feces | | Cholera, typhoid, bacterial dysentery |
| Water-washed | Disease-spread enhanced by scarcity of water, making cleanliness difficult | | Trachoma, scabis |
| Water-based | Water provides the habitat for intermediate host organisms, transmission to humans through water contact | | Schistosomiasis, dracunculiosis |
| Water-related | Insect vectors (e.g., mosquitoes) rely on water for habitat, but human water contact not needed | | Malaria, filariasis, yellow fever, dengue fever |

Table 2. Classification of water-borne diseases caused by pathogenic pollutants

With reference to pollution by pathogens, typical water quality is indicated by the number of fecal coliforms (a type of bacteria) present in water, which is as follows:

- more than 2000: heavy fecal pollution
- between 2000 and 1000: distinct pollution
- between 1000 and 200: moderate pollution
- between 200 and 50: slight pollution
- less than 50: no fecal pollution.

### 3.1.2. Oxygen-Demanding Substances

The amount of dissolved oxygen (DO) present in water is an important measure of the quality of water, as it is the basic necessity for survival of aquatic plants and animals. The saturated value of DO in water is in the order of 8–15 mg/l, depending on temperature and salinity of water. The minimum recommended amount of DO for healthy fish life is often set at around 5 mg/l. Oxygen-demanding substances decompose in water by microbial actions, during which they utilize the DO present in water. Oxygen-demanding wastes are usually biodegradable organic substances present in municipal and industrial wastewaters. In addition, certain inorganic compounds may also be decomposed, thus contributing to DO depletion in water. Even naturally-occurring organic compounds such as dead leaves or bird droppings, may also contribute to oxygen-demanding substances.

Oxygen demand is commonly measured as chemical oxygen demand (COD), which is the amount of oxygen needed to chemically oxidize all the oxygen-demanding substances, and biochemical oxygen demand (BOD), which is the amount of oxygen required by micro-organisms to degrade the wastes biologically. BOD has traditionally been the most important measure of the strength of organic pollution of water.

The concentration of DO in water is the commonly used indicator of a river's health. As DO drops below 4 or 5 mg/l, fish and other aquatic life are threatened, and the forms of life that can survive begin to reduce. In extreme cases, when anaerobic conditions set in, higher forms of life, such as fish, are killed or driven off. In addition, as the DO level of water falls, undesirable odors, tastes, and colors are generated that reduce the acceptability of water for domestic supply, and attractiveness for recreational use.

### 3.1.3. Nutrients

Nutrients are chemicals, such as nitrogen, phosphorus, carbon, sulfur, calcium, potassium, iron, manganese, boron, and cobalt, which are essential to the growth of living organisms. In terms of water quality, nutrients are considered as pollutants when their concentrations are high enough to allow the excessive growth of aquatic plants and other life forms that reduce the attractiveness of water bodies for drinking water supply, recreational use, and as a habitat for diverse aquatic species.

Excessive concentration of nutrients in water often leads to blooms of algae, which eventually die and decompose in the water body itself. Such decomposition results in depletion of DO, thereby affecting the water body's capacity to sustain normal life forms. This phenomenon is extremely important in the case of lakes and ponds, as recurrence of such blooms will eventually lead to what is referred as "eutrophication" or "death" of these water bodies. Of the nutrients, the concentrations of nitrogen and phosphorus are critical in limiting algal growth. Major sources of nitrogen and phosphorus are agricultural run-off, municipal wastewater, run-off from animal feedlots, chemical fertilizers, and nitrogen deposition from the atmosphere. Table 3 presents the major sources that contribute to the presence of nitrogen and phosphorus in surface water bodies.

| **Source** | **Contribution (%)** | |
|---|---|---|
| | **Nitrogen** | **Phosphorus** |
| Sewage | 31.0 | 58.0 |
| Industries | 1.8 | 1.0 |
| Agricultural runoff | 10.6 | 24.6 |
| Groundwater | 42.0 | 2.5 |
| Urban runoff | 5.5 | 10.0 |
| Rain | 8.5 | 1.2 |

Table 3. Sources of nitrogen and phosphorus in surface water bodies

### 3.1.4. Thermal Pollutants

Heated wastewater discharges into water bodies result in a rise in water temperature that may drastically alter its ecology. For some species, such as trout and salmon, any increase in temperature is life threatening, although for some other species warm water might be considered beneficial. As water temperature increases, two factors combine to make it more difficult for aquatic life to get sufficient oxygen from water. First, due to the fact that metabolic rates tend to increase with temperature; generally by a factor of two for each 10 °C rise in temperature. This causes an increase in the amount of oxygen required by organisms. Second, supply of DO reduces due to a decrease in the solubility of oxygen in water at higher temperature.

Heat is also an industrial discharge. A large steam-electric power plant requires an enormous amount of cooling water. A typical nuclear power plant, for example, warms about 150,000 $m^3$/hour of cooling water by 10 °C as it passes through the plant's condensers.

### 3.1.5. Non-Toxic Chemicals

Chemicals, such as salts, are naturally accumulated in water, as a stream or run-off passes through soils and rocks on its way to sea. The concentration of these non-toxic salts is an important indicator of the usefulness of water for various application. Drinking water, for example, has a recommended maximum total dissolved solids (TDS) concentration of 500 mg/l. In the case of irrigation water with TDS exceeding 500 mg/l, careful water management to maintain crop yields becomes increasingly important. On irrigated lands, especially in arid regions, salts accumulated due to evapo-transpiration are causing salinity of lands. Salinity problems have major impacts on irrigated lands in Iraq, Pakistan, Mexico, Argentina, Mali, India, and north Africa.

### 3.1.6. Toxic Chemical Compounds

The toxic chemical compounds that pollute water bodies are, for example, heavy metals, pesticides, organic compounds, etc. Most metals are toxic. The term "heavy metal" is often used to refer to metals with a specific gravity greater than about 4 or 5. In terms of their environmental impacts, the most important heavy metals are mercury (Hg), chromium (Cr), cadmium (Cd), and arsenic (As). They differ from other toxic substances in that they are totally non-degradable, which means that they are virtually indestructible in the environment. In higher doses, heavy metals can cause a range of adverse impacts on the body, including nervous disorders and kidney damage, creation of mutation and induction of tumors.

Pesticides include a wide range of chemicals that are used to kill organisms that humans consider undesirable. Pesticides can be insecticides, herbicides, rodenticides, or fungicides. Pesticides, because of their persistent nature in the environment, accumulate in the fatty tissues of the body, causing harmful effects.

### 3.1.7. Petroleum Compounds

Pollution from petroleum compounds (i.e., oil pollution) first came to public attention with the *Torrey Canyon* disaster in the English Channel in 1967. Despite British and French attempts to burn it, almost all of the oil leaked out and fouled French and English beaches. The acute effect of oil on birds, fish, and micro-organisms is well catalogued. The subtle effects of oil on other aquatic life is not so well understood and is potentially more harmful.

### 3.2. Effects of Water Pollution

The effects of water pollution can be broadly summarized into three categories, as presented in Table 4.

| **Category** | **Pollutants involved** | | **Effects** |
|---|---|---|---|
| Public health | Pathogens, toxic compounds (pesticides, heavy metals, etc.) | | Water-borne diseases, toxicity due to bio-accumulation in food chain |
| Aesthetics | Floating and suspended matters. Color, odor ($H_2S$), taste (algae, high $Cl_2$) | | Aesthetic degradation |
| Ecological | Low DO, organic matters, nutrients | | Ecological imbalance affecting biodiversity |

Table 4. Effects of water pollution



### 3.2.1. Bioaccumulation or Biomagnification

Bioaccumulation is the phenomena of accumulation of certain substances, especially heavy metals, pesticides, and toxic chemicals, which could not be metabolized or readily excreted by human or animal bodies, causing detrimental effects at the top of the food chain. These substances accumulate in the fatty tissues of organisms. Figure 1 depicts bioaccumulation of DDT (dichloro diphenyl trichloroethane), a pesticide.

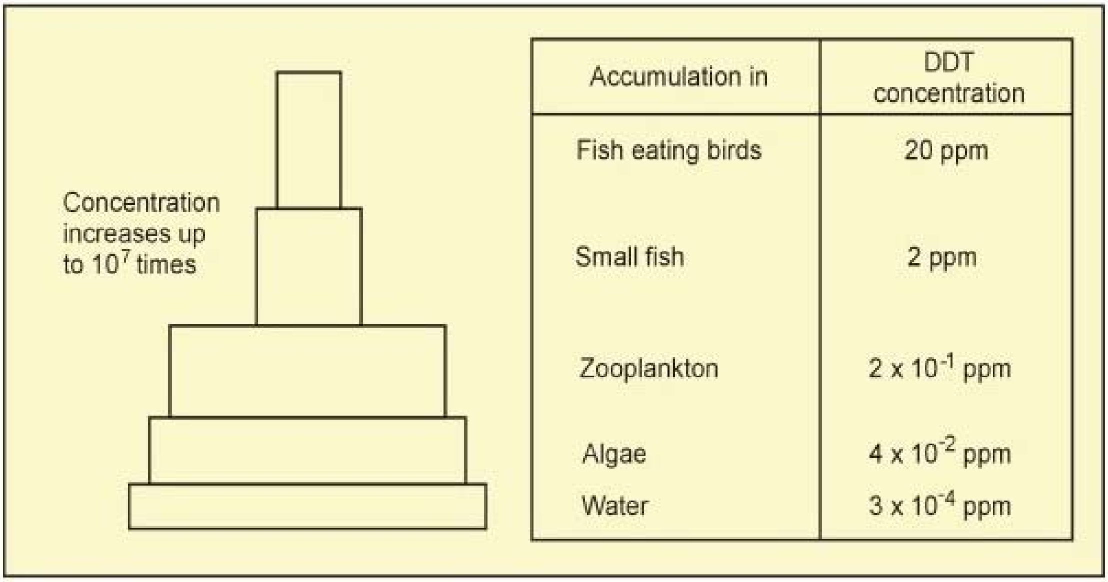


Figure 1. Bioaccumulation of DDT

The harmful effects of the process of bioaccumulation are further complicated by the phenomena of "biophysical alterations." This is the phenomena in which substances in physical forms that are harmless are converted into harmful forms after release into the water body. For example, liquid mercury is not very toxic, and most of what may be ingested is excreted by the body. However, ingestion of mercury that has been converted into organic form causes nervous disorders, coma, and, in extreme cases, death. An example of the ingestion of organic mercury is the human consumption of fish that has ingested and converted mercury into organic form.

### 3.2.2. Effect on Biodiversity

As pollutants enter water bodies they disturb the ecological balance and the species diversity will decrease. The typical effects of water pollution on biodiversity in aquatic ecosystems are depicted in Table 5 and Figure 2.

| Location | Zone | Species diversity |
|---|---|---|
| Sewage outfall | Degradation zone | Sludge worms, sewage fungus, snails |
| 2 km downstream | Maximum degradation | Maximum algae, protozoa, small number of snails |
| 8 km downstream | Recovery | Snails, insects, flies, and beetles |
| 24 km downstream | Recovery | Snails, insects, flies, and beetles |

Table 5. Effects on aquatic species in pollution zone of Cox's River, New South Wales, Australia

Source: Connell, D. W., *Water Pollution*, University of Queensland Press, Australia (1981).

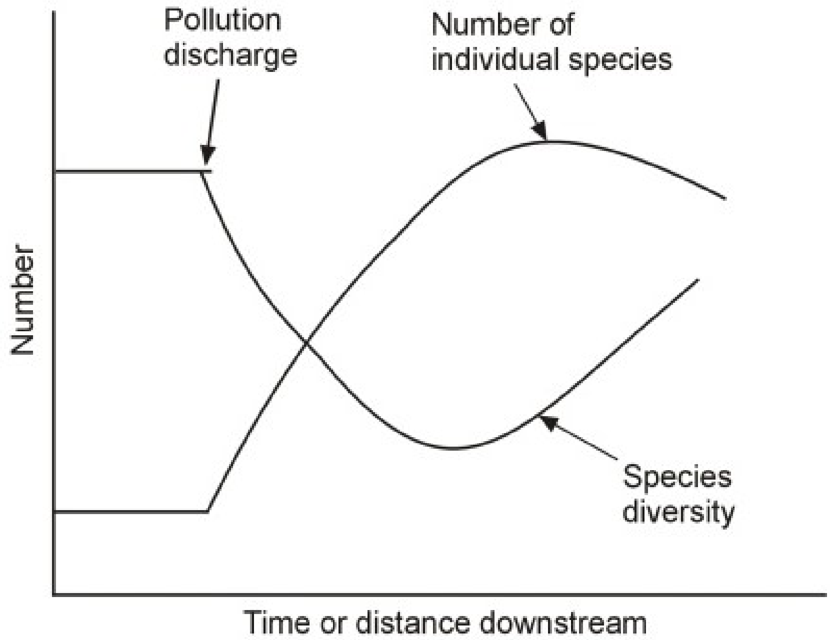


Figure 2. Effect of pollution on biodiversity

## 4. Management of Water Quality

If the quantity of pollutants disposed into water bodies are within their assimilation capacities (i.e., the capacity to render the pollutants harmless, through physical dilution, chemical transformation, or biological degradation), it will not result in any adverse effect. However, ever-increasing industrialization and urbanization processes have resulted in the generation and disposal of pollutants in quantities that far exceed the assimilation capacities of natural environments, and their accumulation has started to blow up into public health and environmental crises. The proclaimed death of Lake Erie, due to eutrophication, and the Minamata episode of fish food poisoning, due to mercury pollution, are just two examples of the consequences of water pollution that had the effect of awakening the world to the need to understand the management of water quality.

Maintaining water quality is of utmost importance to public health and the environment as a whole. The main objective of water quality management, therefore, is to maintain the quality of water bodies sufficiently for various beneficial uses, such as drinking, irrigation, industrial, and recreational purposes. The strategies for water quality management depends on the type of polluting source. Control of pollution from non-point sources such as agricultural and stormwater run-off require a wide range of planning and policy approaches. Adoption of “best management practices,” such as area-wide wastewater management planning, land use management, watershed management, etc., are common measures that are taken to abate non-point source pollution.

For point source pollution, such as from municipal sewage and industrial effluent discharges, there are treatment technologies available to control pollutants entering water bodies. The purpose of wastewater treatment is the elimination from wastes, prior to their discharge to the receiving water and land, of pathogens, chemicals, organics, and other material that could have detrimental effects on human health and the environment. In the past few decades, considerable efforts have been made to explore various options for waste treatment. Many waste treatment technologies have now been well established and practiced all over the world. All these technologies assist in reducing the pollutional strength of wastes by decreasing the pollutant concentrations and thus eliminate any adverse impacts on the receiving environment.

Conventional wastewater treatment methods for domestic and low-strength organic wastewater typically consist of:

- Preliminary treatment, such as screening or comminution (i.e., the grinding/shredding of large-sized, solid particles for removal at later stages of treatment), and grit removal.
- Primary treatment, such as sedimentation.
- Secondary treatment by biological processes, such as trickling filters (biofilters), activated sludge process, etc., followed by secondary sedimentation. Treatment processes employed for the removal of nutrients also are considered as secondary treatment.
- Tertiary treatment, such as filtration and disinfection.
- Treatment of sludge or biosolids that are generated during the previous treatment steps.

Apart from biological processes, there are many secondary treatment processes employed in industrial effluent treatment. They include chemical precipitation, flocculation, adsorption, chemical oxidation, ion exchange, acid–alkali addition, and sludge digestion, condition, and dewatering.

## 4.1. Preliminary Treatment

The preliminary treatment of wastewater is carried out to remove coarse and readily settleable inorganic solids, such as sand and grit particles. Their removal is carried out using screens and grit chambers respectively. Screening is the first unit operation in wastewater treatment. A screen is a device that has parallel bars fixed at uniform spacing, that retains coarse and floating matter in wastewater by acting as a physical barrier. Due to the kinetic force, running wastewater may also carry sand and silt particles, which can be removed by reducing the velocity of flow. Their removal is carried out in grit chambers, which are simply a wider cross section of flow channels with arrangements to remove settled silt and sand.

## 4.2. Primary Treatment

After removal of coarse and floating solids in preliminary treatment, the primary treatment endeavors to remove suspended solids in wastewater, which is carried out in sedimentation tanks or clarifiers. The suspended solids may be either organic or inorganic non-filterable residues (NFR). The basic principle of removal of suspended matter in sedimentation is to allow wastewater to stand still for a certain period so that the suspended particles can settle in a basin. The sedimentation removes 70–90 percent of suspended solids, thereby effecting a 30–40 percent reduction in oxygen-demanding substances in wastewater. Normal detention time in sedimentation basins is about 2–3 hours. Primary treatment also results in the removal of pathogenic and chemical pollutants, by removal of solid particles to which they are attached or adsorbed. The order of their removal in sedimentation basins are:

- bacteria: 10–20 percent
- viruses: 50–60 percent
- chronic toxins: 60–80 percent.

Many modifications to improve the removal efficiency of sedimentation process are available. Important among these are the placement of plates or tubes in the sedimentation basin itself. These are called plate settlers or tube settlers. The plates and tubes, by increasing the surface area available for settling of solids, increase the efficiency of their removal during the process. Sedimentation basins are equipped also with surface skimming devices and bottom scraper devices to remove floating materials and accumulated sludge, respectively.

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**Bibliography**

Angelakis, A.; Asano, T.; Diamadopoulos, E.; Tchobanoglous, G. 1995. *Wastewater Reclamation and Reuse*. (Selected proceedings of the International Association for Water Quality second international symposium on wastewater reclamation and reuse, Iraklio, Crete, Greece, October 17–20 1995.) [This is a compilation of articles on a wide range of issues of wastewater reuse, including pilot-scale and field-scale case studies for application.]

Baker, M. N. 1949. The Quest for Pure Water. *American Water Works Association Journal*, pp. 1–11. [A pioneering article on water reuse.]

Clark, J. W.; Viessman, Jr., W.; Hammer, M. J. 1977. *Water Supply and Pollution Control*. New York, Harper and Row. [An elaborate introductory text on water supply and pollution control engineering.]

Clarke, R. 1993. *Water: The International Crisis*. Cambridge. Mass.: MIT Press. [This presents the highlights of social and environmental impacts of water resource depletion.]

Connell, D. W. 1981. *Water Pollution*. Brisbane, University of Queensland Press. [Text on various aspects of water pollution.]

Environmental Systems Information Center (ENSIC). 1995. Municipal Sewage Sludge Management. In: *Environmental Systems Review No. 39.* Bangkok, ENSIC, Asian Institute of Technology. [This is a comprehensive compilation of technological advances in the treatment of sewage sludge.]

Gleick, P. H. 1993. *Water in Crisis: A Guide to the World's Fresh Water Resources*. New York, Oxford University Press. [This presents a comprehensive and up-to-date discussion on the issues of world water resources and issues involved in their conservation.]

Kadlec, R. H.; Knight, R. L. 1996. *Treatment Wetlands*. New York, CRC Press. [This is a comprehensive treatise on constructed wetlands with extensive compilation of data on their functioning and performance.]

Kalbermatten, J. M.; Julius, S. D.; Gunnerson, C. G.; Mara, D. D. 1983. Appropriate Sanitation Alternatives: A Planning and Design Manual. In: *World Bank Studies in Water Supply and Sanitation No. 2*. Baltimore, Johns Hopkins University Press. [This work provides detailed insight into planning and design aspects of appropriate sanitation alternatives in developing countries.]

Masters, G. M. 1998. *Introduction to Environmental Engineering and Science*. New York, Prentice Hall. [This text provides an elaborate overview of scientific and engineering aspects of environmental pollution problems.]

Staudenmann, J.; Schonborn, A.; Etnier, C. 1996. *Recycling the Resource*. (Proceedings of the second international conference on ecological engineering for wastewater treatment, School of Engineering, Wadenswil, Zurich.) Zurich: Transtec Publications. [This is a compilation of articles presenting case studies of wastewater reuse in various countries.]

Vigneswaran, S.; Visvanathan, C.; Jegatheesan, V. 1998. *Industrial Waste Minimization*. Malaysia, Environmental Management and Research Association of Malaysia. [A comprehensive text on waste minimization and recovery of resources from wastes presenting a number of case studies.]

**Biographical Sketches**

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**M. Sundaravadivel** is an Environmental Engineer with the Central Pollution Control Board, Ministry of Environment and Forests, Government of India. He holds a Bachelors Degree in Civil Engineering and a Masters Degree in Environmental Engineering. He has been working in the field of environmental management and industrial pollution control since 1989, particularly in the area of environmental audit, waste minimization and cleaner production in agro-based industries. He has also been an engineering consultant for planning, design and development of wastewater collection and treatment systems for many large cities of India. Currently, he is engaged in research on "environmental economic approaches for liquid and solid waste management in small and medium towns of developing countries" at the Graduate School of the Environment, Macquarie University, Sydney, Australia.