CHAPTER 16 BOX 2

SEWAGE WASTES IN THE MARINE ENVIRONMENT

SEWAGE

The most fundamental and unavoidable wastes produced by human populations are human feces and urine. Almost all cities, towns, and villages in the United States and all the world's major cities have extensive sewer systems to collect these materials and transport this sewage away from our living environment. The development of sewers was probably the single most effective advancement for human health protection in history. In the Middle Ages, sewage was simply thrown into the streets in many cities. Apart from the obvious aesthetic problems caused by human excrement in the streets, this practice almost certainly fostered the devastating plagues of disease that decimated urban populations of entire continents during this period. Hence, for many decades, the practice of collecting sewage and discharging it into a river or ocean to be diluted and washed away was viewed as essential and beneficial. This view has changed almost totally since the 1970s.

FIGURE 16B2-1 Sewage treatment plants are often located on the water's edge. This large secondary-treatment, the Hyperion plant in Los Angeles is located on a prime stretch of Pacific Ocean beach just west of Los Angeles International Airport.

Sewage disposal to rivers and oceans is now seen by many people as a pollution problem that must be completely stopped.

Nature of Sewage Wastes

Sewage is a natural material that consists primarily of the water used to carry solid fecal material through sewers. The water contains small concentrations of dissolved nutrients, trace metals, and organic compounds that originate either in the water supply or in human excretions. In addition, sewage contains solid organic matter that has a wide range of particle sizes. This solid matter, which is composed partly of paper fibers, also includes low concentrations of nutrients and trace metals and a variety of bacteria, **parasites,** and viruses. Many of these organisms are benign to humans and aquatic species, but others are pathogenic to humans and some are thought to be pathogenic to some aquatic species.

Although aquatic and ocean ecosystems are capable of assimilating sewage with no harmful effects, sewage discharges have caused pollution in many lakes, rivers, estuaries, and coastal ocean areas. Pollution has resulted from one or more of three problems. First, pathogenic organisms in sewage can reinfect humans if sewage is discharged into waters where people swim or otherwise contact the water, or if it is discharged into waters where harvested shellfish concentrate the pathogens. Second, organic matter and nutrients in sewage can produce blooms, hypoxia, and anoxia in discharge waters if the assimilative capacity for these wastes is exceeded. Finally, sewage is often contaminated with toxic compounds that enter the sewers from industrial discharges, street runoff, or household chemicals.

Only a few decades ago, many rivers, estuaries, and coastal areas near major cities were severely impacted by sewage pollution. Many waterways were simply overwhelmed by large quantities of organic matter. As a result, they became anoxic, causing biota, including fishes, to die, and creating significant aesthetic problems (odors and floating material). As environmental consciousness arose and as city populations began to look toward the water for recreation, two approaches to solving the sewage pollution problem were adopted. First, pipelines called "outfalls" were built to carry sewage offshore into the ocean, where dilution would be greater and where pathogens would die before reaching beaches. Second, sewage treatment plants were designed and developed to reduce oxygen demand and floatable material in the sewage before discharge.

Sewage Treatment

The many different technological approaches to sewage treatment can all be characterized by one of three treatment levels (**Fig. 16B2-2**):

- *Primary treatment* usually involves removing floating material, grinding up solids, and removing some particulate material by allowing it to settle out to form **sewage sludge**, which is not discharged but still must be disposed of. Some, but not all, pathogens die or are removed to the sewage sludge.
- *Secondary treatment* usually includes a primary treatment

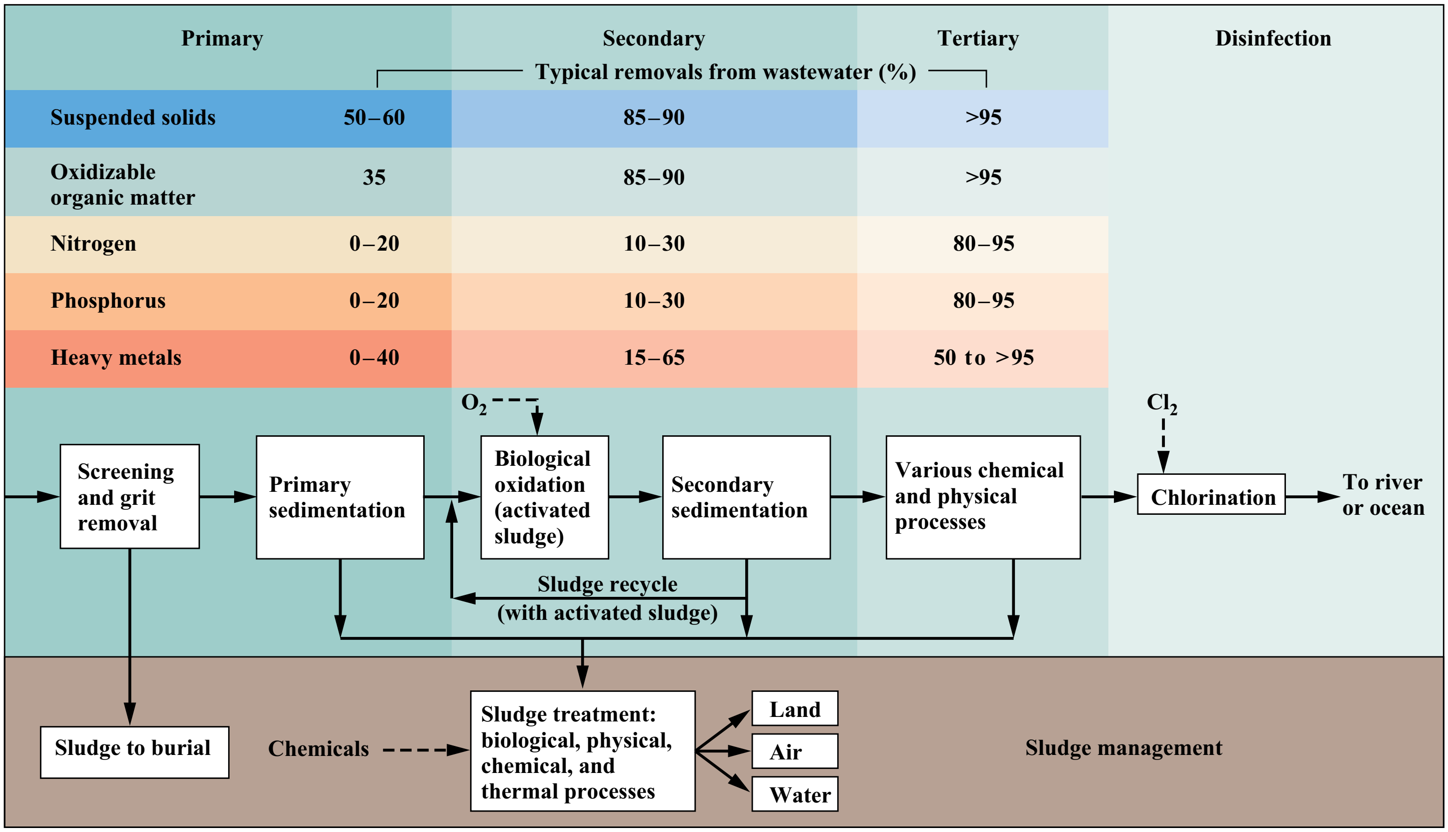

FIGURE 16B2-2 Sewage treatment is designed to remove suspended solids and organic matter from the waste stream before it is discharged to rivers, estuaries, or the ocean. Most areas of the United States are serviced by secondary-treatment plants that remove most of the suspended solids and organic matter but are not very effective at removing nitrogen, phosphorus, and toxic trace metals. Tertiary treatment, which removes nutrients, and disinfection, which kills most remaining pathogens, are employed in very few locations because they are technologically complex and costly. All sewage treatment processes produce a semisolid sludge that must be disposed of on land or by incineration. In some locations, this sludge was disposed of for many years by being dumped into the ocean, but in the United States this practice was stopped in 1992.

step, followed by a secondary step in which bacteria that use sewage organic matter for food are encouraged to grow in the sewage (Fig. 16B2-2). Most of these bacteria are removed in the secondary sewage sludge. Secondary treatment generally removes more than 90% of the BOD (which stands for "biochemical oxygen demand" and is a measure of oxygen-demanding organic matter) and more than 90% of the bacteria found in raw sewage. Some nutrients, trace metals, and toxic organic compounds are also removed to the sludge, but secondary treatment is not designed for this purpose and a high proportion of each of many of these compounds remains in the treated liquid effluent that is discharged.

- *Tertiary treatment* processes are generally designed to remove nutrients, such as nitrogen and phosphate, from the effluent that remains after secondary treatment.

In the United States, all communities are required to perform secondary treatment, although in a very few exceptional cases this requirement is not met or is legally waived. Only a few communities are required to use tertiary treatment, which is very costly and often technologically unreliable.

Sewage treatment and diversion of treated sewage to the open ocean have dramatically improved the water quality in many rivers and estuaries. For example, salmon have returned to the Thames River in England after it had been anoxic and little more than an open sewer for many decades before treatment was started. Because some parts of San Francisco Bay were anoxic in the 1960s, the shore was covered in rotting debris and slime, and odors drove people away from the Bay. San Francisco Bay is now dramatically improved and no longer anoxic. Many other bays and estuaries have undergone similar improvements, but the story is not all good.

The United States has spent tens or hundreds of billions of dollars to build and operate secondary-treatment plants in almost all communities. In many locations, expenditures on sewage treatment have bought major environmental improvements. In others, where sewage inputs are small or where residence time at the discharge site is short, secondary treatment has bought little or no environmental benefit because assimilative capacity was not exceeded before treatment was started.

Many pathogens and toxic compounds are partially deposited in the sewage sludge, which is disposed of separately from the effluent discharge. However, secondary treatment was not designed to remove pathogens and toxic compounds, so a large proportion of many of these contaminants remains in the treated effluent and is discharged. Consequently, pollution by pathogens or toxic compounds in treated sewage effluents still remains a problem, particularly where residence times of the receiving waters are long and where commercially valuable shellfish beds are near discharges. For example, even though the Bay is no longer anoxic, shellfish beds remain closed and several metals at times exceed water quality criteria in South San Francisco Bay as a result of the inputs of treated sewage.

Sewage sludge must be incinerated, deposited in landfills, or spread on agricultural land. Toxic substances and pathogens in the sewage sludge cause environmental impacts with each of these options.

Ocean disposal of treated sewage still causes significant environmental problems in some areas. Problems include nutrient-induced eutrophication of the coastal ocean, contamination by toxics, contamination of beaches and shellfish by pathogens, and damage to benthic ecosystems as a result of high organic loadings.

Eutrophication

Eutrophication of the coastal ocean and dead zones are discussed in Chapter 13. The primary cause of this eutrophication is believed to be nitrogen compounds discharged in agricultural runoff and treated sewage. Tertiary sewage treatment is successful in reducing phosphate concentrations in effluents, but potential technologies for nitrogen removal are more complex and costly. Consequently, the growing incidence and widespread recurrence of blooms and anoxia caused by eutrophication of the coastal oceans are growing pollution problems related to sewage effluent which, at present, sewage treatment practices are inadequate to address.

Toxic Substances

Although some toxic compounds are removed in sewage sludge, a considerable proportion of many toxic substances remains in the treated effluent. Once in the environment, toxic substances are taken up by organisms and sediment particles (especially fine-grained particles). In discharge locations where receiving waters have long residence times or low-energy sedimentation regimes, the continuous introduction of toxic substances can cause a buildup of concentrations in sediment or waters. In most locations where toxic substances accumulate from sewage discharges, other sources (e.g., runoff and industrial discharges) also contribute toxic substances, and it is difficult to assess the relative importance of sewage and the other sources.

Although toxic substances cannot be eliminated completely from sewage, they are unlikely to cause problems in the environment if their concentrations in sewage reflect only the background levels of these compounds in human food and water supplies. Consequently, major efforts are under way to prevent toxic substances from entering sewer systems. In the United States, a vigorous and extensive pretreatment program requires removal of toxic substances from industrial wastes before they are discharged to sewers. This program has drastically reduced inputs of toxic substances to sewage plants from industrial sources. However, only limited efforts have been made to reduce inputs of toxic substances from cleaning products, other household sources, and illegal disposal of chemicals. The principal source of toxic substances in most major cities' sewage is therefore the home. In some areas, sewers are connected to storm drains through which urban runoff may contribute substantial quantities of toxic substances. Frequently, toxic industrial wastes are dumped illegally into storm drains and sewers to save treatment costs or the costs of disposal in secure waste disposal landfills.

Drugs

A number of drugs used by humans to combat medical problems are either excreted from the body in wastes or enter the sewage stream when people dispose of unused drugs by flushing them down a toilet or washing them down a sink drain. Some of these drugs survive the sewage treatment process and are discharged with the liquid effluents. Consequently, low concentrations of a number of these drugs have been detected in estuaries and the oceans. Because many of these chemicals have powerful pharmaceutical effects on humans, it is likely that some also affect at least some marine species. Little is yet known about these possible effects. There is particular concern that estrogen and other fertility control drugs may interfere with the reproductive cycles of some marine species.

Pathogens

Sewage treatment is not designed to destroy or remove pathogens, but it does substantially reduce concentrations of some bacteria. Studies of the fate and effects of pathogens in sewage effluents discharged to the oceans are extremely difficult because of the low concentrations of pathogens in the environment and difficulties inherent in their isolation and measurement. Consequently, little is known about the fate of most pathogens in the oceans.

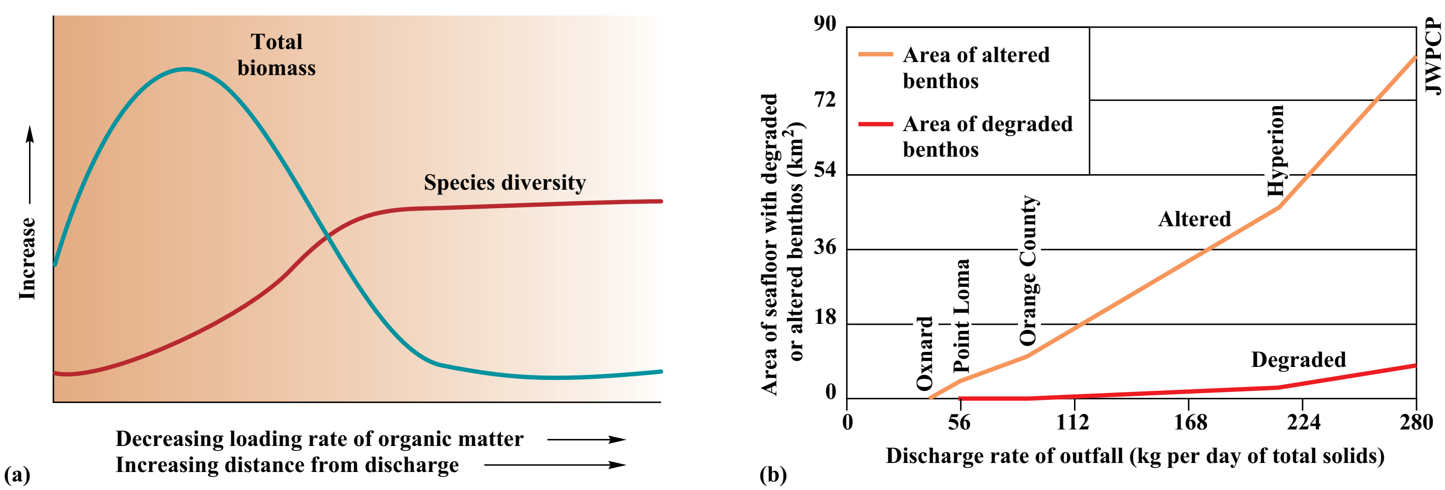

FIGURE 16b2-3 Degradation of the benthic environment in areas affected by sewage discharges to the marine environment. (a) Species diversity and biomass vary across a gradient of increasing sewage pollution. In the area on the right side where the loading rate of sewage is low, species diversity is not decreased and the total biomass is increased. Increasing biomass without decreasing the species diversity could be considered an enhancement of the environment. (b) The area of sediments with altered and degraded benthic infauna increases as the rate of sewage discharge from outfalls increases in similar hydrographic regimes. The large outfalls off the California coast—JWPCP (the Joint Water Pollution Control Plant in Los Angeles County) and Hyperion—adversely affect very large areas, whereas the smallest outfalls (Oxnard and Point Loma) do not cause any area to be degraded.

Beach water quality and the safety of shellfish from pathogens are monitored by measuring concentrations of indicator bacteria, usually *Escherichia coli* (*E. coli*) or, more recently, *Enterococcus*. These organisms are present in all mammalian feces, not just human sewage, but they pose no significant human health risk themselves. Indicators are not perfect, because they are not specific to human feces and because pathogenic organisms are transported in different ways and die at different rates in the environment.

Bacterial monitoring for indicator organisms has reduced the incidence of diseases carried by shellfish or contracted through water contact. However, bacterial pollution still necessitates the periodic closing of beaches, and vast areas of coastal and estuarine zones in the United States and elsewhere in the world are closed to shellfish harvesting. Many pathogenic bacteria and viruses have been found to survive in seawater for much longer than was believed to be the case until near the end of the past century, and more human health problems may be due to sewage in the marine environment than was previously thought. In particular, the incidence of temporarily debilitating intestinal upsets caused by sewage-carried bacteria may be much higher than has been recognized. Such relatively mild upsets are poorly monitored and reported by health authorities.

Effects on the Benthos

The benthic ecosystem surrounding some ocean sewage outfalls is substantially altered by the discharge. The alterations are related to and probably caused primarily by the organic sewage particles deposited in the sediment. If current energy is low, these particles accumulate in sediments surrounding the outfall, and the effects on the **benthos** depend on the rate at which organic matter accumulates. At rates only slightly above background rate, the benthos are enhanced because the greater food supply increases the biomass and species diversity remains high (**Fig. 16B2-3a**). At higher rates, some species are disadvantaged by the higher suspended particulate loads and others are advantaged. Hence, biomass increases or remains high, but species diversity declines. As loading rates increase further, the benthos become dominated by a few tolerant species, and biomass eventually declines (**Fig. 16B2-3a**). Because loading rate usually decreases progressively with distance from the outfall, the effects also decrease as this distance increases.

Although it is somewhat arbitrary, a point can be identified in the gradient of effects around an outfall where the more severely impacted sediments are considered degraded and the less severely impacted sediments are not. The area of degraded sediments surrounding an outfall varies with the rate of discharge of organic particulate matter (**Fig. 16B2-3b**). For outfalls in similar current regimes, a small volume of discharge may cause no degraded sediments, whereas a higher volume of discharge may cause a significant area of degraded sediments. Hence, if sewage is discharged through many small outfalls that are designed to maximize the dispersion of organic matter, the benthos will be moderately enhanced. However, if the same treated sewage is discharged through a few large outfalls, significant areas of ocean floor may have degraded benthos.

These effects are analogous to those of fertilizer applied to a lawn. If the fertilizer is spread, the lawn will flourish. If it is dumped in one pile, it will burn and kill the grass close to and under it. Unfortunately, in the United States and elsewhere, environmental regulators have pursued a strategy of permitting only a small number of large outfalls in the belief that this restriction would limit any adverse impacts to only a few areas of the ocean.

For many years, large volumes of sewage sludge were dumped through an ocean outfall offshore of Los Angeles and from barges into the oceans offshore of New York, Philadelphia, and the United Kingdom. This practice was highly controversial. The media and public incorrectly blamed it for a wide variety of pollution problems, including the 1976 nutrient-induced anoxia off the New Jersey coast (Chap. 13) and the washup of floating medical wastes, including syringes, on New York beaches. Sewage sludge dumping contributed to these problems, at most, in a very minor way.

Lessons Learned

Public fears have caused sewage sludge dumping in the ocean to be prohibited. However, many scientists believe that the high cost and environmental and human health impacts associated with land-based disposal alternatives far outweigh any environmental gains realized by terminating ocean dumping.

Sewage sludge dumping has caused or contributed to some pollution problems. These problems were related to toxic chemicals and pathogenic organisms in the sewage sludge and organic overloading of the seafloor, particularly at the Los Angeles outfall. If toxic substances were prevented from entering sewers and pathogenic organisms in sewage sludge were killed by modified treatment processes, sewage sludge could be disposed of safely in the ocean and might even have beneficial effects because of its food value. However, contrary to the historical practice of restricting dumping to small sites, disposal would have to be spread over a sufficiently large area to prevent overloading of sediments or the water column with oxygen-demanding organic matter.

Sewage treatment, although expensive, has dramatically reduced the worst impacts of historical sewage disposal in the marine environment. The remaining impacts can be reduced only by the adoption of new and different approaches to sewage treatment technologies that more effectively remove toxic substances and nutrients, especially nitrogen, and kill all pathogenic organisms. Removal of all organic matter from sewage effluent is not necessary for disposal in the oceans, because, if adequately dispersed, such material will be assimilated without adverse effects and may in some instances even be beneficial.

CREDITS