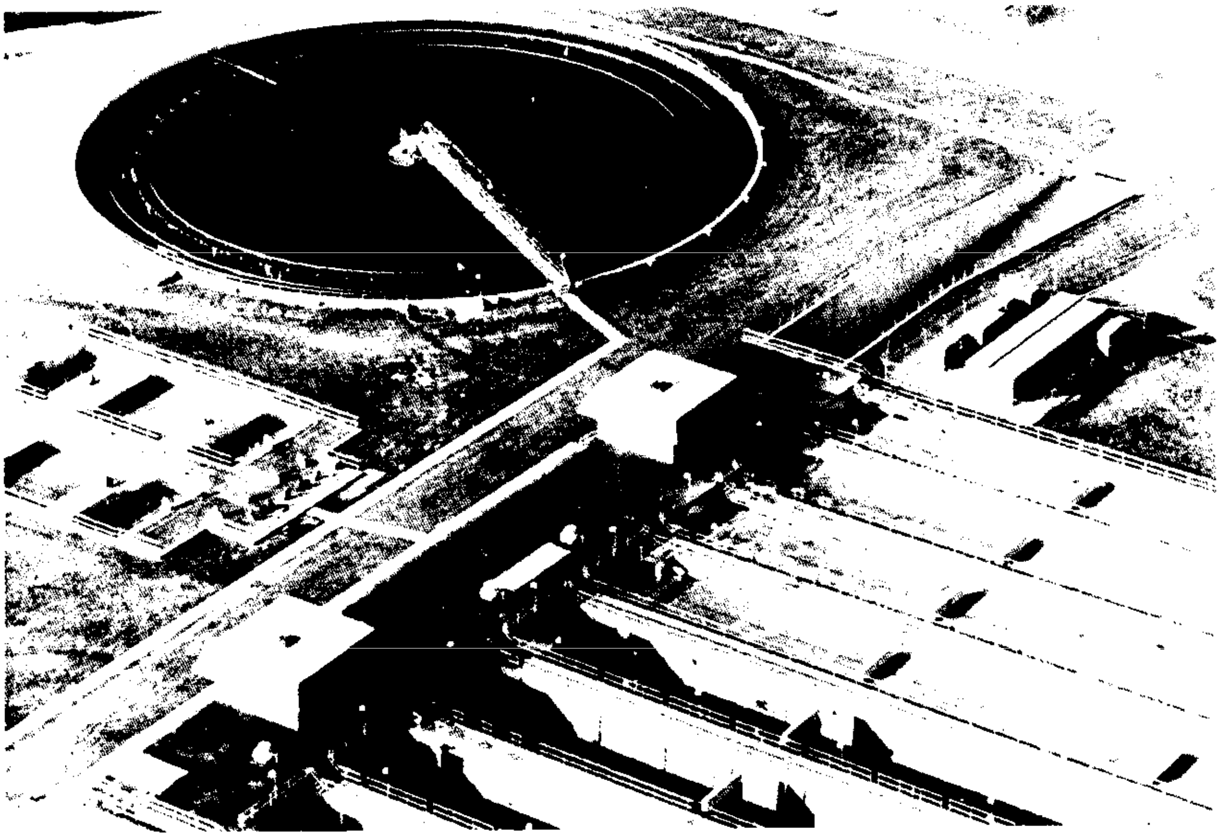

Photo Credit: Stephen C. Delaney

Chapter 9
Managing Municipal Effluent and Sludge

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Managing Municipal Effluent and Sludge

OVERVIEW

The treatment of municipal wastes generates two products: sewage sludge (the mostly solid material separated from the original waste) and effluent (the liquid remainder). Large quantities of these products are disposed of in marine waters. The treatment of municipal wastes and the management of these products raise many concerns, for example:

- the dumping of sewage sludge in coastal and open ocean waters;
- the impacts of toxic pollutants (in particular, metals and organic chemicals from industrial discharges into sewers) in sludge and effluent on marine resources;
- the constraints imposed by the presence of toxic pollutants on the beneficial use of sludge and effluent;
- the impacts of conventionized pollutants (including solids and fecal bacteria), other microorganisms (e. g., viruses), and nonconventional pollutants (e. g., nutrients) in sludge and effluent on marine resources; and
- whether current levels of municipal treatment will be maintained as Federal funding for the construction of treatment plants declines.

Municipal waste management in the United States has been shaped by events that occurred during the past 150 years. In the 19th century, the increased use of water delivery systems and flush toilets dramatically increased the amount of rinsewater and raw sewage flowing from households (1 75,551). The rinsewater and sewage was usually diverted into cesspools or existing stormwater drains, but these often were unable to handle the increased flow and health problems arose from the contamination of soil and wellwater.

In response, cities began channeling wastewater into newly built sewers that discharged into surface waters, including marine waters (175,551). Initially, these discharges received no treatment because people assumed that the receiving water would dilute the waste and prevent health problems. In 1909, almost 90 percent of wastewater carried in sewers received no treatment. However, it was soon discovered that discharges into rivers contaminated drinking water supplies in downstream communities, causing major public health problems such as epidemics of typhoid fever.

Cities then began to develop processes to filter wastewater and treat bacteriological contamination prior to discharge (1 75,551). Many processes developed between 1900 and 1935 are still important components of current municipal treatment (318). One problem arises, however, regarding the nature of the wastes being treated. The original processes were not designed to treat metals and organic chemicals, yet industries discharge wastewater containing these pollutants into municipal sewers. Thus the sludge and effluent products left after treatment are often contaminated with these substances.

The initial responsibility for developing large and efficient disposal systems was usually carried at the municipal level; suburban areas often were annexed and special district agencies (e. g., the Boston Metropolitan Sewerage Commission) were created to facilitate such development. However, the institutional structure to regulate sewage treatment and disposal has grown rapidly and has gradually passed to the State and Federal levels. The Federal Government, for example, spent over $40 billion in the last 15 years to help local sewerage authorities build or upgrade municipal treatment plants (569). The current legal framework for managing municipal effluent and sludge is described in box U.

The generation of both sludge and effluent is expected to increase in coastal areas as populations increase and as more communities are serviced by municipal treatment plants. Effluent discharges into marine and fresh waters probably will increase accordingly because this is the only means currently available for large-scale disposal. In some situations, water conservation or the re-use of effluent (e. g., via water reclamation for irrigation or groundwater

Appendixes

recharge) could reduce the need for discharges. Several management options are feasible for sludge, including, for example, dumping in marine waters and beneficial use on cropland. The demand to dump sludge in marine waters could increase, because the use of other options may be constrained by regulatory and social factors and because dumping sometimes may be economically and even environmentally preferable when compared with other options.

TREATMENT PROCESSES AND PRODUCTS

General Wastewater Treatment Processes

About 70 percent of domestic wastewater in the United States is channeled into publicly owned treatment works (POTWs)[1] for treatment (1 59). The remainder is discharged into private septic systems or, in some cases, discharged without treatment into various waterbodies. These wastestreams are complex mixtures, generally composed of water, suspended solids, organic material, oil and grease, dissolved nutrients, microorganisms, and metals and organic chemicals.

The exact composition of wastewater entering POTWs is highly site-specific and complex because its components can come from a variety of sources: household chemicals, human wastes, industrial and commercial discharges into sewers (box V), and rainwater and street runoff from combined sewer systems (figure 33). In addition, about 60 percent of the material periodically cleaned from septic tanks is transported to and treated in POTWs (638). Composition also varies with time, particularly in systems that receive large inputs from combined sewers or seasonal industrial discharges.

POTWs treat raw wastewater by removing or degrading organic materials or, in the case of some bacteria, by destroying them. Most of the remaining solid organic and inorganic material is removed, forming a sludge. The remaining liquid effluent typically contains much less than 1 percent solids, while sludge contains from 1 to 7 percent solids (prior to further dewatering).

Treatment levels are defined primarily on the basis of the percentages of two conventional pollutants—biochemical oxygen demand (BOD) and total suspended solids (TSS)—that are removed from the wastewater. At the first or "primary" treatment level, debris is physically screened, and some suspended solids settle in sedimentation tanks. Typically, up to about 60 percent of the suspended solids are removed during primary treatment (633).

' 'Secondary' or biological treatment uses microorganisms to destroy or remove additional amounts of B0D and TSS. Any additional suspended solids that are removed are added to the sludge, so secondary treatment produces more sludge than primary treatment. More advanced, or ' 'tertiary, treatment generally is used to remo~e additional suspended solids or nutrients (table 20). It often entails the use of chemicals (e. g., aluminum sulfate, ferric chloride, polyelectrolytes) to precipitate the target pollutants (633,634).

Technologies developed in the early 20th century to treat municipal wastewater still are used, though they have been modified and improved, as the basis for treatment at most municipal plants. One example is anaerobic digestion. Many new. technologies have been developed in the last few decades, particularly for sludge treatment (e. g., physical-chemical treatment, pure oxygen-activated sludge systems, and ammonia stripping), but few are widely used in municipal treatment plants (318).

The costs for building and operating municipal treatment plants vary with the particular combination of processes used to achieve a specified treatment level. Costs can escalate rapidly as the required level of treatment is increased, in part because of additional costs for sludge treatment processes (not to be confused with sludge disposal techniques), but economies of scale can counter this to a degree (650,661).

[1] The terms "municipal treatment plants" and "publicly owned treatment works", are used interchangeably here.

[Page Omitted]

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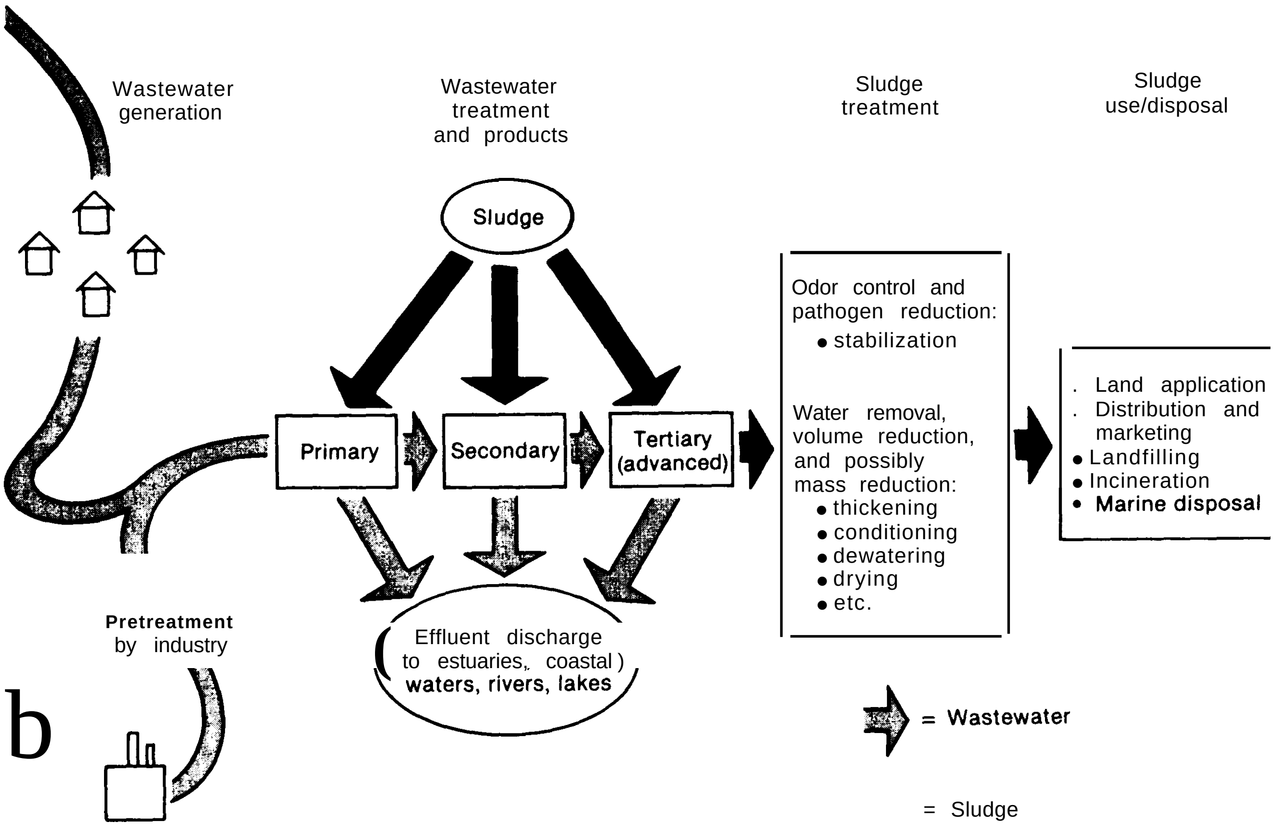
Figure 33.—Generation, Treatment, and Disposal of Municipal Effluent and Sludge



SOURCE. Adapted from U.S. Environmental Protectlon Agency, Intra-Agency Sludge Task Force, *Use and Disposal of Municipal Sludge*, EPA 625I1O-844IO3 (Washington, DC September 1984)

Table 20.—Definitions of Municipal Treatment Levels

Treatment level	Treatment requirements
Primary	Approximately 30°/0 removal of BOD and 60°/0 removal of TSS
Secondary	Removal of both BOD and TSS to levels of 25-30 mg/1, but not less than 85°/0 removal; pH between 6.0 and 9.0
Tertiary	Removal of both BOD and TSS to levels less than 9 mgjl, or removal of over 95°\0 of BOD and TSS; additional requirements for removal of nutrients (e.g., nitrates, phosphates) on site-specific basis

ABBREVIATIONS: BOO = biological oxygen demand
TSS = total suspended solids
[a]Treatment levels required by the Clean Water Act and codified at 40 CFR Part 133

SOURCES Off Ice of Technology Assessment, 1987, based on 40 CFR Part 133, and Science Applications International Corp , Overview of Sewage *Sludge and Effluent Management*, contract prepared for U.S Congress, Office of Technology Assessment (McLean, VA 1986)

not very effective against parasites (e. g., protozoan cysts).

Furthermore, the densities of bacteria in effluent (even including the fiftyfold dilution factor) are usually still too high to achieve compliance with water quality standards for recreational and shellfish-growing waters. In addition, both viruses and bacteria tend to become concentrated in sludge because of their tendency to associate with solid material (although large numbers remain in the effluent, as well). For these reasons, "disinfection' techniques (table 21) are often used to further reduce microorganism levels in effluent prior to disposal.

Chlorination is the most commonly used effluent disinfection technique in the United States. It has

Table 21.—Advantages and Disadvantages of Selected Effluent Disinfection and Sludge Treatment Processes

Technique	Used for[a]	Advantages	Disadvantages
Effluent disinfection:			
Chlorination.	DI	Commonly used; 98 t0 99% destruction for bacteria; high removals of viruses and cysts	Low removal of bacterial spores; formation of chlorine residuals and chlorinated hydrocarbons; residual test not correlated with concentration of microorganisms
Ozonation	DI	99% removal of fecal coliform; high removal of viruses; destroys phenols, cyanides, trihalomethanes; no chlorinated byproducts	Toxic gas; requires onsite generation; expensive; removal of spores and cysts unknown
UV radiation	DI	Initially effective on all microorganisms	Only penetrates a few centimeters; microorganisms sometimes reactivated; potential microorganism mutagenesis; unpredictable
Gamma radiation	DI	Penetrates deeper than UV radiation	High costs; worker safety
Heat	DI	Destroys most pathogens	High energy costs
Chlorine dioxide	DI	98 to 99°/0 bacteria removal; high virus removal; no chlorinated compounds; small measurable residual	Three times cost of chlorination; unstable, sometimes explosive; requires onsite generation
Sludge treatment			
Aerobic digestion	ST,DI	Removes up to 85°/0 of microorganisms and 40% of volatile solids; more rapid, simpler, less subject to metal upset than anaerobic digestion, PSRP[b]	Costly (requires oxygen); susceptible to upset by pH, organic chemicals, metals; slower at cold temperatures; not always easy to dewater; no commercial gas byproducts
Anaerobic digestion	ST,DI	Removes >85% of microorganisms and 40°/0 of volatile solids; easier to dewater; preferred at larger plants; commercial gas byproducts; PSRP	More susceptible to upset than aerobic digestion; gas explosions; higher capital costs
Thermophilic aerobic digestion . . .	ST,DI	Faster than aerobic; near complete destruction of bacteria and viruses; heat self-generated; PFRP[b]	Requires solids content > 1.5°/0 and heat retention equipment; only in emerging/development status
Air drying	DW,DI	Reduces some solids and microorganisms; PSRP	Requires long time (>3 months)
Heat drying	DW,DI	Significant reduction in volume; destroys most bacteria; useful for distribution and marketing products; PFRP	Subject to putrefaction; requires associated digestion; needs prior costly dewatering
Heat treatment (under pressure) . .	DW,DI	Sterilization; readily dewatered; PFRP	Expensive
Liming	ST,DI	Destroys bacteria; binds metals, so less leaching; PSRP	Sludge solids not destroyed, so microorganisms can regrow if pH falls prior to total drying
Chlorination	DI	Free of odors; dewaterable	No significant solids reduction; requires lime to neutralize pH; chlorinated byproducts
Comporting	DI	PSRP and PFRP	Requires large space

= disinfection; DW = dewatering, ST = stabilization.
bpSRp = process to Significantly Reduce Pathogens; PFRP = Process to Further Reduce Pathogens (see text for details).

SOURCE: Office of Technology Assessment, 1987; after Science Applications International Corp., Overview *of Sewage Sludge and Effluent* Management, prepared for U S. Congress, Office of Technology As*sessment* (McLean, VA: 1986).

been considered economical and effective and it usually destroys virtually all fecal coliform bacteria in effluent. Several concerns, however, have been raised about chlorination. First, it may only temporarily inactivate, rather than destroy, microorganisms present in effluent. Second, it is not as effective against pathogenic viruses as it is against fecal coliform bacteria.[3] Finally, chlorinated hydrocarbons can be formed as byproducts of the process and pose significant risks to organisms in the vicinity of municipal discharges, although information on chlorine byproducts in municipal wastewater is limited (503,636).

Alternative effluent disinfection methods such as ozonation and ultraviolet light treatment may be more effective than chlorine against viruses. These methods have rarely been used in the United States for drinking water or municipal wastewater treatment, although ozonation has been widely used in Europe to purify drinking water (142,503). Both methods are hard to apply and expensive, so chlorination may be the only practical means of disinfection in most locations. To combat chlorine's disadvantages, long outfalls that discharge into deep and dispersive ocean waters have been used to dilute pathogen concentrations sufficiently to meet water quality standards.

Sewage sludge also can undergo additional treatment or ''conditioning. In particular, sludge that is to be disposed of on land is required to undergo certain technology-based processes to reduce microorganisms; these processes involve varying types of disinfection, stabilization, or dewatering (table 21) (650).[4] Some processes, such as anaerobic digestion, have been in use for over 60 years (318). Others have been developed recently; for example, ionizing radiation has been used on a pilot scale in Boston and on a commercial scale in Miami (59,503).

These sludge treatment processes are grouped into two categories, Processes to Further Reduce Pathogens (PFRP) and Processes to Significantly Reduce Pathogens (PSRP). If food crops are to be grown within 18 months of land application, the Environmental Protection Agency (EPA) regulations require that a PFRP be used. PFRPs destroy most bacteria and viruses by subjecting sludge to elevated temperatures over a specified time, but again the actual reduction is variable; in addition, some parasites such as protozoan cysts are not readily destroyed (205). If no food crops are involved, sludge treated by a PSRP can be applied to land, subject to certain restrictions (e. g., on public access, grazing, pH, and metals and polychlorinated biphenyls (PCB) content).

Other sludge treatment techniques include chemical fixation and encapsulation for sludges containing high levels of contaminants, earthworm conversion, and emerging processes such as anaerobic fixed-film biological treatment.

Incidental Removal of Metals and Organic Chemicals

POTWs are designed specifically to remove conventional pollutants from wastewater, but not to remove metals and organic chemicals. As some of these pollutants pass through POTWs into receiving waters, they sometimes upset the efficiency of POTW treatment systems.[5] Not all metals and organic chemicals pass through POTWs, however, because treatment processes do result in the unintentional or ''incidental removal or degradation of some of these wastewater pollutants.

Incidental removal can take several forms—volatilization, removal to sludge, or biodegradation. The metals that are incidentally removed tend to be incorporated into sludge (637), and some organic chemicals also can be incorporated into sludge, from which they often are volatilized during subsequent sludge treatment.[6] Municipal treatment

[3]The use of fecal coliform bacteria as an indicator species is discussed in ch. 6

[4]Disinfection reduces odor, as well as bacterial densities; stabilization reduces organic material and, correspondingly, the level of microbial activity, thus reducing levels of odor and microorganisms; dewatering and some types of stabilization can also reduce volume of sludge.

[5]'Upsets' refer to large or sudden changes in the concentrations of metals or organic chemicals that kill the microorganisms used in treatment processes; as a result, municipal effluent can be discharged without adequate treatment (503), For example, an upset at a POTW in Rhode Island, and subsequent discharge of effluent with excess BOD levels, was attributed to the dumping of cyanide into the municipal sewers (497).

[6]For biodegradation of chemicals to occur, however, microorganisms in the treatment plant generally must be acclimated to a small but constant input of the chemicals. However, variable inputs are probably more common and hinder acclimation; thus, many chemicals that could in principle be incidentally removed through biodegradation will instead pass through to receiving waters (503),

processes thus destroy some pollutants and redistribute the remainder.

The degree of incidental removal varies greatly among POTWs, particular treatment techniques, and individual pollutants (637,666). According to one study of 50 POTWs, different treatments showed a range of efficiencies for incidental removal for some selected priority pollutants (637). For example, POTWs with primary treatment removed 10 to 57 percent of metals and O to 62 percent of organic chemicals, while POTWs with secondary treatment removed 34 to 85 percent of metals and 40 to 94 percent of organic chemicals.

These results suggest that 15 to 66 percent of the metals and 6 to 60 percent of the organic chemicals could pass through POTWs with secondary treatment. This study has been criticized, however (94). In particular, critics noted that if the pollutant in question was not detected (i. e., its concentration was below the minimum detection level), the concentration was recorded as being at the minimum detection level, This procedure, in combination with other factors, could underestimate actual removal efficiencies.

Effluent and Sludge Composition

Numerous studies have documented the composition of different effluents and sludges (101, 173, 524,637,638,639,650,666). The composition of both products is highly site-specific and variable over time, depending on the nature of sources discharging into municipal sewers and on the destruction and redistribution (i. e., incidental removal) of pollutants during treatment processes.

Whatever the degree of incidental removal, however, both effluent and sludge will almost always be contaminated to some degree with metals and organic chemicals (637). In one study of POTWs in New Jersey (including some that dump sludge in marine waters), for example, an average of 27 percent of Clean Water Act (CWA) priority pollutants were present in effluent and sludge (160).

Some waste treatment processes can further alter the composition of sludge and effluent. In particular, the use of chlorination to disinfect effluent prior to discharge can create and increase chlorinated hydrocarbons in the effluent; in one study, the concentration of chloroform in effluent increased by 70 percent (704). In general, though, the majority of chlorine apparently ends up as chloride ions rather than in chlorinated organic compounds (636). In addition, metals tend to associate with solid material, so sludge tends to have higher concentrations of metals than does effluent from the same plant (503).

Although treatment processes destroy high levels of some bacteria, remaining bacteria and other microorganisms can be distributed in both effluent and sludge. Under the right conditions, these organisms can proliferate in effluent and sludge and constrain subsequent management. Furthermore, some bacteria cannot be detected with traditional techniques but apparently can remain viable in marine waters for extended periods of time (in some cases, years) (ch. 6). The apparent absence of human pathogens at or near sludge disposal sites in the open ocean, for example, may actually reflect our inability to detect such organisms rather than their actual absence.

Given the numerous pollutants that have been or could be detected in sludge and effluent, EPA and others have attempted to determine which components are "most important' or of 'greatest concern. " For example, as part of an effort to develop new regulations for sludge management, EPA identified a list of about 50 metals and organic chemicals that could cause environmental or human health impacts and these could be the focus of future regulatory efforts (31 1,643).

AMOUNTS OF EFFLUENT AND SLUDGE GENERATED AND DISPOSED

Effluent and Sludge Generation

Over 15,000 POTWs currently operate in the United States and each year they treat and discharge approximately 9.5 trillion gallons of wastewater. More than 2,200 POTWs are located in coastal counties, and they discharge about one-third of the Nation's municipal effluent (503,608). POTWs also produce increasing amounts of sewage sludge. The total amount generated by all POTWs more than doubled during the last decade, and almost 40 percent originates from POTWs located in coastal counties (table 22).

By the year 2000, total sludge production could increase to over 10 million dry metric tons (377, 503). The amount of effluent is expected to increase to between 13 and 16 trillion gallons per year. These increases will result from expanded use of secondary and advanced treatment processes, which produce more sludge, and increases in population, sewerage hookups, and numbers of POTWs (654).

Land-Based Management Technologies for Effluent and Sludge

Only about 2 percent of the Nation's total effluent is not discharged into surface waters (503). Instead, it is used to irrigate or fertilize agricultural and forest land, or for groundwater recharge, industrial uses, aquiculture, and underground injection to prevent saltwater intrusion. In Los Angeles County, for example, water reclaimed by five municipal treatment plants is used for landscaping, irrigation, groundwater recharge, and industrial processes (503).

The choice of disposal or treatment options generally is driven by site-specific factors such as POTW size and location, regulatory climate, State policies, qualitative assessments of impacts, and costs (502). Most land-based disposal or treatment of sludge involves land application, the use of the sludge as a commercial product for household or municipal use (known as distribution and market-

Table 22.–Amounts of Effluent and Sludge Generated by Municipal Treatment Plants (POTWs)

Product and treatment level[a]	All POTWs			POTWs discharging into estuaries			POTWs discharging into coastal waters		
	Number	Amount[b]	Percent[c]	Number	Amount	Percent	Number	Amount	Percent
Effluent:									
No discharge	1,577	0.49	1.9	0	0.00	0.0	0	0.00	0.0
Primary	1,023	2.35	9.1	55	0.94	17.1	11	0.15	18.2
Advanced primary	2,102	2.81	10.8	52	1.22	22.2	6	0.35	42.7
Secondary	8,005	10.47	40.3	272	2.43	44.2	46	0.31	38.4
Tertiary	2,775	9.84	37.9	121	0.91	16.5	7	0.01	0.7
Total	15,482	25.96	–	500[d]	5.50	–	70	0.82	–
Sludge:									
No discharge	1,577	0.00	0.0	0	0.00	0.0	0	0.00	0.0
Primary	1,023	0.40	5.9	55	0.18	11.8	11	0.03	15.0
Advanced primary	2,102	0.75	11.0	52	0.35	23.1	6	0.09	45.0
Secondary	8,005	2.85	41.5	272	0.71	46.7	46	0.08	40.0
Tertiary	2,775	2.86	41.6	121	0.28	18.4	7	0.002	<1.0
Total	15,482	6.86	–	500	1.52	—	70	0.20	–

[a]Treatment levels are defined in table 20; except no discharge = no discharge into waterbodies, and advanced primary = levels intermediate between primary and secondary levels.
[b]For effluent, amounts are in billion gallons per day, For sludge, amounts are in million dry metric tons per Year.
[c]Percent of total amount (of effluent or sludge, as appropriate).
[d]The total of 570 POTWs (500 into estuaries and 70 into coastal waters) differs slightly from the total of 578 cited in ch. 3, because Of differences in the Way POTWs were classified during different analyses of data available from EPA

SOURCE: Office of Technology Assessment, 1987, after Science Applications International Corp., *Overview of* Sewage *Sludge and Effluent* Management, prepared for U.S Congress, Office of Technology Assessment (McLean, VA: 1986).

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ing), landfilling, and incineration (650). Other approaches used for significantly smaller amounts of sludge include incorporation into construction materials (e. g., brick, asphalt) and animal feed, and degradation by earthworms.

Land application usually involves spreading sludge on agricultural and forest land or using it in reclamation projects (e. g., on strip-mined land), and it has been the subject of much research (429, 525,591). Distributing and marketing sludge commercially involves using or selling composted or heat-dried sludge as a nutrient enricher and soil conditioner. Landfilling consists of placing sludge in an area dedicated solely to disposal and then covering it with soil, Incineration includes burning sludge alone, co-combustion with municipal waste (to yield usable energy), and emerging technologies such as gasification and liquefaction (660). In general, it is used for sludges with a very high organic content where land is scarce (3 18); about 150 incinerators or co-combustion facilities now operate in the United States (660).

Together, these land-based options are used to treat or dispose of about 90 percent of the sludge generated in the United States. Up to one-half of all sludge is landfilled or put in surface impoundments, about one-fifth is incinerated, and about one-fourth is applied to the land (including distribution and marketing) (503,634). [7]The use of these

[7] A more precise accounting of the prevalence of the various land-based options is not possible because of inconsistencies in how POTWs record and report data. Some POTWs do not report methods, some

options varies geographically and with POTW size. In 1980, for example, coastal POTWs landfilled 54 percent, ocean-dumped 22 percent, and land-applied 5 percent of their sludge. Small POTWs use land application or landfilling to dispose of almost three-fourths of their sludge, while larger POTWs use a greater variety of methods, including incineration.

Marine Disposal of Effluent

The most common way to dispose of effluent is to discharge it through pipelines into nearby waters. Almost 600 POTWs discharge effluent directly into estuaries or coastal waters (table 22). Although these POTWs represent only 4 percent of the Nations's total, they account for about one-fourth (2.3 trillion gallons annually) of all municipal effluent because many of them serve large urban areas. Of this, about 2.1 trillion gallons of effluent are discharged annually into estuaries (503). About three-fifths of the effluent discharged into marine waters receives secondary or greater treatment; effluent discharged into estuaries generally receives greater treatment than does effluent discharged into coastal waters.[8]

Pipelines can be designed so that discharges are more likely to meet specified water quality goals. For example, the use of very long pipelines, in combination with design features such as large multiport diffusers,[8] can result in effluent discharges that are highly diluted and far from shore (375,387).

report multiple methods without distinguishing amounts, and most do not list distribution and marketing as a separate option (R Bastian, U S EPA, pers comm., September 1985).

[8]In addition to treated sewage effluent, raw sewage also enters marine waters from routine discharges and combined sewer overflows ((CSOs) For example, about 40 million gallons of raw, untreated sewage is discharged daily into the New York Bight. C S0s usually occur during storms and result in wastes flowing untreated into receiving waters, and they arc a major problem in certain areas. In Seattle, for example, about 2 billion gallons of wastewater overflows annually and receives no treatment (460,.503) Moreover, any industrial waste Mater contained in these overflows never receives the "incidental'' treatment provided by POTWs In Boston, CSOs discharge about 9 billion gallons and are considered (along with sludge and industrial wastes) one of the major sources of pollutants in Boston Harbor,

[9]A "multiport diffuser' is a pipeline that has several ports or openings, located at various points along the pipeline, from which cf'fluent can be discharged. As a result, effluent is discharged in multiple locations rather than only one, which allows greater mixing with surrounding water and greater dilution

Marine Disposal of Sewage Sludge

Sludge is disposed of in marine environments in two ways, by dumping from barges or ships or by discharge from pipelines. Discharges of sludge into estuaries and coastal waters take place only in southern California and Boston and total about 110,000 dry metric tons of sludge or solids each year[10] (503). The discharge of sludge by the City of Los Angeles will cease when a sludge dehydration/incineration facility is completed in 1987. Under court order, Boston is developing secondary treatment facilities and alternative sludge management options (148, 166). Sludge discharges into Boston Harbor could continue until these improvements are in place in the mid- 1990s.

The amount of sludge that is dumped in marine waters has increased steadily, from over 2.5 million wet metric tons in 1959 to about 7.5 million wet metric tons in 1983 (648). This equals about 7 to 10 percent of all sludge generated in the United States (503). After the 1977 Clean Water Act amendments banned the dumping of sludge that would "unreasonably degrade' the ocean, over 100 small municipalities stopped dumping at sea, but these accounted for less than 5 percent of all dumped sludge. Because of a 1981 court decision (City of New York v. *United States Environmental protection Agency; see* ch. 7), nine sewerage authorities in New York and New Jersey have centinued to dump sludge at the 12-Mile Sewage Sludge Dump Site in the New York Bight, which has been used since 1924 (table 23) (306,503).

The use of the 12-Mile Sewage Sludge Dump Site is now being phased out and sludge dumping is being moved to the Deepwater Municipal Sludge Site (ch. 3). As of November 1986, Nassau and Westchester Counties had shifted all dumping to the deepwater site; New York City had shifted 10 percent; and the sewerage authorities in New Jersey had shifted 25 percent (F. Czulak, U.S. EPA Region II, pers. comm. November 1986). New York City has indicated that it will not be able to move all its dumping to the deepwater site prior to 1988 (502).

[10]The Los Angeles County Sanitation Districts mixci "t entrate'' (solid particles derived from centrifuge processes; these essentially are sludge particles but arc not technically termed as such) with its effluent discharge.

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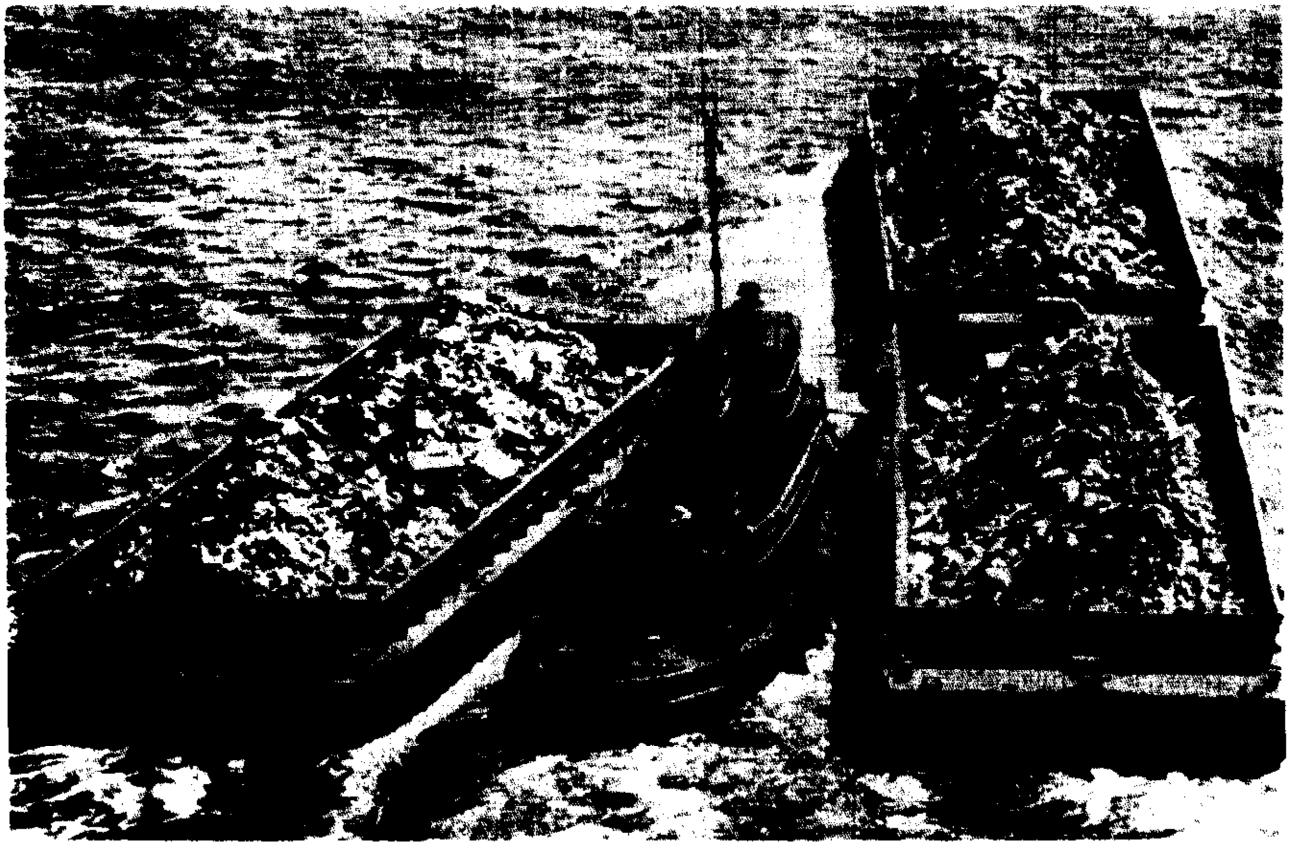


Photo credit: National Oceanic and Atmospheric Administration

After sludge is produced at municipal treatment plants, it can be managed in several ways, including land application, landfilling, incineration, distribution and marketing, and marine dumping. When dumped, sludge is loaded onto barges (like those shown here, which are loaded with municipal waste and debris) or ships for transport to the dumping site.

Table 23.—Costs of Dumping Sludge at the 12-Mile Sewage Sludge Dump Site and the Deepwater Municipal Sludge Site

Permittee	Amount dumped in 1985[a]	Total cost, 12-mile site[b]	Total cost deepwater site[b]	Ratio of costs, deepwaterH2-mile
New York City, NY	3.03	4.0	18.6	4.6
Middlesex County, NJ	0.94	3.3	11.5	3.5
Passaic Valley, NJ.	0.80	2.4	13.2	5.5
Nassau County, NY.	0.52	0.7	2.5	3.5
Westchester County, NY	0.43	1.3	3.5	2,7
Essex-Union Joint Meeting, NJ.	0.31	0.8	2.1	2.7
Bergen County, NJ	0.28	0.9	2.6	2.9
Rahway Valley, NJ.	0.17	0.8	2.3	3.0
Linden-Roselle, NJ	0.09	0.2	1.9	c
Total or average.	6.57	14.4	58.2	4.0d

[a]In millions of wet metric tons.
[b]In millions of dollars, adjusted to 1982 dollar values.
[c]Not available.
[d]Weighted average ratio for entire New York Bight, excluding Linden-Roselle.

SOURCES: F. Czulak, U.S. Environmental Protection Agency Region 2, personal communication, Dec. 18, 1988; and T.M. Leschine and J.M. Broadus, "Economic and Operational Considerations of Offshore Disposal of Sewage Sludge," *Wastes in The Ocean, Volume 5*, D.R. Kester, et al. (eds.) (New York: John Wiley & Sons, 1985), pp. 287-315.

Future Demand for Marine Disposal of Sludge

It is difficult to predict the future demand for marine disposal of sludge. Many municipalities would probably be interested in dumping sludge in marine waters if the regulations are changed to allow increased dumping. Several large coastal municipalities (e. g., Baltimore, Boston, Washington, DC, Jacksonville, Philadelphia, San Diego, San Francisco, and Seattle) have expressed interest in maintaining dumping as a potential option should other options fail (32,532). In addition, Orange County, California, has proposed that it be allowed to discharge sludge into deep ocean waters on an experimental basis (see box W).

Estimating the amount of sludge that might be dumped in marine waters in the future is extremely difficult because:

- it is unclear whether current relatively restrictive Federal policies will change;
- it is unclear how many east coast communities would find it economically feasible to dump at the Deepwater Municipal Sludge Site;
- land-based disposal options could often be more attractive, especially if levels of toxic pollutants in sludge are reduced; and
- the granting of waivers from secondary treatment requirements (under Sec. 301(h)) could result in less sludge being produced by coastal municipalities, since lower treatment levels generate less sludge.

Costs of Sludge Disposal

The costs of sludge disposal and management options are determined primarily by sludge treatment requirements; economies of scale; land acquisition costs; capital, operating, and maintenance costs; transportation costs; and energy requirements (138, 504,635,639). Transportation alone can account for most of the costs associated with land application, landfilling, and ocean dumping.

The relative costs of dumping sludge at the 12-Mile Sewage Sludge Dump Site and of land-based disposal will vary. Dumping in marine waters generally is less costly, because it does not require the sludge to be dewatered, as is necessary for land application and incineration (306). Dumping will certainly be more costly at the Deepwater Municipal Sludge Site than at the 12-mile site. On average, dumping at the deepwater site is expected to cost four times more than dumping at the 12-mile site (table 23). These estimates largely reflect short-term transportation costs, but they may underemphasize the degree to which future capital investments reduce long-term costs. Dewatering, for example, would reduce the volume of sludge produced, which would reduce the number of trips to the deepwater site and decrease transportation costs, but it would also increase treatment costs prior to disposal (306). Dumping at the deepwater site generally could be less costly than land-based disposal for most municipalities currently dumping sludge (553).

GENERAL FATE OF SLUDGE AND EFFLUENT

Dumped Sludge

The potential for impacts from municipal waste disposal depends on what happens after disposal. When dumped from barges or ships, sludge is initially diluted[11] by currents and by turbulence from the wake, typically by a factor of several. hundred within a few minutes and by a factor of 5,000 or more after 4 hours (385,387). Dilution is greater if the material is released in many smaller amounts rather than a few large ones (280). Subsequent dilution is much slower, so initial dilution greatly influences the concentration of sludge components to which marine organisms will be exposed (387).

After initial dilution, most of the particles in sludge are still denser than the surrounding seawater and tend to descend as a large ' 'cloud' at a rate dependent on size and density. When it reaches water of equal density, the cloud tends to

[11] ' Initial dilution is considered to occur until a discharge ceases rising in the water column (i. e., until it reaches water of equal density), or until dumped material either ceases moving in the water column or reaches the bottom (280).

spread horizontally (385, 387, 503). Individual particles then slowly disperse and may settle toward the bottom.

The rate at which particles accumulate on the bottom is influenced by factors such as volume, dumping rate, type and size of particles, and physical and chemical processes. Large particles, for example, settle more rapidly than small ones; furthermore, the y can be formed when small particles aggregate, a process enhanced when freshwater waste such as sludge mixes with saltwater. However, this tendency is decreased somewhat by dilution, which makes particles less likely to collide and aggregate (387).

The extent of settling—in terms of amount of material and area covered—varies significantly among different sites. In enclosed and shallow environments with little tidal action (e. g., many estuaries), material can accumulate on the bottom in the general vicinity of the dumpsite when sludge is dumped over a long period (85,87 ,400). These types of marine waters, however, are not used for sludge dumping in the United States.

In contrast, in more open and well-mixed waters such as are used in the United States, most particulate material (perhaps as much as 90 percent) is transported out of the immediate area by currents and may disperse over an area of several hundred square kilometers (387). In the New York Bight, for example, most particles disperse away from the immediate dumping area over the course of days or weeks; some particles and associated pollutants move into and accumulate in other areas of the Bight such as Christiaensen Basin (located northwest of the dumpsite).

The decomposition of the organic material in dumped sludge depends on the activity of microorganisms. Initially, much of the decomposition is performed by microorganisms that are present in the sludge before it enters marine waters. These microorganisms are adapted to survive in freshwater (the main component of sludge) and they may not survive when the sludge enters marine waters, thereby reducing the initial decomposition of organic material, Some decomposition also occurs after the material settles on the bottom, but it tends to be slower in the conditions typical of bottom sediments and for sludges with low organic content. It also tends to be slower in waters that have low oxygen levels, since many or most of the decompose microorganisms require oxygen. Some observers suggest that decomposition could be enhanced by ‘ ‘seeding’”’ sludge with microorganisms developed (e. g., by genetic engineering) to survive in both fresh and marine water (R. Colwell, Univ. Maryland, pers. comm., October 1986; also see ref. 105).

Discharged Effluent

When discharged from a pipeline, effluent is primarily fresh, buoyant water which tends to form a “plume” that rises in the water column. The plume rises, entraining saltwater in the process, until it reaches either water of equal density or the surface; the plume can spread horizontally at either point. The particles in the effluent, already present at a concentration of less than 1 percent, are diluted as they mix with the denser saltwater, but the degree of initial dilution varies greatly. For pipelines that discharge into shallow water and that are not equipped with diffusers, dilution is only about a factor of 10 (280). In contrast, large outfalls that discharge in relatively deep water and that are equipped with long mulitport diffusers can achieve initial dilution of up to a thousandfold (280). Individual particles begin to sink slowly after this initial plume rise and dilution.

As with sludge, the fraction of particles in effluent that disperses from the discharge point varies markedly under different conditions. In the relatively dispersive conditions in the Southern California Bight, for example, only about 10 percent of the particles may settle in a well-defined zone around the discharge point (350), although accumulation of these particles can still result in significant Impacts.

IMPACTS FROM EFFLUENT AND SLUDGE DISPOSAL

Marine Impacts From Particulate Material, Microorganisms, and Nutrients

Pollutants such as particulate material (suspended solids, organic material), fecal coliform bacteria and other microorganisms, and nutrients in sludge or effluent can cause a variety of beneficial and adverse impacts on marine environments.

Some observers argue that the beneficial nature of sludge and effluent disposal in marine waters has not been appreciated by the public (509,638). In estuaries and coastal waters, nutrients such as nitrogen and phosphorus can stimulate phytoplankton productivity, and in turn possibly enhance commercial fisheries. In the open ocean, nutrients from sludge dumping could stimulate increases in productivity, since lack of nutrients is a major constraint on productivity in most of these waters. Overall productivity, however, would still remain low relative to estuaries and coastal waters.

In contrast, the adverse impacts associated with dumping and discharges of sewage wastes have received considerable attention. One common problem is that particulate material can accumulate in the disposal area, especially if the activity is continuous or frequent, and alter bottom (i. e., benthic) habitats. This can lead to changes in population sizes or the diversity of marine organisms. The major change in species composition that typically occurs is a shift from communities dominated by suspension feeders, such as crabs and mollusks, to ones dominated by deposit feeders, such as worms (350).

These types of impacts are present in a range of sites around the country. In southern California coastal waters, for example, pollutants including suspended solids, and some metals and organic chemicals have affected about 5 percent of the benthic communities to some degree (350,387). One small area (less than 10 km^2) around two outfalls was severely affected and up to about 85 km^2 of surrounding areas was moderately affected. At one dumpsite near Delaware Bay, once used by Philadelphia, gradual accumulation of material to the south and west of the site seems to have caused changes in benthic species abundance and diversity (686). In the New York Bight, the most severely degraded areas (about 10 to 15 km^2) occur just west of the dumpsite, on the margin of Christiaensen Basin (387).

Excessive inputs of nutrients and organic material (i. e., eutrophication) can lead to hypoxia—low dissolved oxygen levels—and other serious consequences. In some shallow and enclosed marine waters, these impacts have been caused at least in part by effluent discharges. Both problems, however, also are caused by other factors. Seasonally recurring episodes of extreme hypoxia in the New York Bight, for example, are caused by a Combination of factors: natural stratification of the water prevents the mixing and reoxygenation of bottom waters; nutrients from a wide variety of sources, including raw sewage and municipal effluents carried by the Hudson and Raritan rivers, increase plant life, which can lead to reduced oxygen supplies when the plants die and are decomposed by microorganisms (416,548,632).[12]

Pathogenic microorganisms present in effluent and sludge can cause a variety of impacts, too, such as the contamination and closure of shellfish beds. Some cases of shellfish contamination have been unequivocally linked to sludge dumping, for example, at the old Philadelphia dumpsite (595). Such contamination may be partially reversible; 3 years after dumping ceased at the Philadelphia dumpsite certain pathogenic microorganisms were relatively rare, although still detectable (595). Although contamination by pathogenic microorganisms is common in the vicinity of effluent discharges, the microorganisms can also come from raw sewage, combined sewage overflows, and runoff. Some viral pathogens present in effluent discharges (e. g., enteric viruses) have high survival rates in marine waters and, if ingested, may adversely affect human health by causing gastrointestinal disorders and other diseases.

[12]In 1976, the public attributed the presence of fecal material on New Jersey and New York beaches to the dumping of sludge in the New York Bight. However, several other sources of material (including the raw sewage carried into the Bight from the Hudson and Raritan rivers), together with high river flows and various climatic factors, apparently were responsible for these episodes (377,547,632).

Marine Impacts From Metals and Organic Chemicals

The potential for *metals* in both sludge and effluent to cause adverse impacts depends on many chemical and physical factors (ch. 4). Organisms can ingest certain metals that sometimes cause immediate toxic effects (including death). Furthermore, because metals are persistent they can bioaccumulate within organisms and cause further impacts (e. g., impair growth or reproduction in fish and benthic invertebrates) (55). Most metals do not biomagnify in successive levels of the food chain. However, mercury—a common pollutant in sludge —can be converted by marine organisms to a form that has direct acute toxic effects on the organisms, biomagnifies in the food chain, and is toxic to humans.

Many organic *chemicals also* are persistent in the environment and often bioaccumulate. In contrast to metals, however, many also can biomagnify. These chemicals can cause severe sediment contamination problems, and a variety of short- and long-term effects on organisms.

Information on the potential impacts of metals and organic chemicals in effluent discharges has been summarized for 25 of the 30 largest coastal POTWs that applied for Section 301(h) waivers (503,649). If these POTWs were allowed to continue to provide less-than-secondary treatment, 12 were considered to have the potential to cause significant impacts because of large quantities of metals (e. g., copper, nickel, thallium, zinc) and organic chemicals (e. g., naphthalene, pentachlorophenol) in their effluents. Potential and observed impacts included contamination of sediments and organisms; fish disease and reproductive failure; degradation of benthic and plankton communities; and closures of shellfisheries and fisheries (503). Effluents from the other 13 applicants were considered to lack this potential (649).

Toxic pollutants in combined sewer overflows (CSOs) also have caused major impacts in marine waters (503,647). [13] For example, overflows into Puget Sound have contributed to toxic "hotspots' in Elliot Bay, where the sediments have average concentrations of metals and organic chemicals greater than sediments from the deep central part of the Sound. Elevated levels of copper and lead also were found in fish exposed to the overflows and sediments. In San Francisco Bay, sediments located near CSOs had elevated concentrations of numerous pollutants, including many metals, and the sediments were considered unsuitable to support the normal diversity and abundance of organisms (233, 503). In contrast to Puget Sound, however, fish near the CSOs in San Francisco Bay did not exhibit elevated amounts of metals.

[13] The Water Quality Act of 1987 set aside some Construction Grants funding for the correction of CSOs that cause water qualit y problems in marine waters; the amount set aside is not to exceed 1 percent of the Construction Grants funding for fiscal years 1987 and 1988 and 1.5 percent for fiscal years 1989 and 1990.

Impacts From Land-Based Disposal

Land applied sludge can be used beneficially as a fertilizer or soil conditioner on agricultural and forest lands (34,429,502,525). Seattle, for example, has applied sludge to forest lands and recently determined that revenues from the sale of sludge for forest application will at least partially offset the costs of sludge treatment and other management options (P. Machno, Seattle Metro, pers. comm., 1985; ref. 469).

Controversy surrounds many land application projects, however, because pathogens, metals, organic chemicals, and even nutrients in the sludge can cause adverse impacts (167). Nutrients such as organic nitrogen and ammonia, for example, can be converted by microorganisms into nitrates, which can leach into and contaminate surface water or groundwater.

Because of public health concerns, the presence of pathogens is a major factor limiting land application. Modern treatment processes can reduce the densities of most bacteria and some viruses, but not parasites, and sludges subjected to these processes are allowed to be land-applied in certain situations. Additional reduction of pathogens results from sunlight and drying after application. Despite this, bacteria, viruses, and parasites can survive in soil for months, depending on soil temperature, pH, organic content, and other factors. Viable pathogens have been found in runoff from fields that were subject to land application of sludge. No cases of human disease, however, have been documented to date from land application of treated sludge, although disease outbreaks have been linked with application of untreated sewage wastes (ch. 6).

Potential impacts from metals are another limiting factor. In general, metals adsorb strongly to particles or are not highly water soluble, so they tend to be retained in the soil. They are more mobile in sandy or acidic soils, however, from which they can leach into and contaminate surface runoff and groundwater. Some metals (e. g., cadmium, chromium, zinc, nickel) can be taken up by plants, sometimes affecting productivity, and excessive amounts of metals in plants can affect livestock or human health (1 18,387).

Some organic chemicals are lost from the soil through volatilization, but the fate of others depends on properties such as their volubility in water (503). They usually do not affect plant productivity significantly, but they can be ingested from soil or root surfaces by livestock, accumulate in animal tissues, and be consumed by humans.

The impacts associated with *landfilling* sludge are similar to those for land application. Anaerobic conditions are more common in landfills, however, which tends to retard the conversion of nitrogen and ammonia into nitrates, so there is generally less potential for leaching of nitrates into groundwater. Decomposition of organic material in landfills also can produce various gases; methane can be explosive, while carbon dioxide can acidify soils and increase the volubility of metals.

Sludge *incineration* significantly reduces the amount of material to be disposed, totally destroys pathogens, and can destroy more than 99 percent of organic chemicals under proper conditions. However, emissions of particulate material can affect ambient air quality, and emissions of volatilized metals or products of incomplete combustion can increase risks to human health. Incineration residuals, particularly metals, also remain in scrubber water or bottom ash, which also must be disposed of (usually in landfills, thereby adding to the potential risk of groundwater contamination).

Risks to Humans From Sludge Disposal Methods

Extensive research has been conducted on the potential risks to humans from different sludge disposal methods. EPA has developed a series of environmental and human health hazard indices for 50 pollutants found in sludge (656). Based on these indices, it appears that *contaminated* sludge applied to human food-chain cropland poses the greatest risk to humans, primarily because of the threat of PCBs and other nonvolatile, insoluble organic chemicals (503). In contrast, application of uncontaminated or even moderately contaminated sludge to non-food-chain croplands poses much less risk to humans. Evidence also suggests that risks to humans from land incineration and ocean dumping might be less than those from land application (503).

MAJOR ISSUES RELATED TO MARINE ENVIRONMENTS

The many issues that influence the management of sewage sludge and effluent in marine waters can be grouped into five broad categories:

1. compliance and enforcement,
2. how toxic pollutants and hazardous wastes affect sewage management,
3. new regulatory initiatives regarding sludge management,
4. the role of marine waters in waste management, and
5. the role of land-based disposal alternatives. [14]

Compliance and Enforcement

Municipal treatment plants have been slower than industrial facilities to respond to the original requirements of CWA. Originally, municipal plants were to achieve secondary treatment by 1977. Congress extended this date to 1988, and in 1984 EPA issued a National Municipal Policy statement affirming this goal. As of September 30, 1985, however, 37 percent of all major POTWs[15] still were not in compliance with secondary treatment requirements, in part because many have *not* com-

[14] The issue of ensuring funding of future municipal treatment plant construction, under the Construction Grants Program, is discussed in detail in ch. 1; indirect effects of the program on the above issues are discussed here when appropriate.

[15] "Major" POTWs include those discharging more than 1 million gallons per day or serving more than 10,000 people.

pleted the necessary construction (327). Substantial progress has been made during the last year in bringing POTWs onto a compliance schedule (designed to achieve compliance by mid-1988) or into actual compliance (table 24), As a result, under existing construction schedules, it appears that compliance could be achieved by the mid-1988 deadline by about 87 percent of major POTWs (table 24) (655), Almost 200 major POTWs, however, currently do not have compliance schedules and hence are likely to miss the deadline.

Even where required facilities have been built and are operational, some frequent and often serious violations of discharge standards have occurred. About 6 percent of the major POTWs that have completed construction have exhibited significant noncompliance. Noncompliance by these POTWs was attributed to inadequate facilities to provide required treatment levels; inadequate industrial pretreatment and treatment of combined sewer overflows; problems in maintaining sewer systems; and lack of appropriate local institutional structures to finance capital and operating costs and to efficiently manage facilities (327).

Implementing and enforcing CWA goals and requirements has been difficult, in part because of limited resources for monitoring and restrictions on the types of penalties that EPA can impose (327). Furthermore, these requirements focus largely on the removal of conventional pollutants. Quantities of metals and organic chemicals can be significant, however, and are likely to decline only if pretreatment is implemented and enforced.

Effect of Toxic Pollutants and Hazardous Wastes on Sewage Management

Many problems associated with municipal waste disposal stem from the presence of toxic metals and organic chemicals, which municipal treatment plants are not designed to treat. Hundreds of these pollutants enter municipal systems legally and illegally, although often at extremely low concentrations, and they are primarily contributed by industrial sources. A small portion is "incidentally" removed from wastewater, and some pollutants become incorporated in sludge. If POTWs continue to receive industrial wastes that contain these pollutants, questions will continue to arise regarding the ability of POTWs to produce clean effluent and sludge.

If levels of these pollutants in POTW influents were reduced, however, the feasibility of some disposal options, such as land application, would be enhanced.[16] Many constraints hamper the achievement of such a goal, however, including poor compliance with and enforcement of regulations, lack of standards for some management options, and lack of permit limits for some pollutants.

The lack of standards presents problems for both sludge and effluent disposal. Most sludge disposal options are not covered by regulations that limit metals and organic chemicals in sludge, leaving

[16] Models developed for EPA suggest that full implementation of pretreatment regulations could reduce, in both sludge and effluent, the amount of CWA priority metals by about one-half and the amount of priority organic chemicals by about three-fourths (503).

Table 24.—Status of Major Municipal Facilities (POTWs) Not in Compliance With National Municipal Policy[a]

Status of POTW	Number of major POTWs (October 1985)	Number of major POTWs (July 1986)	Number of minor POTWs[b] (October 1985)
On final enforcement schedule or under referral[c]	835	1,066	586
Returned to compliance	162	234	—
Unresolved	581	191	2,775
Total subject to National Municipal Policy	1,578	1,491	3,361

[a] As of date indicated; data refer only to major POTWs (those designed to treat flows of 1 million gallons per day or more or to service a population of 10,000 or greater) not yet in compliance with the National Municipal Policy (which affirmed the goal of compliance by July 1, 1988; see box A).
[b] Represents only those minor POTWs that require further construction to achieve compliance; data are not available for minor POTWs that have completed construction but are not in compliance.
[c] Referral represents cases referred t. Department of Justice or State Attorneys General for civil action; such cases usually result in the establishment of a final compliance schedule.

SOURCES: U.S. Environmental Protection Agency, Office of Water, "State Breakout of NMP Majors Construction Required, Status at End 3rd Quarter FY1986" (Washington, DC: data as of end of July 1, 1986); and Management Advisory Group to the EPA Construction Grants Program, *Report to EPA: Municipal Compliance With the National Pollutant Discharge Elimination System* (Washington, DC: June 1986).

POTWs without clearly defined goals for sludge quality. Among POTWs that receive significant quantities of industrial discharges, most have effluent discharge permits that contain limits on some metals but only a few organic chemicals (503). In part, this reflects the lack of State water quality standards for some metals and most organic chemicals (668). POTWs can also develop their own ' 'local' limits on industrial discharges of metals and organic chemicals into sewers. Local limits on industries are generally developed, however, only if a POTW must meet a specific limit contained in its own discharge permit. Since most POTWs do not have limits on organic chemicals in their permits, there is little incentive for them to develop corresponding local limits on their industrial users.

Some of these problems are being addressed by EPA and the States. For example, EPA is developing comprehensive sludge disposal regulations and promoting the use of water quality-based permitting as a means of controlling toxic pollutants (49 FR 9016-9019, Mar. 9, 1984). EPA also has the statutory authority to develop regulations for potentially toxic substances that are currently unregulated by CWA but which may be present at high concentrations in municipal wastestreams. Under paragraph 4(c) of the 1976 Toxics Consent Decree, for example, EPA has identified six such pollutants, but no regulations have been developed (644).

These important issues—enforcement, local limits, additional national standards, and water quality criteria—are discussed in further detail in chapters 1 and 8. For most of these issues, improved implementation of existing programs at all *levels* of involvement is critical and will require much more rigorous enforcement. This will only be possible if funding for monitoring and enforcement programs is increased.

The issue of legal hazardous waste discharges into sewers is particularly vexing. Eliminating the Resource Conservation and Recovery Act (RCRA) Domestic Sewage Exemption and regulating such discharges under RCRA is attractive because POTWs would receive fewer hazardous wastes. This option, however, could lead to increased illegal dumping into sewers and waterways, possibly making the problem worse (666). EPA proposed that the exemption be retained and that POTWs continue to develop and improve pretreatment programs to reduce the levels of hazardous and toxic pollutants that enter treatment plants. This approach thus will require effective implementation and enforcement of the pretreatment program, the likelihood of which is unclear. A related approach might be to develop regionalized waste treatment facilities, specifically designed to collect and treat hazardous or other industrial wastestreams (502).

New Regulatory Initiatives Regarding Sludge Management

The management of sludge is controlled by a patchwork of Federal, State, and local regulations, and no national sludge management program now exists. Instead, institutional arrangements among municipalities, counties, States, and EPA Regions are highly site-specific and complex, and often highly politicized (502).[17] Management also is complicated by a lack of comprehensive disposal standards, changing economic conditions, public opposition, and a relative lack of promotion of the idea that sludge can be used as a beneficial resource. As a result, most municipalities develop options haphazardly to take advantage of short-term opportunities.

Two sometimes antagonistic needs are key parts of the sludge management debate: the needs for stronger Federal guidance and regulation, and more flexibility to accommodate local conditions (502). Proponents of a minimal Federal role would let States develop their own regulations independently, with the Federal Government providing only technical assistance and guidance. Because local sludge management decisions are highly site-specific and often difficult to implement (502), local managers need considerable flexibility in designing and implementing sludge disposal options.

[17] These and other institutional issues are discussed in a contract prepared for OTA which summarized case studies of sewage management and pretreatment programs in Boston, Hampton Roads, Houston, Los Angeles County, Miami, New York, Philadelphia, and Seattle (502). These localities were chosen to achieve diversity in geography and type of waterbody, use of sludge dumping, degree of industrialization, pretreatment program status, sludge management alternatives, and institutional or policy issues

According to this perspective, however, Federal regulations do not allow sufficient flexibility or promote consideration of site-specific factors.

In contrast, proponents of an increased Federal role question whether current regulations for both sludge and effluent provide sufficient protection for the public and the environment. They contend that the Federal Government should continue to establish minimum national standards for most pollutants, conduct broad multimedia assessments, and possibly develop a large-scale, uniform national program with mandatory requirements for all States. Minimum standards, for example, could be included in the National Pollution Discharge Elimination System to provide performance goals for POTWs and promote the use of sludge as a resource.

In response, EPA has developed two new regulatory initiatives involving State sludge management programs and Federal regulations for sludge disposal. Under these initiatives, the Federal Government would play a stronger role in some areas: promoting the use of sludge as a resource, developing technical regulations for sludge disposal, and providing more technical assistance. [18]

First, EPA proposed a new rule to aid States in designing sludge management programs (51 FR 4458, Feb. 4, 1986); final action on the rule is scheduled for February 1987. Under the rule, States would develop plans for managing sludge (including promoting beneficial uses). To obtain EPA approval, a State would have to:

- demonstrate that it can ensure compliance with Federal regulations by overseeing how individual POTWs manage sludge;
- demonstrate that the State can monitor sludge to verify compliance and take enforcement actions against violators;
- possess legal authority to assess civil penalties for violations; and
- meet various reporting requirements on sludge inventories, noncompliance, and other aspects of sludge management (150, 151).

[18]EPA also has drafted new regulations to establish conditions under which dumping in marine environments would be allowed; the regulations originally developed for ocean dumping of sewage sludge were overturned in court (see ch.7).

These regulations would focus on improving sludge quality by implementing and enforcing pretreatment programs and sludge sampling and monitoring. According to EPA, the regulations would give States flexibility in using existing programs and institutional arrangements. Other than the loss of Federal funds for program development, there appear to be few penalties for States that do not submit plans for programs.

Second, EPA is developing technical regulations for five major sludge management methods—land application, landfilling, incineration, distribution and marketing, and ocean disposal. Federal regulations have never been promulgated for some of these options (e. g., for distribution and marketing), although nonbinding guidance has been issued. The new regulations would complement the regulations for State programs and would focus on quantifying the risks from and allowable concentrations of metals and organic chemicals in sludge; EPA identified pollutants that are candidates for regulation, and pollutants selected for actual regulation will be controlled either by numerical criteria for different disposal options or by technology-based management practices (311). These regulations would place sewage sludge management within a multimedia context; for a given situation, the risks of different options could be compared and the most environmentally acceptable option identified.

The regulations are scheduled for proposal in 1987. In a preliminary review, EPA's Science Advisory Board (SAB) indicated that the risk assessment methodologies being used by EPA to develop the regulations do not provide a clear way to compare the human health risks of different sludge management options (245); the SAB recommendations focused on improving these methodologies. In addition to this shortcoming, the regulations do not sufficiently address pathogens. Current regulations for pathogens are technology-based and focus on fecal coliform bacteria; they do not directly address other pathogens such as viruses and parasites.

Role of Marine Environments in Municipal Waste Management

If policy choices about waste disposal in different marine environments are made within the context of a waste management hierarchy that includes other management options, then marine waste disposal may be acceptable in some cases and unacceptable in others. Furthermore, the particular policy choices made about disposal in estuaries and coastal waters could greatly influence decisions about land-based and open ocean disposal.

For example, a goal of maintaining or improving the quality of estuaries and coastal waters could preclude the dumping of sludge in coastal waters, where most of it currently occurs. This could increase the need for either land-based disposal or open ocean dumping of sludge. A comparison of the benefits and risks of all sludge disposal options could suggest that the best use of uncontaminated (i.e., containing minimal amounts of metals, organic chemicals, pathogens) sludge might be either on land or in open ocean waters. On the other hand, the choice of treatment or disposal options for contaminated sludge would be less clear because of the risks of groundwater contamination from land application or landfilling, air pollution from incineration, or marine impacts from dumping. EPA's new regulatory initiative will address some of these issues. Still, some basic questions regarding sludge and effluent disposal in marine environments remain unsettled.

Should Sludge Dumping Be Allowed in Marine Waters?

The basic choice to be made in any disposal operation is between dispersal or containment (387). Containment of sludge in marine waters is technically difficult, expensive, and can increase adverse impacts. Dispersal, on the other hand, is feasible and since its objective is to minimize the buildup of disposed material on the bottom, it reduces the probability of impacts.

Dispersal is generally greater in large and well-mixed water masses, where wastes are mixed rapidly into a large volume of water and dispersed over a wide area (132,387). These conditions are prevalent in open ocean environments and well-mixed coastal waters. In contrast, estuarine and calmer coastal wasters generally are less well-mixed or flushed. In addition, they receive large inputs of waste material from other sources. This section focuses on sludge *dumping,* while the proposed *discharge* of sludge by Orange County, California, into ocean waters is described in box W.

At the relatively deep Deepwater Municipal Sludge Site, for example, particles from dumped sludge are expected to be well-dispersed and result in little or no accumulation on the bottom (595). Although bottom-dwelling organisms at the site might be affected and monitoring should be conducted, the impacts are likely to be less severe than those seen near the present less dispersive site in the New York Bight Apex (416,548).

Relatively *uncontaminated* sludge thus could probably be dumped in open ocean waters without causing severe impacts, as long as a dispersal strategy and appropriate disposal technologies were used (51,87,338,387,402). In general, sludge should be dumped slowly in deep, dispersive waters to obtain the greatest mixing and dilution. Furthermore, impacts might be minimized by varying the location and frequency of disposal operations (509). Barges or ships could help achieve this goal, since the disposal location can be changed as needed. Shifting dumping to the Deepwater Municipal Sludge Site is one example of this strategy.

On the basis of these factors, there would be little rationale to eliminate dumping as a disposal option. In addition, controlled dumping under dispersive conditions also might be used beneficially to increase productivity in certain marine environments, for example midcontinental shelf areas with a naturally relatively barren benthic community (509).

On the other hand, however, most sludge dumped in marine waters will continue to be contaminated to some degree with microorganisms, metals, and organic chemicals. Furthermore, the likelihood that programs for reducing toxic pollutants in municipal wastes will be fully implemented and enforced is unclear. The uncertainties associated with our ability to detect microorganisms (including human pathogens) in marine waters, and to sufficiently reduce the amounts of metals and organic chemicals in sludge, thus argue in favor of a policy that call for restricting (at least to some degree) the dumping of sludge. For these reasons, many public groups remain adamantly opposed to dumping in any form.

If marine dumping of sludge is to continue, it seems prudent to use a dispersal strategy (e. g., dumping in well-mixed and deep waters) and to minimize the presence of metals, organic

Box W.—Proposed Discharge of Sludge by Orange County

The difficulty in accommodating environmental concerns, economic factors, and political considerations is exemplified by a recent proposal from Orange County, California, to discharge sludge through a pipeline into the ocean on an experimental basis. This type of discharge is currently illegal under the California Ocean Plan, but the Federal Water Quality Act of 1987 contained a provision allowing EPA to grant a permit for this project. The County's motivation for the proposal is both environmental and economic: ocean discharge would be environmentally preferable to land-based alternatives, and it would be about four times less costly than landfilling, the recommended alternative (294), with annual savings of up to $10 million.

Relatively uncontaminated sludge would be discharged about 8 miles offshore into the open ocean, at a depth of about 1,300 feet (50,116). This would be the only pipeline in the Southern California Bight that is located off the edge of the continental shelf and it would be four times deeper than any other discharge in the area. It would be designed with large diffusers to increase dispersion, and the project would include a long-term monitoring program. Analyses of potential impacts from such a discharge indicate that disposal of relatively uncontaminated sludge in appropriate waters (deep and open, with high dispersal capability) probably would cause relatively minor impacts, except on a small area around the discharge point (50,385). Orange County has proposed that the discharge be allowed only if inputs of metal and organic chemicals into its POTWs were sufficiently controlled, and that it be terminated if observed impacts were deemed unacceptable by the permitting authorities.

The proposal has been criticized by environmental groups for several reasons. The discharge would be located in the Bight, which already receives massive discharges of effluent from three large sewerage authorities (the City of Los Angeles, Los Angeles County, and Orange County) and several smaller ones, as well as some sludge from Los Angeles County. These discharges have been the source of intense and continuing public debate, particularly with regard to two issues: general degradation of the environment, and the presence of pollutants such as DDT in sediments and fish. EPA has already encountered great public opposition when the three large authorities applied for waivers from secondary treatment requirements for effluents.

Current disposal practices clearly have caused some localized degradation of a small portion of the benthic environment. Although the proposed discharge could be terminated if unacceptable impacts were observed, critics note that no scientific definition of "unacceptable impacts" currently exists; as a result, there is no clear point when termination would be deemed necessary (N.K. Tayor, Sierra Club Clean Coastal Water Task Force, pers. comm., January 1987). In addition, these observers contend that discharges into deep ocean waters may not be degraded as rapidly as in other environments because of low oxygen levels and that enhancement of productivity in these waters would be minimal at best.

DDT was legally discharged in relatively large amounts into the Bight until 1970; some apparently still remains in pipes and sewers because small amounts are present in some municipal effluents entering the Bight. It persists in the environment, has contaminated sediments and many organisms, and is known to have caused reproductive failure in fish-eating birds such as the brown pelican. Although the presence of DDT is primarily a result of past practices, its presence is still of concern because it continues to be detected in organisms from these coastal waters (52). Its presence also fuels the controversy about current municipal disposal practices, particularly the ability of municipal treatment plants to control industrial discharges into sewers and reduce the amounts of toxic metals and chemicals in effluent and sludge.

Chemicals, and pathogens. This strategy would clearly preclude dumping in estuaries and poorly-mixed coastal waters.

In addition, if increased dumping were allowed, another legitimate concern is whether the magnitude of dumping could be sufficiently controlled. Economic pressures might force a substantial increase in the amount of sludge being dumped in the ocean. The Marine Protection Research and Sanctuaries Act (MPRSA) permitting process may be adequate to temper these economic incentives; in addition, fees or taxes could be imposed on ocean dumpers so that the total cost of dumping is comparable to the cost of other disposal options. It may be difficult, however, to levy such a tax or fee on

POTWs using ocean dumping because the MPRSA only allows the collection of fees to process permit applications.

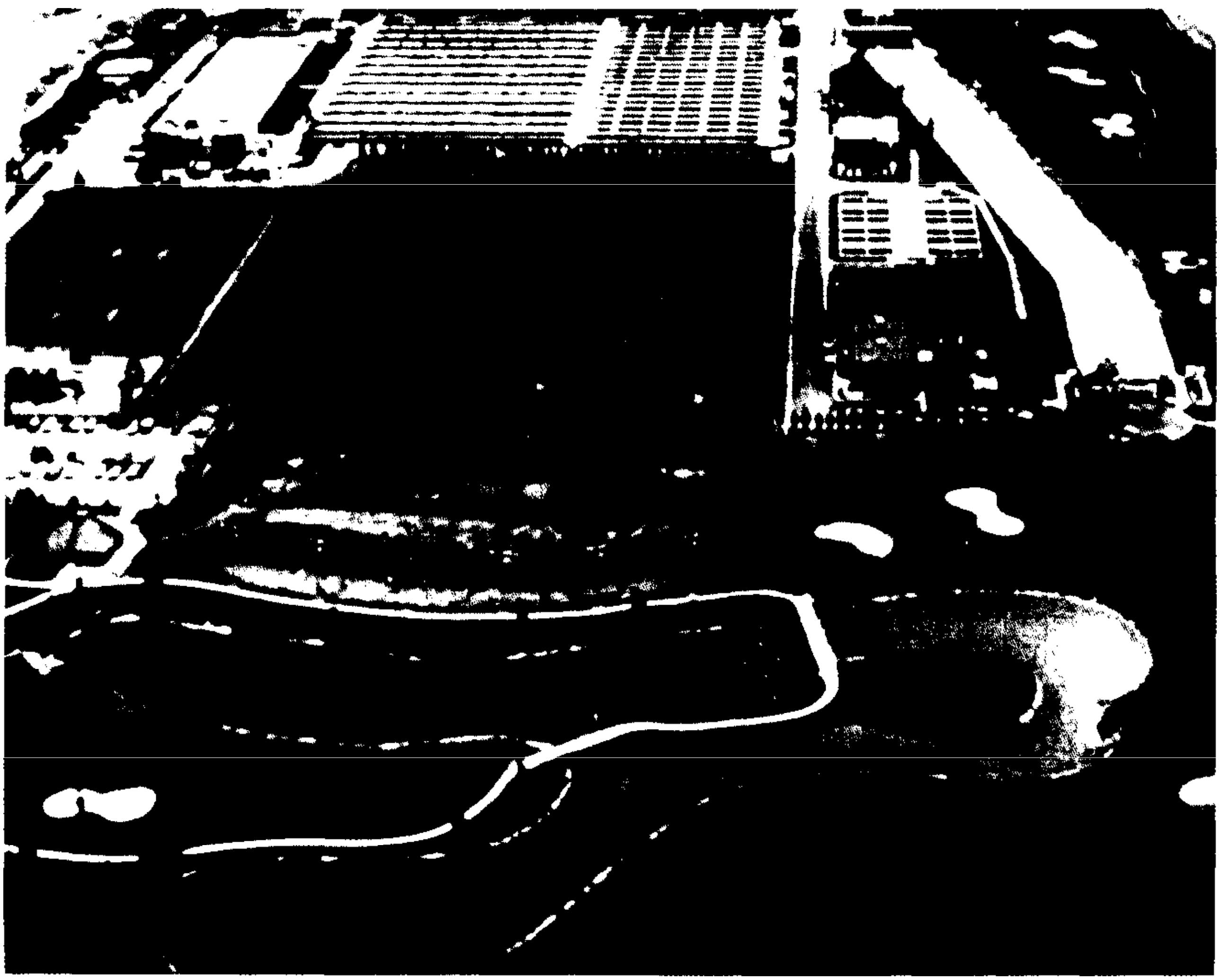
Treatment Levels for Effluent Discharges

Effluent cannot be readily contained and instead is generally discharged from pipelines. Since pipelines are fixed in one position and result in relatively low rates of initial dilution (280,509), their use can lead to the accumulation of particulate material in localized areas. Even so, these discharges can be suitable and dispersion can be enhanced if:

1. the amounts or concentrations of pollutants in effluents are reduced, and
2. pipelines are properly designed and placed in well-mixed and dispersive waters at appropriate distance from shore and depth (387).

Because of historical precedent and the current structure of municipal systems, few people question the need to discharge sewage effluent into estuaries and coastal waters.

At the same time, however, other options such as water conservation and reclamation could be used in some situations to reduce discharges into



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marine and fresh waters. For example, the development of small plants to treat and reclaim municipal wastewater might be environmentally and economically preferable to the continued development of larger and more expensive POTWs that discharge effluents into surface waters, especially as these larger plants begin to age and as Federal funding for the construction of municipal treatment plants declines (N. K. Taylor, Seirra Club Clean Coastal Water Task Force, pers. comm. 1987). The incentives to develop water reclamation and conservation plants are greatest in the more arid areas of the country.

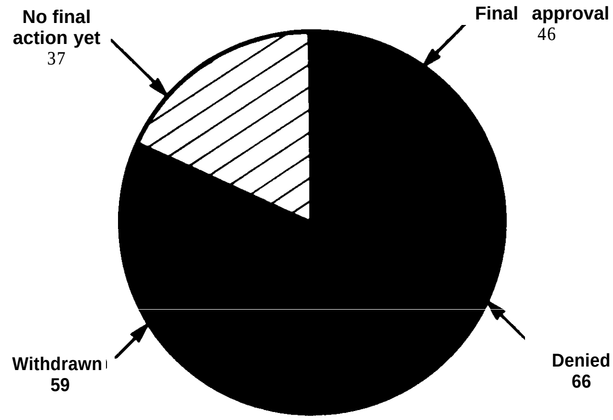
For discharges into marine waters much disagreement exists about the acceptable levels of two conventional pollutants—suspended solids and biochemical oxygen demand—in such discharges and whether some POTWs should be allowed to provide less-than-secondary treatment. Under Section 301(h) of CWA, POTWs could apply for waivers from secondary treatment requirements in areas where environmental quality would not be harmed, primarily to reduce construction and operating costs. The implementation of the waiver program, as well as its merit, has been debated extensively (122,225,310,533,649).

There is little doubt that substantial cost savings, amounting to several billion dollars in construction costs and up to $100 million in annual operation and maintenance costs, could be achieved by allowing some waivers (504,575). Comparing cost savings to costs of subsequent changes in receiving water quality is difficult, however, because of the variety of other factors that can affect water quality.

From a technical perspective, the question of whether lower treatment levels should be allowed can only be determined on a case-by-case basis, after evaluating site-specific factors. These factors are evaluated as part of the 301(h) application process (40 CFR Part 125, Subpart G) and include:

- the quality of receiving water (i. e., ability to disperse material, degree of previous impacts);
- the sensitivity of indigenous organisms and communities; and
- the relative contributions of pollutants from other sources (e. g., nonpoint pollution, industrial effluents).

Figure 34.—Status of 301(h) Applications, As of Jan. 2, 1987



SOURCE: R. DeCesare, Office of Water, U.S. Environmental Protection Agency, personal communication, January 1987.

As of January 1987, EPA had decided that all relevant criteria appeared to be satisfied for 46 of **208 waiver applications (figure 34).** Only a few large coastal POTWs, however, received approvals (e.g., Los Angeles County). Some municipalities (e.g., Seattle) withdrew their applications in part because of major public controversy.

From a policy perspective, prohibiting such waivers in the future could be justified because of the overall extent of pollutant inputs from many sources into estuaries and coastal waters and the expected trend of degradation in many of these waters. Indeed, some environmental groups have suggested that the Section 301 (h) waiver provision be rescinded.

In one sense, this issue is largely moot, however, because decisions about most waivers have been made and no additional applications can be submitted. In addition, the National Municipal Policy calls for most POTWs to achieve secondary treatment by mid-1988. It is complicated, however, by uncertain future economic conditions. Many POTWs have not yet secured funding for building or upgrading plants to the secondary level, and Federal Construction Grant funds for such activities will be significantly reduced in the next few years.

In anticipation of reduced Federal funding, some States are developing revolving funds (through bond sales or initial capitalization by State appropriations) to meet future POTW construction costs (143,520). Some municipalities are turning to private developers in an attempt to finance necessary construction, although it is unclear whether incentives are sufficient for private developers to invest on a large scale in municipal treatment plants (143,685).

These economic conditions could lead to reconsideration of the issue of required treatment levels in the future, as municipal treatment needs in coastal areas increase and as older treatment plants require maintenance or expansion. At the same time, and in combination with general concerns about the quality of marine environments, they also could provide incentives to consider other options for managing effluent such as water reclamation and reuse.

Role of Land-Based Alternatives in Sludge Management

The availability of land-based sludge management options is a critical factor in decisions regarding marine disposal of sludge. In the context of the waste management hierarchy, use of sludge as a beneficial resource on land (or in marine waters) would generally be preferred to disposal. From a technical perspective, relatively uncontaminated sludge could be land-applied, under proper conditions (e. g., appropriate measures to control runoff), as a beneficial resource without causing significant impacts. In addition, destruction of uncontaminated sludge by incineration might also be preferred in many situations.

Implementation of land-based alternatives, however, often is difficult for several reasons. First, local public opposition to land application or incineration can be intense because sludge is often considered an undesirable waste and because of concerns about health risks arising from use of these methods. Second, long-term management arrangements often are difficult to maintain (502). Third, standards to compare the various land-based disposal alternatives have been lacking (502), but EPA is developing regulations to address this problem. Finally, most sludges are contaminated with pathogens and toxic pollutants, which limits the environmental acceptability of land-based (and marine) disposal options, especially those involving beneficial uses.