CHAPTER 4

Environmental Public Works Management and Technologies

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Contents

Boxes

Tables

CHAPTER 4

Environmental Public Works Management and Technologies

In the haste to get new Federal water and related environmental programs in place, consultations and concurrence to ensure equitable and effective results have been neglected if not ignored.[1]

The Federal Government's role in environmental protection includes legislation, policies, and regulations to preserve the quality of the Nation's air and water supplies and to control the disposal of wastes. State and local officials must implement these Federal policies as they supervise, manage, operate, and maintain the public works infrastructure that supplies water, treats wastewater, and collects and disposes of solid wastes.

Ensuring good water quality requires planning, managing, and operating a wide range of public works facilities including reservoirs, locks and dams, flood control structures, and drinking water and wastewater treatment plants. Equal care in managing solid waste and hazardous waste disposal facilities is also necessary because of the potential movement of contaminants through groundwater or overland flow. The U.S. Environmental Protection Agency (EPA) has the Federal lead for environmental protection, setting standards for drinking water quality and surface waters, establishing pollutant limits on the discharge of effluents from municipal wastewater treatment plants and industrial point sources, and addressing issues of disposal of municipal solid and hazardous waste. The agency's responsibilities are established by a set of major environmental laws (see table 4-l).

Meeting EPA standards is not an easy task and places substantial technical, management, and financial demands on States and communities often ill-equipped to meet them. Technologies are essential tools for public works officials in carrying out risk assessments and implementing environmental protection measures. Maintenance, construction, repair, and rehabilitation techniques can improve performance and extend the service lives of existing facilities, and innovative systems, demand management, and improved fiscal and operational methods can reduce inefficiencies and foster more effective operations. The gulf between the capabilities of States and localities and their legal responsibilities poses difficult dilemmas for policymakers.

This chapter provides a snapshot of the three major environmental public works service areas: drinking water supply, wastewater treatment, and solid waste disposal. It examines related management and financing issues and technologies and the ways Federal standards and programs affect the State and local governments responsible for carrying out the requirements and providing services.

Drinking Water

The drinking water supply system includes the sources, facilities, and activities needed to transmit, store, treat, and distribute water to residential, commercial, industrial, and agricultural consumers. Groundwater is the source of about one-half of drinking water supplies by volume, with surface water (rivers, streams, lakes, and reservoirs) providing the remainder. Many groundwater and some surface water sources need very little treatment, usually simple disinfection with chlorine. However, some local water sources have been contaminated and require filtration, aeration, or chemical treatment. For example, technologies to remove nitrates contaminating aquifers must now be used in parts of the Midwest after decades of agricultural fertilization.[2] Federal and State Governments regulate and oversee the local suppliers of drinking water to ensure that it is free from biological and chemical contaminants.

Water Storage and Supply

supplying drinking water has historically been a local government service, provided by municipally owned systems, investor-owned water utilities, homeowner's associations, and water wholesalers. About 30 percent of all public water systems are

[1] Stephen S. Light and John R. Wodraska, "Forging a New State-Federal Alliance in Water Management,'' *Natural Resources Journal,* vol. 30, summer 1990, p. 479.

[2] James Manwaring, American Water Works Association Research Foundation, personal communication, Dec. 15, 1989.

Table 4-l-Major Federal Environmental Public Works Legislation

1948	Water Pollution Control Act authorized the Federal Government to conduct research and grant loans to States.
1956	Water Pollution Control Act Amendments gave permanent Federal authority to become involved in water pollution policy and make construction grants to States.
1963	Clean Air Act asserted Federal interest in controlling air pollution.
1965	Solid Waste Disposal Act established the Federal research and development program.
	Water Quality Act authorized Federal water quality standards on interstate waters and required States to set standards.
1966	Clean Water Restoration Act increased Federal grant share to 50 percent of project costs and increased grant funding.
1967	Clean Air Act amendments authorized Federal standards and enforcement.
1969	National Environmental Policy Act required impact statements on all major Federal actions.
1970	U.S. Environmental Protection Agency (EPA) formed to administer numerous media programs.
	Clean Air Act Amendments expanded Federal regulatory authority and required States to adopt implementation plans.
1972	Federal Water Pollution Control Act (Clean Water Act) set minimum wastewater treatment standards and established construction grants.
	Coastal Zone Management Act authorized Federal grants to States to develop coastal zone management plans under Federal guidelines.
	Marine Protection Act regulated the dumping of waste products into coastal waters.
1974	Safe Drinking Water Act set standards for water quality.
1976	Resource Conservation and Recovery Act (RCRA) supported recycling and discouraged landfills.
	Toxic Substances Control Act authorized EPA to regulate the manufacture, sale, or use of any chemical threatening the health of humans or the environment.
1977	Clean Air Act Amendments strengthened EPA enforcement.
1980	Comprehensive Environmental Response, Compensation and Liability Act established Superfund for chemical dump site cleanup.
1984	Hazardous and Solid Waste Amendments (of the RCRA) targeted hazardous waste management.
1986	Safe Drinking Water Amendments strengthened Federal requirements.
	Water Resources Development Act initiated user fees and cost sharing for water projects.
1987	Clean Water Act Amendments required that wastewater construction grants be phased out by 1991 and replaced until 1994 by capitalization grants to State Revolving Loan Funds.
1990	Clean Air Act reauthorization with additional controls on autos, buses, and trucks.
	Superfund extended through 1994.

SOURCE: Office of Technology Assessment, 1991.

community water systems, providing service year round to about 219 million people, primarily residential users. A few very large community water systems (0.5 percent of the total) serve more than 43 percent of the population, while at the other end of the scale are a huge number of small systems (see table 4-2), which serve less than 2.7 percent. About 40 million people draw drinking water from private wells, which are not subject to the Federal drinking water standards and are not regularly tested for contaminants. Noncommunity water systems provide intermittent service primarily to transient and nonresidential users.

Siting and constructing new reservoirs is increasingly difficult because the number of available sites is diminishing, new water supplies must be protected, and resistance for environmental reasons is high. Furthermore, the costs of developing new supplies and storage facilities rise as better sites are

Table 4-2-Community Water Systems in the United States

Number of people served	Number of systems
25 to 500	37,425
501 to 3,300	13,995
3,301 to 10,000	4,029
10,001 to 100,000	2,802
More than 100,001	279

SOURCE: Office of Technology Assessment, based on U.S. Environmental Protection Agency data, 1991.

preempted.[3] Thus, water utilities find it easier and cheaper to protect raw water supplies than to develop new supplies or treat water contaminated in storage. Many have programs to control erosion and protect reservoirs, watersheds, and well-heads so as to reduce chemical and equipment requirements, efforts that require extensive monitoring and enforcement of waste discharges and surface runoff.[4]

Water Distribution, Consumption, and Pricing

Drinking water distribution systems transport water from the treatment plant to the customer. The elevated storage tanks, ground storage reservoirs, pumps and pumping stations, mains from 6 to 54 inches in diameter, pipes, valves, and connections for distribution can account for up to 80 percent of drinking water costs. Systems in poor repair lose treated water through leakage, raising costs even higher. An examination of eight systems ranging in output capacity from 0.3 MGD (million gallons per day) to about 75 MGD showed amounts of such unaccounted-for water ranging from less than 1 percent up to 37 percent.[5] Small systems generally had a higher percentage of unaccounted-for water.

Average water usage is from 80 to 150 gallons per capita per day in the United States, although actual human consumption is between 1/2 to 1 gallon per capita per day. The cost of drinking water is typically $1.00 to $1.50 per 1,000 gallons; annual cost per person ranges from about $30 to $80 annually. Wide regional cost variations exist in the United States, because water is not evenly distributed geographically. This uneven distribution creates difficulties in matching supply with demand.[6]

Managing Supply and Demand

In localities where water shortages have prompted mandatory reductions, water use is declining; short-term conservation rules due to drought conditions have also reduced usage. For example, Massachusetts' plumbing code now requires new and replacement toilets to use not more than 1.6 gallons per flush v. 3.5 gallons per standard flush.[7] Mandatory reduction rules have been enacted in some communities on Long Island, New York, and in California. Greater attention is being paid to reservoir management and operation and optimizing multipurpose water systems through regional compacts such as the Washington Sanitary Sewer Commission.

Optimizing site-specific characteristics, such as storage, flow, and quality, of surface and groundwater supplies, a process known as conjunctive use,[8] can increase the amount of good quality water and improve supply quality. Tacoma, Washington, has a conjunctive use strategy by which it augments water from its principal source, the Green River, during periods when large amounts of suspended clay materials create high turbidity, with high-quality groundwater to reduce treatment requirements.[9]

Water utilities require large investments, partly because high seasonal demands usually occur during periods of low stream flows, necessitating large storage facilities. Thus, water systems generally operate at levels of output well below capacity, creating an incentive for utilities to encourage consumption, often through low prices for high-volume users. Although human consumption is a small percentage of total water used, almost all water must be treated to drinking quality standards.

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[3] Kenneth D. Frederick, Resources for the Future, "Water Resource: Status, Trends, and Policy Needs," discussion paper ENR88-02, 1988, p. i.

[4] Wade Miller Associates, Inc., *The Nation's Public Works: Water Supply* (Washington DC: National Council on Public Works Improvement, May 1987), p. 53.

[5] Patrick C. Mann and Janice A. Beecher, *Cost Impact of &@ Drinking Water Act Compliance f& Commission—Regulated Water Utilities*, NRRI *report 89-6* (Columbus, OH: The National Regulatory Research Institute, January 1989), p. 19.

[6] Frederick, op. cit., footnote 3, p. i.

[7] Average household savings is estimated to be from 9,400 to 25,700 gallons per year.

Sues. Army Corps of Engineers, The Hydrologic Engineering Center, *Elements of Conjunctive Use Water Supply*, Research Docum ent No. 27 (Washington, DC: March 1988), p. iv.

[9] Ibid.

Drinking Water Standards

Regulating drinking water to protect public health was historically a State and local responsibility. During the late 19th century, the threat of cholera and typhoid epidemics prompted many States and localities to establish sanitary commissions, which evolved into departments of public health, to supervise sewage treatment and monitor drinking water purity. During the first half of this century, continued small-scale outbreaks of waterborne infectious diseases motivated numerous States and local governments to adopt ordinances to control pollution and protect drinking water supply from contamination.[10] However, growing concern in the 1960s and early 1970s over the purity of the Nation's drinking water prompted passage of the Safe Drinking Water Act (SDWA) of 1974[11] as an amendment to the Public Health Service Act. The act and its amendments require EPA to set standards for drinking water quality and for the protection of underground sources; the States must enforce the standards. All public water supply systems—whether publicly or privately owned-are subject to the mandate.

Dissatisfied with EPA's implementation of the 1974 act and faced with the threat of suits by environmental advocates, Congress enacted the SDWA Amendments of 1986[12] to simplify the EPA regulatory process, stiffen the requirements, and accelerate the schedule for EPA to establish and implement new National Primary Drinking Water Regulations. Congress specified 83 contaminants for which EPA was required to promulgate regulations and identify the best available technology by June 1989, and required that 25 contaminants be added to the list every 3 years. To assure compliance, EPA has imposed various requirements for monitoring water quality, maintainingg records, and issuing reports. All public water systems are required by the statute to test on a scheduled basis for all contaminants for which EPA has established standards. The 1986 amendments also authorized continued, but relatively small, grants to States and localities, as well as new Federal assistance intended to help small systems monitor for unregulated contaminants and install disinfection equipment.

The Water Quality Act Amendments of 1987 addressed such issues as nonpoint source pollution, storm water discharges, the National Estuaries Program, toxics control, and sewage sludge management. Other laws with provisions aimed at improving U.S. water quality include the Resource Conservation and Recovery Act; the Comprehensive Environmental Response, Compensation, and Liability Act; the Federal Insecticide, Fungicide, and Rodenticide Act; and the Toxic Substances Control Act.

If a State assumes primacy, or primary enforcement authority, for drinking water, it takes on responsibility for ensuring that its localities meet the requirements of the national laws and regulations, and most States have done so. The 1986 SDWA Amendments, while providing some flexibility to the regulations, added to the States' workload by requiring additional review and analysis to ensure compliance. Some States voice concern that they cannot meet these requirements with their available resources and personnel (see box 4-A) and must consider abandoning primacy; they are apprehensive about the responsibility, liability, and costs associated with failed systems.[13]

Recent Regulatory Changes

Water systems are currently trying to comply with recent changes in drinking water regulations such as testing for the additional contaminants listed in the SDWA and seeking technology alternatives. Controlling the frost set of contaminants requires systems to change their processes without knowledge of future regulations or the identities of additional contaminants. New regulations call for all surface water supplies to be filtered, and EPA has combined this requirement with disinfection regulations into one set of standards for surface water. Systems that do not filter must now do so, regardless of existing water quality.

In addition, legislation also requires that new disinfection standards be promulgated for water supplies. One goal of the new standards is reducing trihalomethanes (THM) and other byproducts of chlorine disinfection. However, EPA faces a dilemma in setting standards: reducing the level of

[10] Council on Environmental Quality, The *16th Annual Report of the Council on Environmental Quality* (Washington DC: U.S. Government Printing Office, 1985), p. 7.

[11] Public Law 93-523, 88 Stat. 1660.

[12] Public Law 99-339, 100 Stat. 642.

[13] John Trax, National Rural Water Association, personal communication, Apr. 17, 1990.

chlorine is likely to increase biofilm growth in water distribution systems, because less residual disinfectant will remain in treated water. This may well lead to a new set of operating problems. How best to regulate lead in drinking water is also problematic, because lead has been widely used in service lines and solder for household plumbing.

Coliform monitoring regulations have been changed to determine simple presence or absence as opposed to a density (parts per volume) measurement. These changes will increase the number of samples needed by a utility to show compliance and are likely to increase substantially the number of utilities in violation because low levels of coliform, which do not pose a public health risk,[14] are likely to be present.

Risk and Uncertainty in Standard Setting

Although an appendix to the EPA National Interim Primary Drinking Water Regulations of 1976 mentions that ". . . priority should be given to the selection of the purest source. . . ,"[15] this approach is not stressed in legislation or in EPA regulations. EPA's water quality standards are based on maximum contaminant levels (MCLs) determined by animal studies. While monitoring equipment can measure some contaminants in parts per trillion, standards determined by animal modeling cannot project human toxicity to this accuracy. Moreover, MCLs ". . . for one contaminant do not recognize the additive or synergistic behavior of the many contaminants that are present together in wastewaters."[16] Scientists' ability to develop new chemicals and to measure their presence in the environment in minute amounts far surpasses the ability to understand and evaluate long-term human health risks.

Removing a contaminant from drinking water to meet an MCL standard is more costly than preventing its introduction in the first place. Complex and specific EPA regulations for drinking water and sewage treatment may conflict with regulations of other Federal agencies, creating problems for operators and raising costs. For example, the process of

Photo credit: Dan Broun, OTA Staff

Americans count on being able to draw safe drinking water from every household tap.

removing radionuclides from drinking water creates radioactive sludge that is difficult to dispose of because it is a radioactive waste. If engineers adjust water disinfectants to reduce corrosion in distribution systems, the changes may reduce chlorine's effectiveness, yet adding more chlorine to achieve the same disinfection level will increase the carcinogenic THMs.

Technologies for Safe Drinking Water

Most newer water treatment methods are specialized, expensive, and not designed for amass market, making it difficult for localities to introduce new technologies.[17] SDWA regulations are aimed at THMs, volatile organic compounds (VOCs), and soluble organic compounds (SOCs), with more contaminants to be added overtime. As standards for each new contaminant are promulgated, new methods or new chemicals become important. 'Although the SDWA can be expected to stimulate the development of alternative treatment processes, at this time

[14] Edward Geldreich, senior research microbiologist Drinking Water Research Division, U.S. Environmental Protection Agency, personal communication, Sept. 10, 1990.

[15] Daniel A. Okun, ' 'Philosophy of the Safe Drinking WaterAct and Potable Reuse, " *EnvironmentalScience & Technology*, vol. 14, No. 1 1, November 1980, p. 1298.

[16] Daniel A. Okun, "Reuse: Panacea or Pie in the Sky," *Journal of the American Water Works Association,* vol. 77, No. 7, July 1985, p. 26.

[17] See for example, Wade Miller Associates, Inc., op. cit., footnote 4.

Box 4-A—State Water Quality Programs and New Technologies

State public works officials and engineers play important and often pivotal roles in the difficult process of ensuring the quality of a State's drinking water systems and wastewater treatment plants. For example, in Ohio, the Ohio Environmental Protection Agency (OEPA) has primacy in the approval process for new construction, upgrades, improvements, and expansions of drinking water facilities[1] The system's engineer or a consultant must prepare project plans and submit them to OEPA's office of Drinking Water for approval. OEPA engineers provide initial advice and suggestions about project feasibility and acceptance through the State office or one of four regional offices. Following initial acceptance, project designs can be completed and submitted for a more detailed review for compliance with State construction and environmental standards.[2]

Ohio uses the "Ten State Standards," which are guidelines for conventional treatment equipment and procedures. Developed before many of today's environmental regulations or more sophisticated treatment technologies, these standards are considered very conservative. Although Ohio is trying to move away from these standards to encourage innovative technologies, the permit process favors familiar technologies with a proven track record. Moreover, public works operators often must back up innovative systems with conventional technology in case the new process fails, resulting in costly redundant systems.[4]

The Office of Drinking Water is short of experienccd engineers, and current salaries are not sufficient to attract or retain needed staff.[5] Because the State currently has a 6- to 9-month backlog of project design approvals, State engineers do not have time to examine thoroughly proposals that include new technologies, The State legislature has considered increasing the staff and raising salaries in response to pressure from contractors and construction companies that are losing money because of the delays.

Oklahoma has a more decentralized approach for environmental decision making,[6] and five different State agencies have authority in environmental permitting. Municipal drinking water or wastewater treatment plants require approval from the State's Department of Health, while permits affecting water and agriculture involve the

[1]Robcrt Stevenson, manager of operations, Toledo Water Treatment Plant, personal communication, Oct. 18, 1989.

[2]Ashley Bird, manager, Engineering Section, Division of Public Drinking water, Ohio Environmental Protection Agency, personal commmnication, Oct. 20, 1989.

[3]Wade Miller Associates, Inc., *The Nation's Public Works: Report on Water Supply* (Washington, DC: National Council on Public Works Improvement, May 1987), p. 75.

[4]Whit van Cott, commissioner of water, Toledo, Ohio, personal communication, Oct. 18, 1989.

[5]Other States have the same problem. Virginia and Pennsylvania report that their salaries make it difficult to compete with private engineering firms for young engineers; they also cite the lack of institutional memory due to high turnover. Virginia attempts to give young engineers broader experience and a sense of how systems operate in practice by rotating newly hired engineers in the regional offices for 2 months before they begin reviewing plans. The rationale is that newly hired engineers will be better able to judge a new process if they have seen some of the technologies in the field.

[6]Jon Craig, chief for Wastewater Construction Grants, Oklahoma Department of Health, personal communication, Oct. 11, 1989.

there is no single technology that will remove all regulated contaminants.''[18] The complexity of the water treatment process, coupled with variations in water supply characteristics, make the search for major new technologies difficult. Moreover, new treatment methods will bring new difficulties. For example, research on treating surface water supplies with granular activated carbon (GAC) found that dioxins were formed in the carbon reactivation process; after evaluation, an afterburner was installed to eliminate dioxin byproducts.[19]

Current Basic Treatment

Natural waters contain dissolved inorganic and organic substances, bacteria and plankton, and suspended inorganic material. Customary treatment methods to remove these substances include flocculation, sedimentation, filtration, and chemical precipitation.[20] Raw water is brought to a mixing tank where chemicals are added; the water is then transferred to a flocculation tank for additional mixing. Particulate matter, chemical floe, and pre-

[18]Mann and Beecha, op. cit., footnote 5, p. 9.

[19]Robert Clark et al., "Removing Organic Contaminants From Groundwater,' *Environmental Science and Technology, vol. 22,* October 1988, pp. 1126-1130.

[20]"Water Treatmen," Standard Handbook *of Environmental Engineering (New York ,NY: McGraw-Hill),* pp. 5.76~5.123.

State Department of Agriculture. Discharge permits for industry fall under the State Water Resources Board. If an oil or petroleum facility needs a discharge permit, the State Corporation commission has jurisdiction, and the Department of Mines has jurisdiction over mining activities. If an environmental issue is not clearly defined, it is handled by the Pollution Control Coordination Boarb, made up of representatives from all these agencies plus **private citizens.**

The State of Oklahoma does not have primacy in wastewater discharge permitting; thus permits are issued by the U.S. EPA. The State submits National Pollutant Discharge Elimination System permit applications to the EPA regional office in Dallas for review. Primacy can have an impact on technology choice, since a State review agency is more likely than the ERA regional office to recommend technology appropriate to the location. Also, if a small community system is in violation, or about to be, the State agency can act more quickly to assist or solve the problem.[7] Although Oklahoma's various agencies do not conduct evaluations of new or innovative systems, the Department of Health has indicated interest in the use of more such technologies. The State's Revolving Fund also encourages their use, and a municipality will be placed higher on the funding priority list if its plans incorporate innovative systems. The Water Resources Board sets standards in line with the Clean Water Act, providing some incentive to develop new technologies.[8]

Virginia uses a two-part permitting process for drinking water facilities comprised of standard technologies.[9] One permit is issued for construction and one for beginning operation of the completed facility. construction plans for standard technology are submitted to one of the State's six regional offices for review. Engineers in Virginia's regional offices perform the complete engineering review of the plans and then send them to the head office in Richmond for approval. The two top administrative engineers of the Division of Water Supply and the Comissioner of the Health Department must approve the plans. Like Ohio, Virginia has a large plan review backlog, largely due to staffing shortages. Moreover, a more rigorous process is required for innovative technologies. The manufacturer or supplier of a new technology must bond the product or system, discouraging promoters of unproven equipment After bonding, the plans follow the same mute.

Pennsylvania has a special "Innovative Technologies" permit for new technologies,[10] which requires a 12-month pilot test including source water checks to rneasure their effectiveness. Unlike the standard technology permitting process, innovative technology permits require oversight approval from the Division of Water Supplies in Harrisburg. This approval, however, is required only on the new technology portion of the plan. Although special requirements, such as those in Virginia and Pennsylvania eliminate some risk associated with new technologies, they tend to inhibit some systems from trying innovative technologies.

[7]Ibid.

8James Barnet, director, **Oklahoma State Water Resources Board, personal communication,** Oct. 12, 1989.

9**Allen Hammer,** director, **Division of** water **Supply Engineering, Virginia Department** of **Health, personal communication, Oct.** 20,1989.

10**Fredrick** A, **Marrocco,** chief, Division of **Water** Supplies, Pennsylvania **Department** of **Environmental** Resource% **personal communication,** Oct. 20, 1989.

cipitates from suspension are then removed through gravity in settlement tanks. Filtration removes matter held in suspension by passing the water through a porous medium. Disinfection, using chlorine, chlorine dioxide, ozone, or potassium permanganate, destroys pathogenic bacteria.

Chlorine has been the disinfectant of choice for more than 70 years and is currently added to about 90 percent of U.S. potable water supplies.[21] Chlorine is readily available and inexpensive and its characteristics are well known; water treatment specialists depend on it and rely on residual chlorine in the storage and distribution system. U.S. consumers do not object strongly to the levels applied; some suggest the taste of chlorine is proof that the water is properly treated.

However, the byproducts of chlorination include potentially carcinogenic halogenated byproducts, principally THMs.[22] Reducing chlorine to achieve the THM standard can lower the disinfection ability

21National **Research Council, "News Report,"** informational **document, October** 1989, p. **14.**

22**Much** is *written* about **the THM byproducts** of **chlorination,** but they represent only about 10 percent of the chlorine byproducts. Factors **affecting** byproduct components include source water quality, seasonal factors, water treatment process selection and operations, and disinfection processes and chemicals.

to the point that pathogenic bacteria are not killed,[23] and may require the addition of other treatment steps (See box 4-B).

Most European systems have well-protected storage facilities and short distribution systems, and rely on oxidation and disinfection with ozone[24] combined with biological treatment and postfiltration **GAC** for water treatment. Large amounts of THMs are not formed in treatment plants, since chlorine is used sparingly and is carefully monitored, because consumers do not want a chlorine taste in the water.[25] However, ozonation does have its own set of byproducts, some of which are also chlorine byproducts.[26]

Alternatives to Chlorine

Other processes, such as adsorption, aeration, ion exchange, oxidation, and distillation, are being used to remove dissolved substances. For each of these operations, the quantity and concentration of chemicals added, speed of mixing, technique, and settlement times will have an impact on the final results. The pH, turbidity, chemical composition of the water, type of coagulant, and such physical factors as water temperature and mixing conditions also affect the results.

EPA has investigated technologies for removing SOCs and VOCs from groundwater. Each technology must be tested under field conditions before EPA will advocate its use. GAC adsorption, a broad-spectrum technology for treatment of organic contaminants, has been field tested, and tests on packed tower aeration are still under way. Other technologies being evaluated are powdered activated carbon, alone or in combination with other processes such as ozone oxidation, reverse osmosis, and ultraviolet treatment. Although many of these processes are effective for removing SOCs, they have high capital and/or operating costs.

Reverse osmosis (RO) takes advantage of the phenomenon that solutions passed under pressure through a semipermeable membrane will result in solutions with lower concentrations of dissolved substances.[27] Membranes are very thin films capable of selectively separating suspended or dissolved solids from water depending on size and molecular weight. They can be constructed from a number of synthetic polymers, including cellulose acetate, cellulose-based polymers, polyamides, and polysulfone. RO and electrodialysis are currently the membrane processes with the most applicability for drinking water treatment; in fact, RO has proven successful in desalination plants. Ultraviolet light is effective for disinfection when the water supply is highly clarified and bacterial loads are moderate, although it does not provide any residual disinfection.[28] Ultrafiltration, an emerging technology, nanofiltration, and RO all rely on applied pressure **to** drive water through the membrane. In electrodialysis, an electrical current separates the salts.

Membranes limit the amount of chemicals needed for water purification, reduce the size of treatments, and can reduce operations and maintenance costs. New developments in membrane technology may lower energy requirements (less feed pressure), improve centaminant removal rates, and resist permanent organic fouling. However, membrane processes do require pretreatment, periodic cleaning, and disposal of filtration residue.

Work on innovative technologies must be carefully monitored to see whether performance meets the design criteria. However, ". . . once treatment units are installed, . . . there is generally little follow-up to see if designs are proper or are adequate mechanically to stand up for a reasonable period of time. ' '[29] Without the followup evaluations much of the value of the demonstration projects is lost.

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[23] Studies have shown, though, that precursor control through physical removal mechanisms may be the best way to minimize all chlorination byproducts. See Alan A. Stevens et al., "Formation and Control of Non-Trihalomethane Disinfection By-Products," *Journal of the American Water Works Association,* vol. 81, No. 8, August 1989, pp. 54-60.

[24] Ozone is an oxidizing agent that controls bacteria in the water and destroys taste and odor compounds. It oxidizes iron and manganese, leaving insoluble compounds that can be removed by filtration. Ozone gas is a hazardous material, requiring special care in handling.

[25] Rip Rice, president, Rice International Consulting Engineers, personal communication, Dec. 13, 1989.

[26] "Report on the Workshop on By-Products of Ozonation," *Water Research Quarterly, vol. 6, No. 4,* July-September 1988, pp. 13-15; and ibid.

[27] Talbert N. Eisenberg and E. Joe Middlebrooks, *Reverse Osmosis Treatment of Drinking Water* (Stoneham, MA: Butterworth Publishers, 1986).

[28] Mann and Beecher, op. cit., footnote 5, p. 8.

[29] James A. Goodrich and S. Bala Krishnan, "Drinking Water Treatment Technology for Groundwater Remediation," paper presented at the Third National Outdoor Action Conference on Aquifer Restoration Groundwater Monitoring and Geophysical Methods, Orlando, FL, May 22-25, 1989.

Box 4-B—Alternative Process for Water Treatment[1]

If the reactions of disinfectants with organic compounds in a water supply pose major problems, then procedures to remove dissolved organics can minimize the amount of chlorine needed and reduce the concentrations of halogenated byproducts and nonhalogenated organics. Such an alternative process might include the following steps:

1. abandon prechlorination and enhance physical removal of organics by flocculation and sedimentation;
2. oxidize organics, through ozone, permanganate, or advanced oxidation processes such as ozone/hydrogen peroxide or ozone/ultraviolet treatment;
3. follow oxidation with biological filtration in sand, in dual media filters, or in filters having some granular activated carbon (GAC) as media replacement;
4. add postfiltration GAC adsorbers, primarily to remove disinfection byproducts, and to ensure the adsorption of soluble organic compounds; and
5. add small amounts of chlorine or chlorine dioxide to provide a stable residual disinfectant, protect the distribution systems against biological regrowths, and produce high-quality water with virtually no chlorine taste.

[1]This box is based on Rip Rice, president, Rice International Consulting Enterprises, personal communication, Dec. 13, 1989.

Dual Systems

Dual systems, which supply potable and nonpotable water through separate pipes, although not a new concept,[30] offer an alternative to ***the high cost*** of treating all water to drinking water quality, particularly for new systems. Dual systems can be used for systems of any size but are attractive for small systems where high treatment costs must be met by relatively few customers. Wastewater treatment requirements produce a high-quality effluent that may be too valuable to be discarded;[31] using reclaimed wastewater for nonpotable purposes in **dual** distribution systems can:

- relieve the pressure on high-quality waters so that these can serve larger populations;
- cost less than developing additional high-quality freshwater sources for nonpotable uses;
- reduce the burden of pollution on the receiving body of water; and
- reduce the risk of utilizing water drawn from polluted sources.

Although the installation of a dual system requires additional capital expense for parallel pipe networks and additional valves and connections, the construction excavation is performed only once, and the system operating costs are lower. These systems have proven economical; operating systems include the Irvine Ranch Water District (California), Colorado Springs (Colorado), and St. Petersburg (Florida). The City of San Diego recently passed an ordinance establishing a water reclamation master plan and implementing strategy for the city. These systems will become more economically attractive as water source development and wastewater treatment become more costly due both to inflation and environmental regulations. However, retrofitting dual systems in mature water utilities may be too costly an alternative, and some public works officials have voiced concerns about the potential health risks of an inadvertent connection of potable and nonpotable supply lines.[32]

Technologies for the Distribution Network

Although the SDWA requires that regulations be met at the consumer's tap, most compliance efforts focus on water as it leaves the treatment plant.[33] However, distribution systems are related to 20 percent of waterborne disease outbreaks.[34] If the distribution system loses its integrity, treated water can change in quality through chemical or biological

[30]The Roman aqueduct supplied water that was used for nonpotable purposes. Drinking water was drawn from other sources.

[31]David A. Okun, University of North Carolina, "Feasibility of Dual or Multiple Water Supply Systems," unpublished manuscript, 1982.

[32]Richard H. Sullivan, executive director, American Public Worka Association, personal communication, J@ 17, 1990.

[33]Ibid.

[34]Robert Clark et al., "Contaminant Propagation in Distribution Systems," *Journal of Environmental Engineering*, vol. 114, No. 4, August 1988, pp. 929-941.

Photo credit: American Consulting Engineers Council

Using sludge from wastewater treatment plants to fertilize reforestation projects can be a oost-effective disposal method.

transformations.[35] Untreated water may enter the system through pipe breaks, and bacteria can be introduced from a variety of sources, including enclosed reservoirs to which chlorine is not added and living organisms in mains that, when disturbed, may release bacteria into the drinking water.[36]

Leak detection and control are essential both for ensuring against contamination and controlling cost. Significant savings can be achieved through leak detection and repair programs, even where water treatment costs are low. Minor repairs can prevent more serious problems and avoid the expense of additional water damage. Metered systems and those that have full information about their distribution network are more likely to be able to locate and repair problem sections. Leak detection surveys utilize a number of techniques, including visual observation, sonic technology, miniprobe sensors, tracer gases, and infrared photography.[37]

However, many water companies lack even rudimentary data about distribution systems. Useful data would include pipe information such as manufacturer, location, length, pressure, installation contractor, installation date, diameter, material, and placement method; and maintenance information such as maintenance crew or contractor, location, problem type, depth, corrective action, and local surface and subsurface conditions.

Studies indicate that a few pipes in a network account for most maintenance problems,[38] and that each repair shortens the time to the next repair. Pipe breaks are caused by: 1) quality and age of pipe, connectors, and other equipment; 2) the environment in which the pipe is laid, such as the corrosiveness of the soil, frost and heaving, and external loads; 3) quality of the workmanship used in the laying of the pipe; and 4) service conditions, such as pressure changes and water hammer. Additional research is needed to increase understanding of these relationships and to guide future repair and replacement efforts and design and placement activities.

Corrosive water can cause problems by increasing the concentrations of the metal compounds from pipe systems in the water. Lead, cadmium, and other heavy metals are generally present in various amounts in pipe solder material, and other contaminants such as copper, iron, and zinc can be leached from distribution systems. Corrosion is such a costly problem for pipes, valves, pumps, and reservoirs that the higher initial expense of more corrosion-resistant materials is often a sound investment. (See chapter 5 for further details.)

Proposed rules for monitoring water quality within the distribution system prescribe a minimum number of samples based on the population served

[35] Safe Drinking Water Committee, *Drinking Water and Health, vol. 4* (Washington, DC: National Academy Press, 1982).

[36] Robert M. Clark et al., "Distribution System: Cost of Repair and Replacement" paper presented at the Conference on Pipeline Infrastructure, Pipeline Division of the American Society of Civil Engineers, Boston, MA, June 6-7, 1988.

[37] Stephen Maloney et id., *Preventing Water Loss in Water Distribution Systems: Money Saving Leak Detection Programs,* Technical Report N-86/OS (Washington, DC: U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, March 1986).

[38] James Goodrich et al., "Data Base Development and Analysis for Water Distribution Systems," *Hydraulics and Hydrology in the Small Computer Age-'Vol. 1, Proceedings* of the Specialty Conference Sponsored by the Hydraulics Division of the American Society of Civil Engineers, Lake Buena Vista, FL, Aug. 12-17, 1985.

by the system,[39] and suggest that the number of sites sampled be at least three times the number of the required monthly samples. This represents at least an order of magnitude increase over the number of sites currently sampled.[40] When the bacteriological samples exceed the standards, resampling at five additional sites within the immediate neighborhood is required until the problems disappear or the source of the problems is identified and corrected. The proposed regulations do not provide procedures for locating monitoring stations in a water distribution system and assume that water customers will permit the utility to take samples at the tap on request.

Technologies for Small Systems

Small systems serve only 8 percent of the population, but they account for 93 percent of maximum contaminant level violations and 94 percent of monitoring/reporting violations. Package plants, self-contained units that are premanufactured and shipped to a location, are one way to ensure that a small system has an up-to-date treatment plant. These plants have lower installation and operating costs than conventional treatment plants, and offer highly integrated and compact systems and a high degree of automation.[41] Package plants can be economical up to 2 million gallons per day (MGD), a size that accounts for about 90 percent of U.S. water utilities.[42] While package treatment plants can meet SDWA standards,[43] technology change has been slow. Small systems have not yet been subjected to the same level of enforcement as larger systems, and localities that are not in compliance have not had to make changes to meet the regulations. Thus there is little demand for such systems and little incentive for potential manufacturers.[44]

Where centralized treatment is not feasible or cost-effective or where private wells are common, point of use (POU) equipment can be installed at the tap and provide whole-house or single-tap treatment. The equipment is easy to install, treats only the water used for consumption, simplifies operation and maintenance, and generally has lower capital costs.

Point of entry (POE) devices include water treatment equipment installed outside a home or serving a group of homes or businesses and are accepted by EPA for complying with drinking water regulations. Their major use is in sparsely populated areas.[45] POU devices must be used to remove contaminants that are of concern with ingestion, whereas POE devices should be used when skin adsorption or inhalation of a specific contaminant is of concern.

POU and POE systems are operator-intensive and require regular maintenance, monitoring for contaminant breakthrough, and collection and disposal of contaminated media.[46] They also pose a safety risk; they provide untreated supplies that can be accidentally ingested. POU and POE treatment does not alleviate the responsibility of a water utility to provide safe drinking water to its customers.

Bottled water, while not anew technology, can be an alternative source for drinking water in small communities, although in most cases piped water is less expensive[47] Since human consumption amounts to only about 1/2 to 1 gallon per day, treatment of water to drinking quality may not be necessary at some remote locations. Bottled water is regulated by the Food and Drug Administration and meets EPA SDWA regulations.

[39] 52 *Federal Register* 42224; and 40 CFR 141 and 142 (Nov. 3, 1987), "Drinking Water: National Drinking Water Regulation; Total Coliforms; Proposed Rule."

[40] Rolf A. Deininger and Byung H. Lee, School of Public Health, The University of Michigan, "Monitoring Strategies for Water Distribution Systems," unpublished manuscript, n.d.

[41] Wade Miller Associates, Inc., op. Cit., footnote 4, p. 57.

[42] Richard G. Stevie and Robert M. Clark, "Costs for Small Systems To Meet the National Interim Drinking Water Regulations," *Journal of the American Water Works Association,* vol. 74, No. 1, January 1982, pp. 13-17.

[43] Robert M. Clark and James M. Morand, "Package Plants: A Cost Effective Solution to Small Water System Treatment Needs," *Journal of the American Water Works Association,* vol. 73, No. 1, January 1981, p. 30.

[44] Donna Cirola, Culligan Water Systems, personal communication, Feb. 5, 1990.

[45] Benjamin Lykins et al., "POU/POE Devices: Availability, Performance, and Cost," paper presented at the 1989 ASCE National Conference on Environmental Engineering, Austin, TX, July 10-12, 1989.

[46] Kim R. Fox, "Field Experience With Point-of-Use Treatment Systems for Arsenic Removal," *Journal of the American Water Works Association,* vol. 81, No. 2, February 1989, pp. 94-101.

[47] Daniel A. Okun, in *Proceedings: Cooperation in Urban Water Management* (Washington, DC: National Academy Press, 1983), p. 49.

Management and Operating Tools

Technologies to improve the performance of public water systems range from computerized control systems to improved maintenance information systems. Gradually, operators of larger systems are replacing much of their electrical and mechanical control equipment with programmable logic systems that are more reliable and require fewer operator hours.[48]

These systems, called supervisory control and data acquisition systems (see box 4-C), monitor a wide range of data and information on motors, valves, meters, feeders, and sensors, for example, and are oriented to plant operations such as those seen in water treatment facilities.[49] Detroit expects to save at least 20 percent on energy and chemical costs and to boost staff productivity with its new control system.[50] The city also hopes to have better control of the combined sewer system and effluent quality and of supply to its suburban customers.

Maintenance for environmental public works is often neglected and underfunded, leading to higher costs when major repairs are necessary. “It can be five times as expensive to replace sewer pipe after it breaks than to repair it while it is still in one piece: as much as $100 per foot compared to $14.”[51] Technologies to improve maintenance performance begin with information systems that tie together information on the facilities and equipment and repair and replacement activities so that managers can have up-to-date information on equipment inventory, current condition, and maintenance and repair requirements. Such information systems enable managers to devise optimum maintenance strategies, perform life-cycle cost analyses, and avoid losses due to maintenance failures.

Condition assessment is becoming a critical function for operating systems as funds for capital facilities diminish and the need to get the most from existing equipment increases. For water supply and wastewater treatment operations, it is especially important because the majority of the investment is underground and out-of-sight. In addition, using inaccurate condition assessments to prepare bid documents for repair projects results in change orders, inefficient contracts, and lost productivity with the contracting agency. (See chapter 5 for discussion of nondestructive evaluation technologies).

The provision of drinking water involves heavy capital expenditures, long lead times in planning and construction, and high freed costs. Construction is often undertaken well in advance of established demand because of the need to take advantage of economies of scale and the need for coordination of other public services in an area. Recent experience coupled with increasing costs for public service provision underscore the lack of analytical models available for predicting future demand. Very little work has been done to develop models that integrate public works information into demand modeling.[52]

Accurate consumption data are needed for preparing billing materials, developing cost-based rate structures, controlling system losses, planning for future demand, and estimating the need and costs for future facilities. Portable hand-held data entry devices, borrowed from the inventory industry, provide savings by eliminating the printing of meter reading cards and reading them into the billing system. Automatic meter reading equipment based on integrated circuitry and advanced telecommunications technology can provide additional cost savings by totally automating this function. The technology utilizes a device that collects information on utility usage, packages it into a data stream, and sends it through a telephone, cable, radio, or power line carrier to a computer for storage and analysis.[53] Benefits include eliminating the extra work and costs involved in “lock-outs,” estimates, call backs, and premature cancellations; improving customer service with more accurate and up-to-date

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[48]David Mohler, McNamee, Seeley, & porter, personal communication, Mar. 2, 1990.

[49]American Society of Civil Engineers, *Proceedings: Critical Water Issues and Computer Applications, 15th* Annual Water Resources Conference (New York, NY: June 1988).

[50]David Fisher, Detroit Water and Sewerage Department, personal communication Jan. 19,1990.

51 Virginia K@ Dorris, "Systems Link Geography and Data," *Engineering News Record,* vol. 222, June 1, 1989, p. 30.

[52]Robert M. Clark et al., U.S. Environmental Protection Agency, "Cost Models for Small Systems Technologies: U.S. Experience, " unpublished manuscript, n.d.

[53]Donald Schlenger, "Telemetering—State of the Art," *Proceedings,* First *International Conference* on *Infrastructure Research, November 15-17, 1988* (Washington, DC: URISA, 1988), pp. 117-138.

Box 4-C—Supervisory Control and Data Acquisition (SCADA) and Distributed Control Systems (DCS)

SCADA systems were initially used by electric power companies to control remote equipment and facilities and to diagnose system failure and monitor operating efficiency in large, geographically dispersed sites. A variant, DCS, is used to control a small number of individual sites close to a central location and is oriented to plant operations. Advances in computer technology have made these systems more affordable and user *friendly enough* to enjoy wide application,[1] and as system costs have dropped,many utility companies have begun to use these systems.

Orlando, Florida's system is designed to automatically monitor and control removal of effluent from the water system. This system uses microprocessors, called master terminal units (MTUs) at each remote ''pressure zone.'' At each master terminal is a cable-based local area network, similar to those used in many offices today. The MTU's are connected via UHF radio transmission to the central control station. In addition, remote control and data acquisition devices are located at the individual elements of the SCADA system.[2] An operator at a computer terminal can communicate directly with the remote units to control pumps and valves. The effluent removal system can be controlled locally, at the area control center, or remotely, at the central control center. For data acquisition the central computer queries the MTU's, and each MTU queries each local unit. Since the system is distributed rather than centralized, it is easy to diagnose problems and expand system coverage.[3]

These systems make it possible to perform distribution systems analysis in real time and enable the operator to optimize pumping operations and use of water storage facilities, and avoid process and permit violations. At Oakland's East Bay Municipal Utilities District, for example, a DCS monitors sewer system water levels at **eight** remote locations, so that remote treatment facilities can be brought on-line before the main treatment plant **is** overloaded.[4]

[1]Herb Fiddick, Black & Veatch Engineers, personal communication Jan. 12,1990.

[2]Orelan R. Carden, Jr., ''Distributed Control Optimizes Wastewater Reuse,'' InTech, October, 1988, p. 52.

[3]Ibid.

[4]Michael J, Vandaveer, East Bay Municipal Utilities District, personal communication, 1990.

billing information; shortening read-to-bill turnaround and enhancing cash flow; and reducing bad debts. These automated systems can be shared by other utilities, such as gas and electric, as well, reducing expenses for installation and operation. Associated issues involve telecommunications regulations, standardization, cooperation among the utilities, compatibility, legal, and other institutional considerations.[54]

Decision models can help in budgeting future improvement projects by evaluating resource allocation and maintenance management information within a capital budgeting framework.[55] For example, the additional costs incurred for losses in service and repairs to aging pipes[56] must be considered in the decision process together with a host of other more obvious costs. In addition, cost evaluations for system improvements as well as modifications needed to ensure compliance require more thorough consideration in the decision process. Models are needed to assist decisionmakers with these system details.[57]

Since many of the issues and operations with which local government and local utilities are concerned relate to land or location, a geographic information system (GIS) is a useful tool for

[54]Automatic meter reading configurations include: 1) telephone dial-inbound which uses an electronic meter interface unit (MIU) on the customer'S premises through the telephone companies test equipment without ringing the customer's telephone; 2) telephone dial-outbound in which the MIU dials the utility's computer and transmits the latest meter reading, usually at a preset time; 3) a cable TV-baaed system in which the utility communicates with individual MIUs over the cable to obtain the meter reading; and 4) a radio system in which the MIU transmits to a utility receiver. About 50 percent of the existing systems are telephone systems although these are restricted by court rulings related to AT&T; cable systems are a very small part of existing and potential systems.

[55]Lonnie Haefner, Lonnie Haefner Enterprises, Inc., ''Impacts of Advanced Technology Innovation on Public Worka Management and Decision Making,'' OTA contractor report, June 28, 1989, pp. 22-28.

[56]Fadi A. Karaa et al., ''Budgeting of Water Distribution Improvement Projects,'' *Journal of Water Resources Planning and Management*, vol. *113, No. 3,* May *1987, pp. 378-391.*

[57]Robert M. Clark et al., ''A Spatial Costing System for Drinking Water,'' *Journal of the American Water WorksAssociation,* January 1982, pp. 18-26.

planning, management, and operations.[58] A GIS can assist utilities in collecting, storing, analyzing, and disseminating data and information. A GIS also has the ability to manage and display graphic map images, to manage large volumes of nongraphic data that are related to a geographic location, and to perform various retrieval and analytical functions on the combination of graphic and nongraphic data. Public works agencies, departments of transportation, port authorities, and planning organizations have recognized the value of these systems to store, manage, and integrate several related databases.[59] (See chapter 5 for discussion of geographic information systems.)

Wastewater Treatment

Wastewater is a significant component in the water cycle because all treated (and some untreated) wastewater flows into the Nation's waterways. Wastewater (sewage) treatment includes the facilities and activities needed to collect, transport, and treat residential, commercial, and industrial wastewater, and, in the case of combined sewers, surface runoff and groundwater. The Nation has more than 15,000 publicly owned treatment works (POTWs), which can treat approximately 37 billion gallons per day (see table 4-3). Commercial establishments and about 160,000 industrial facilities also discharge their wastes into collection systems served by POTWs. About 39,000 industrial facilities discharge effluent (most of it treated) directly into waterways.

POTW system components include collector sewers, interceptor sewers, combined sewers for wastewater and storm water, flow equalization facilities, wastewater treatment plants, on-site systems and septic tank systems.[60] Collection systems range from low-capacity sanitary sewers that transport wastes from homes to higher capacity sewers that transport industrial sewage and storm water to wastewater treatment plants. Higher capacity sewers consist of both interceptor sewers (that use gravity for transport) and force mains (that use pumps to transport to interceptor sewers at a higher elevation).

Table 4-3-Size, Number, and Capacity of POTWs in the United States

Actual flow range (MGD)	Number	Capacity (MGD)
0.01 -0.1	4,960	251
0.11 - 1.0	7,003	2,671
1.01 - 10.0	2,893	9,372
10.01+	577	24,383
Totals	15,433	36,677

POTW Treatment Levels

Level of treatment	Number	Capacity (MGD)
Less than secondary	2,122	5,529
Secondary	8,403	15,714
More than secondary	3,115	14,373
No discharge	1,762	973
Unknown	46	88
Totals	15.448	36.677

KEY: MGD _ million gallons per day.
POTWs = publicly owned treatment works.

SOURCE: Apogee Research, Inc., from U.S. Environmental Protection Agency, 1986Nee& *Survey Report to Congress: Assessment of Publicly Owned Wastewater Treatment Faclities in the United States* (Washington, DC: February 1987), p. 4.

Combined sewers transport both wastewater and storm water to wastewater treatment facilities. Flow equalization facilities are sometimes used to store wastewater during storm events and discharge to the wastewater treatment plant during low-flow periods. At the wastewater treatment plant, pollutants are removed and/or treated by screening, settling, biological treatment, and disinfection.

Primary treatment removes settleable solids. Prior to the 1972 Clean Water Act this was the maximum amount of treatment provided by most treatment plants. Secondary treatment removes 85 percent of oxygen-demanding materials and suspended solids and destroys most bacteria by disinfection. All municipal plants must now provide at least this level of treatment. Advanced treatment using chemicals and filtration can remove over 99 percent of pollutants from wastewater. All processes except disinfection produce a sludge that must be disposed of by incineration, by application on the land, or by burying it in landfills.

[58] Rebecca Somers, "GeographicInformation Systems in Local Government: A Commentary," *Photogrammetric Engineering and Remote Sensing,* vol. *53, No.* 10, October 1987, pp. 1379-1382.

[59] "Locational Referencing and Highway Segmentation in a Geographic Information System," *ITE Journal*, March 1990, pp. 27-31.

[60] About 25 percent of the U.S. population is served by septic tank/soil absorption systems. James Kreissl, "Alternative Sewers in the United States," paper presented at the 1985 International Symposium on Urban Hydrology, Hydraulic Infrastructures and Water Quality Control, University of Kentucky, Lexington, KY, July 23-25, 1985.

Photo credit:American Safety of Civil Engineers

Pretreatment and treatment programs are aimed at ensuring that industries adequately treat wastewater before discharging Into rivers, streams, and sewers.

Wastewater Treatment Regulation

Until 1972, responsibility for controlling water pollution rested primarily with State and local governments. With the passage of the Federal Water Pollution Control Act of 1972 (Public Law 92-500, the Clean Water Act), Congress significantly increased the Federal role in water quality,[61] and increased Federal assistance for the construction of wastewater treatment plants. EPA was made responsible for setting water quality standards, developing water quality criteria, establishing technology-based effluent limits, and developing a national system of discharge permits.

The Clean Water Act replaced in-stream water quality standards with limits on the pollution levels of discharge from municipal treatment plants and industrial point sources. EPA established the National Pollutant Discharge Elimination System (NPDES) permit system, which made Federal approval mandatory for every point source of wastewater discharge. To ensure permit approval, localities were required to use technologies for wastewater treatment approved by EPA, even if a lower degree of treatment would not reduce water quality.

Pretreatment and treatment programs are aimed at ensuring that POTWs and industry adequately treat wastewater before discharging it into rivers, streams, and sewers. Pretreatment programs are designed to prevent the passage of toxic substances into waterways. When pretreatment fails, toxic substances can kill or inhibit the growth of bacteria that remove pollutants in treatment processes, and interfere with plant operations, contaminate sewage sludge, and create safety and health hazards. Nonetheless, many cities do not bring strong enforcement actions against industries that violate pretreatment requirements.[62]

More flexible regulatory strategies could reduce treatment costs if they include trading between point/nonpoint sources. Reducing pollutant loadings through nonpoint source controls maybe considerably cheaper than increasing treatment standards at the local sewage treatment plant. Even though $400 million was authorized for a nonpoint source program in the 1987 reauthorization of the Clean Water Act, no money was appropriated, and EPA has been slow to implement trading programs.

Wastewater Treatment Issues

Wastewater treatment requirements are being stiffened, and new standards for toxic chemical controls dictate that sludge treatment, handling, and disposal receive more attention. Toxics emitted in off-gases from treatment facilities have already become a major air pollution problem in some U.S. cities. The major issues facing POTWs are discussed below.

Upgrading Existing Facilities

Many POTWs must upgrade facilities to meet NPDES permit requirements that increase treatment requirements, improve plant performance, and meet increased demand from growing communities. Although routine maintenance becomes very costly as systems age, the significant investment in existing facilities and the high cost of replacement may make

[61] Prior legislation includes the Rivers and Harbors Act of 1899, the Water Pollution Control Aet of 1948 and several subsequent laws (see table 4-1).

[62] U.S. General Accounting Office, *Improved Monitoring and Enforcement Needed for Toxic Pollutants Entering Sewers*, GAO/RCED-89-101 (Washington, *DC: 1989).*

repair and rehabilitation of the present system a cost-effective choice.[63]

Infiltration of groundwater and the flow of rain-water and surface runoff into sanitary sewers increase the demand on treatment facilities and can, on occasion, overload them. Flow surges caused by infiltration or inflow can force the bacterial solids used in the treatment process out of the plant, reducing treatment efficiency for long periods. Broken pipes, defective pipe joints, illegal connections of foundation drains, cross connections between storm sewers and sanitary sewers, and illegal connections with domestic storm drain systems are common reasons for flow surges.[64] Many communities already treat as much as one-third more waste-water than necessary because of cracked or loosely fitting sewer pipes.[65] These problems can be solved by a combination of sewer line repair/rehabilitation, adding flow equalization facilities, and increasing treatment plant capacity. However, plant operators are often unable or ill-equipped to collect the data needed to assess and correct these problems.

Combined Sewer Overflows

Combined sewers are conduits that transport domestic and industrial wastewater during dry weather conditions and storm water runoff during wet weather. Combined sewer systems currently serve 12,000 communities nationwide, but approximately 60 communities account for over 80 percent of the total area served by combined sewers.[66]

When storm water runoff exceeds the capacity of the treatment facility, the combined sewer overflow (CSO) enters a receiving water without being treated. Because these discharges are subject to the Clean Water Act regulations, prohibiting discharges with less than secondary treatment, storms create potential for violations and enforcement actions for many communities.

Managing the storm water flows to bring CSO discharge points into compliance has evolved from simple removal of runoff to comprehensive ap-preaches.[b7] Control measures include nonstructural methods, such as improved urban development and resource planning, natural drainage, sewer ordinances and discharge permits, chemical use controls, surface sanitation, and erosion and sedimentation control. Structural controls, often the most feasible alternative in heavily developed urban areas, include onsite storage and infiltration facilities, overland flow modification, and solids separation. Successful and cost-effective storm water management strategies integrate several appropriate, feasible, and economic components for control.[68]

Sludge Management

The addition of chemicals in coagulation, softening, and settling operations yields an unwanted byproduct-sludge. The Nation's POTWs produce about 7.7 million metric tons of sludge annually and production will probably double by the end of the century, since higher level treatment of wastewater will increase sludge production. Sludge management and disposal can consume from 30 to 60 percent of a wastewater treatment operations and maintenance budget.[69] Sludge-related problems include odor objections, incinerator ash disposal, public acceptance of land disposal, and the potential for high concentrations of toxics in sludge. Because of the chemicals used in water treatment and the solids that precipitate out in the treatment process, the sludge can be classified as a hazardous waste. When this occurs, the cost of sludge disposal can exceed the capital and operating costs of treated drinking water.[70]

[63]U.S. Environmental Protection Agency, Center for Environmental Research Information, *Handbook: Retrofitting POTWs*, EPA/625/6-89/020 (*Cincinnati*, OH: July 1989), p. 1.

[64]U.S. Environmental Protection Agency, Office of Municipal Pollution Control, *Infiltration and Inflow Analysis and Project Certification* (Washington, *DC:* May *1985).*

[65]Discussions at the Environmental Protection Agency "Municipal Wastewater Treatment Technology Forum," Ann Arbor, MI, June 6-8, 1989.

[66]U.S. Environmental Protection Agency, *Combined Sewer Overflow Toxic Pollutant* S@, EPA 440/1-84/304 (Washington, DC: A@ 1984), pp. 5, 10.

[67]J. Marsalek, "Stormwater Management Technology: Recent Developments and Experience," NATO *Urban WaterResources AdvancedResearch Workshop, June 22-27,1989, Douglas, Isle of Man,* presentation preprints (Brussels: North American Treaty Organization, 1989), p. 1%.

[68]Ibid., p. 209.

[69]Richard Kuchenrither, Black& Veatch Engineers, personal communication Feb. 13, 1990. As transport costs increase and treatment options diminish, the percentage of total costs is likely to increase.

[70]"Water Treatment," op. cit., footnote 209p. 5.96.

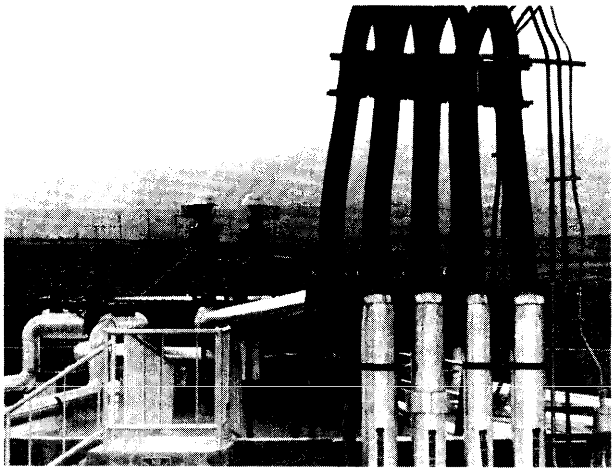

Photo credit: American Consulting Engineers Council

Sludge management, using new equipment (such as that pictured here), and disposal can consume from 30 to 60 percent of a wastewater treatment operations and maintenance budget.

Legislation in 1988 prohibited sludge disposal in the ocean. Although EPA has little information on sludge types, characteristics, quality, amounts, and fate, its proposed rulemaking for disposal makes conventional methods difficult to pursue. The new rules imply support for beneficial use and land application,[71] and will increase sludge reporting and recordkeeping requirements for POTWs.[72] The regulations are risk-based and cover five different types of sludge disposal: incineration, nonagricultural land application, agricultural land application, distribution/marketing, and monofills/surface impoundments. A sludge survey of 200 POTWs will be completed by EPA in mid-1990 and should prove helpful in determiningg the nature and extent of sludge management problems.

Air Toxics

Wastewater treatment is fast becoming an issue in air quality debates. Air quality districts in California have proposed regulating air contaminants from POTWs by requiring additional monitoring and analyses of air toxics, changes in wastewater treatment facilities, and changes in plant operation and maintenance. The proposed regulations include ". . . newly regulated substances, some of which are not detectable in wastewaters entering POTWs."[73] Control measures will involve pretreatment or product substitution, air flow management, and the use of best available technologies. Activated carbon adsorption is a candidate technology, but little is known about its use for removal of VOCs in the wastewater treatment environment. No other methods have been demonstrated in research or commercial facilities for air toxic control.[74] Attempts at remediation of air toxics have brought severe corrosion problems for POTW facilities.[75] Furthermore, little is known about the limitations of existing technologies for treating toxics in exhaust gases from treatment facilities.

Nonpoint Sources

Treated wastewater often contaminates drinking water sources less than nonpoint sources (NPS). The five major contributors to NPS pollution are farms, urban areas, construction sites, mines, and forests where logging is conducted. Contaminants range from sediments and pesticides to spilled solvents and asbestos brake linings. Because NPS pollutants, mostly heavy metals, sediment, and salinity, come from thousands of diffuse sources, controlling them will require monitoring and changing the daily activities of individuals and businesses in every watershed. Agricultural activities, such as tillage practices and animal waste management, are the greatest source of NPS pollution, accounting for 70 percent of the total nitrogen and phosphorus deposited in surface waters.[76] NPS pollutants are the limiting factors in improving or maintaining water quality for both surface water and groundwater. "If Federal and state clean water regulations were totally successful in eliminating pollution from

[71] "Standards for& Disposal of Sewage Sludge," U.S. Environmental Protection Agency Proposed Rule, *Federal Register*, PP. 5746-5902 (Feb. 6, 1989). A range of professional groups, including the Cooperative State Research Service Technical Committee W-170 in its Peer Review Report published July 24, 1989, has raised questions about the scientific and risk assessment methods and quality of data used by the Environmental protection Agency to develop this proposal.

[72] Industrial pretreatment programs can improve sludge quality dramatically and make sludge qualities for all but a few POTWs suitable for beneficial use. Kuchenrither, op. cit., footnote 69.

[73] Kris P. Lindstrom, K.P. Lindstrom, Inc., and Farouk T. Ismail, State Water Resources Control Board, "The Impact Of Toxic Air Q@.@ Regulations on California Publicly Owned Treatment Works: Final Report for the State of California," October 1988, pp. 1, VI-1.

[74] 1bid., p. VI-5.

[75] Blake Anderson, director of technical services, Orange County Sanitation Districts, personal communication, June 6, 1989.

[76] Lyse D. Helsing, "Water Treatment: Solving the Second Generation of Environmental problems," *Chemical Week*, vol. 142, May 18, 1988, p. 32.

(single sources like wastewater treatment plants that convey their pollutants to the stream in a pipe) the Arkansas River would be little changed from the polluted river it is today."[77] Nationally, EPA reports that 65 percent of all water pollution comes from NPS sources. In Western States, with fewer people and less industry, that figure is often closer to 90 percent, and nearly every river is affected.

Wastewater Treatment Technologies

A few systems rely on advanced instrumentation (see box 4-C in section on drinking water) and nondestructive evaluation techniques for locating leaks and breaks, and assessing the condition of the system, including plant, the pipes, and connectors. However, most systems lack accurate information on facility condition.

Pipe and Collection System Technologies

Underground construction, rehabilitation, and pipe replacement using trenchless technologies (equipment that makes it unnecessary to dig trenches to remove or replace pipes) can be extremely cost-effective. Direct savings come from reduced trenching and shoring work and reduced surface restoration requirements. In urban or developed areas, delays due to construction and disruption to buildings and surface plantings are very costly. Indirect benefits include reduced road closures and rerouting of traffic, and reduced destruction of difficult to replace items such as trees, shrubs, and gardens. A variety of trenchless technologies provide widely different benefits.[78] (See chapter 5 for additional information about trenchless technologies.)

Collection system technologies include sewer separation, inlet controls, sewer pipe controls, and severe flow control by overflow regulators. They can also include real-time control of sewer flow and pollutant routing by using peripheral monitoring and telemetry stations and computer-based sewer and pollutant flow prediction methods. Real-time control systems also permit operating the sewer system remotely to release overflows of less polluted batches of combined sewage at points where the environmental impact is the least.[79]

Storage tanks or tunnels outside the sewer system, but connected to it, permit stored combined sewage to be drained during off-peak periods into the wastewater treatment plant. Such facilities allow modifying flow patterns, reducing overflows, and some treatment of the stored volume by sedimentation.[80] They also serve as flood protection and hazardous spill containment during dry weather.[81]

Corrosion can also be a serious problem for concrete and other materials used in sewers, and alternative pipe materials are being examined for their durability and reliability. In sewers the corrosion is generally caused by acids, such as hydrogen sulfide, or by industrial chemicals and solvents. Using lined concrete pipes has prevented corrosion in a number of systems, most notably in southern California where communities that installed the lined pipes have had few corrosion problems. Neighboring systems that chose to use unlined concrete pipes to save initial costs have suffered excessive corrosion. (See chapter 5 for more information on materials and corrosion.)

Treatment Plant Technologies

Treatment plant technologies encompass pretreatment, physical processes, advanced treatment (physical, chemical, and biological), natural systems, disinfection, treatment plant instrumentation, control, and operations. While new technologies can bring real benefits, systems investing in new equipment or turning to new processes are likely to encounter new maintenance problems.

Filters and membranes are increasingly important in advanced wastewater treatment, particularly as materials and manufacturing techniques bring production improvements and lower costs. An advanced wastewater treatment plant in Orange County, California, reclaims treated municipal wastewater for injection into an underground seawater barrier system. The process, which meets

[77] *High Country News*, vol. 21, No. 22, Nov. 20, 1989, p. 11.

[78] D.T. Iseley, Department of Civil Engineering, Louisiana Tech University, "Trenchless Technology-Alternative Solutions to Complicated Underground Utility Nelwork Problems," seminar notes, Second Annual Alumni Appreciation Seminar, Ruston, LA, Nov. 3, 1989.

[79] Ibid., p. 206.

[80] Ibid., p. 207.

[81] Richard Field, "Urban Stormwater Runoff Quality Management: Low Cost Structurally Intensive Measures and Treatment," *Urban Runoff Pollution, NATO* ASI Series G: Ecological Sciences 10 H.C. Torno et al. (eds.) (Heidelberg, Germany: Springer-Verlag, 1990), pp. 677-699.

current EPA drinking water standards, includes reverse osmosis for removal of both organic and inorganic compounds. (See discussion in water treatment section of this chapter.)

Polymers (long, charged hydrocarbon chains) mixed with ferric chloride electrochemically precipitate out suspended particles. Polymer technology has proven successful for advanced primary treatment, because polymers can eliminate up to 85 percent of the suspended solids that remain after secondary clarification. (A secondary treatment plant that is operating properly removes about 85 to 93 percent of influent, suspended solids.)

Although EPA has recently emphasized removing toxics within the plant and using filtration to reduce toxicity, POTWs do not have the equipment or monitoring devices to identify and measure toxics at their facilities. Moreover, information about the nature and amounts of toxics released into municipal waste streams from industrial facilities rarely reaches POTWs.

Sludge Disposal

EPA defines and regulates any residual with a portion of sludge as sewage sludge.[82] Sludge has beneficial plant nutrients and soil conditioning properties, and estimates suggest that nearly 40 percent of municipal sewage sludge is applied to land in the United States. However, sludge contaminants, such as heavy metals, and organic carcinogens and pathogens, must be reduced so that land application does not create a potential health or safety threat.[83] A recent study of the technologies available for sludge disposal listed five primary options: 1) comporting, 2) heat drying, 3) land application, 4) landfilling, and 5) incineration.[84] (See box 4-D for more information.)

Technologies for Small Rural Systems

Many rural communities rely on individual, onsite septic systems to treat wastewater. Although such systems are often inexpensive and cost-effective, age, lax maintenance, thin or poor soil, and a simple lack of space have contributed to septic systems failures or untreated sewage polluting groundwater and entering ditches and streams. Problems are widespread; 80 percent of counties surveyed in one study reported system failure and potential contamination of groundwater and surface water.[85] Moreover some States and counties are not enforcing local sanitation and land-use codes, and in some cases, the codes themselves have led to failures.[86]

Lower cost alternatives to conventional gravity systems include pressure sewer systems, vacuum sewer systems, and small diameter gravity sewers. Pressure systems, which depend on pumps to move wastes from the customer location to the pressure main, are dependent on pump and grinder technology. Vacuum systems use a vacuum to draw wastes into a collection main and then into a collection tank before being pumped to a treatment facility. Small diameter gravity sewers are connected to septic tanks that collect dirt, grease, and solids and prevent them from entering the main collection system. Each of these systems has been used advantageously in rural communities and has unique characteristics that recommend its use under specific circumstances. Thus they demand more of the design engineer than conventional systems. Moreover, even with improvements in materials and design, each of these systems requires regular maintenance and access to on-lot facilities for maintenance and emergency repairs.

Natural systems, aquatic plant systems, land treatment, and wetlands can provide waste treatment for the substantial range of hydraulic and pollutant loading and temporal fluctuations that are characteristic of small systems.[87] Aquiculture systems have

[82] U.S. Department of Agriculture, Cooperative State Research Service Technical Committee W-170, "Peer Review—Standards for the Disposal of Sewage Sludge," unpublished report, July 24, 1989.

[83] U.S. Environmental Protection Agency, Center for Environmental Research Information *Control of Pathogens in Municipal Wastewater Sludge*, EPA/625/10-89/006 (Cincinnati, OH: September 1989).

[84] Black & Veatch, Inc. "Draft Report on Assessment of Technologies," prepared for the Massachusetts Water Resources Authority, Feb. 27.1987.

[85] Study by the American Planning Association for the Illinois Department of Energy and Natural Resources, cited in Paul Tarricone, "Big Trouble in Little America," *Civil Engineering, vol. 59, No. 8,* August 1989, pp. 57-59.

[86] Ibid., p. 58; and James Kreissl, U.S. Environmental Protection Agency, personal communication, Jan. 24, 1990.

[87] U.S. Environmental Protection Agency, Office of Research and Development, Center for Environmental Research Information, *Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment,* EPA/625/1-88/022 (Cincinnati, OH: September 1988).

Box 4-D—Sludge Handling Techniques

Aerobic composting involves the decomposition of sludge organics by microbiological organisms in the presence of oxygen. Nuisance odors can be produced if anaerobic organisms replace the aerobic organisms due to reduced oxygen supply. The end-product can be used as a soil conditioner, or it can be co-composted with municipal solid waste, although the result is a poor-quality product.

Heat drying is used to dewater sludge, generally after mechanical dewatering; and the end-product is a soil conditioner. The specific techniques used include rotary drum dryers, rotary disc dryers, multiple-effect evaporation, and flash drying. Because of the capital costs and operating and maintenance costs, and the operating complexity of these systems, they are used primarily by large POTWs.

Land application refers to the surface application of dewatered sludge and the surface application or below surface injection of liquid sludge to agricultural or other land. Land application is limited by the possible detrimental effects of surface runoff, groundwater leachate, and odors. It is most suitable to small communities because of the large land areas required, but large cities have used the technique as well.

Sludge or sludge ash from combustion can be placed in landfills after sludge is preprocessed by stabilization, dewatering, or some form of chemical treatment to minimize environmental impacts. The freeze-thaw method of dewatering sludge raises by 20 percent the amount of solids after the freeze-thaw cycle; further drying raises the increase to over 50 percent. Such high concentrations are virtually impossible with mechanical dewatering equipment. This method is best suited to small and moderate-size communities in the northern tier of States.[1] Current problems with landfilling are the limitations of existing landfills and problems of siting new landfills.

Sludge can be incinerated and the heat from exhaust gases recovered to produce hot water or steam. Incineration exhaust gases can contain pollutants such as the oxides of nitrogen and sulfur, carbon monoxide, unburned hydrocarbons, and airborne particulates. The ash produced, about 20 to 40 percent of the volume of the sludge solids, may contain heavy metals. Its composition, including ash leachate and chemical characteristics, will determine the appropriate disposal technique, most likely landfilling. Sludge incineration can include co-combustion with processed municipal solid waste or fossil fuels, although this limits the volumes of sludge that can be disposed of and makes the incinerator ash more complex.

Although each technique has limitations for POTW sludge disposal, other methods of sludge disposal have undergone some testing, including:

- *Earthworm conversion*—This does not reduce volume, and the worm population is susceptible to injury from sludge ingredients, cold temperatures, and ammonia.
- *Fuel, made from sludge mixed with alkali and heated under pressure*—Laboratory tests have proven successful, but scale-up and commercialization have not occurred.
- *Oxyozosynthesis or pelletized sludge*—The existing batch process is low capacity.
- *Pyrolysis and gasification*—No full-scale systems exist.
- *Road aggregate production*—The reliability and marketability of large quantities of the product are unknown.
- *Wet-air sludge oxidation via a vertical-tube reactor process*—The commercial process exists, but no facilities are in operation.

[1]U.S. Environmental Protection Agency, "Innovations in Sludge Drying Beds—A Practical Technology," pamphlet, October, 1987; and S. Reed et al., "A Rational Method for Sludge Dewatering via Freezing," *Journal of the Water Pollution Control Federation*, vol. 58, September 1986, pp. 911-916.

been studied for several years, but have limitations, such as climatic effects, pest control, and anaerobic conditions.[88] Rapid infiltration land treatment uses specially constructed basins for draining partially treated wastewater that seeps through the earth, joins the groundwater, and eventually emerges in adjacent surface waters. In some systems treated water is directed to underdrains or storage basins for future use in irrigation.[89]

Wetlands can effectively remove or convert large quantities of pollutants, including organic matter,

[88]Kreissl, op. cit., footnote 86.

[89]U.S. Environmental Protection Agency, Center for Environmental Research Information, ***Design Manual for Land Treatment of Municipal Wastewater--Supplement on Rapid Infiltration and Overland Flow,*** EPA 625/1-8 l-013a (Cincinnati OH: October 1984).

Photo credit:American Consulting Engineers Council

Natural systems and wetlands can provide effective waste treatment for small systems or, as pictured here, drainage for stormwater overflows for larger immunities.

suspended solids, metals, and excess nutrients from point sources and nonpoint sources. Natural filtration, sedimentation, and other processes help clear the water of many pollutants. Some are physically or chemically immobilized and remain still until disturbed; decomposition breaks down other compounds into simpler substances. Research into wetlands for treating discharges from mining operations indicates the potential for successful treatment, with some limitations, especially during cold weather periods.[90] However, the mechanisms that modify and/or immobilize pollutants, especially toxic substances, in wetlands are poorly understood. No adequate design criteria have been established, and wetlands systems operate more like experiments.[91] No long-term operating data exist to confirm that manmade wetlands can continue to function reliably for long periods of time as natural wetlands have. Other disadvantages include the large land area requirements for treatment, the lack of understanding of important biological and hydrological process dynamics, and possible problems with pests.

Operations and Maintenance Technologies

EPA has developed an evaluation methodology for determiningg specific causes of inadequate POTW performance. The first step is a review and analysis of a POTW's design capabilities and administrative, operational, and maintenance practices[92] to determine if significant improvements in treatment can be achieved without major capital expenditures. Typical performance limiting factors are inadequacies in staffing, understanding of process adjustments, and maintenance programs.[93] The

[90] Thomas R. Wildeman and Leslie S. Laudon, "The Use of Wetlands for Treatment of Environmental Problems in Mining: Non-Coal Mining Operations," paper presented at the International Conference on Constructed Wetlands for Wastewater Treatment, Chattanooga TN, June 1988.

[91] Many small cities in the South use lagoons for sewage treatment. The addition of rock/reed filters creates an inexpensive system for wastewater treatment. Such falters are, however, subject to clogging. Jon Craig, chief for Wastewater Construction Grants, Oklahoma State Department of Health, personal communication, June 1990.

[92] U.S. Environmental Protection Agency, *Handbook: Improving POTW Performance Using the Composite Correction Program Approach (Cincinnati,* OH: October 1984).

[93] Ibid.

second step consists of implementing corrective measures to achieve desired effluent quality, and compliance with permit requirements. Environment Canada has successfully demonstrated an operational process audit technique that uses a microcomputer-based, real-time monitoring system with extensive instrumentation to analyze operational improvements.[94] This technique could be used as part of a correction program to obtain additional information.

Computerized control systems can be applied to wastewater treatment facilities in much the same manner as for drinking water treatment. (See discussion on operations and maintenance in water supply section.) Such systems can take undercapacity treatment units off-line and/or use them to equalize flow; they can also equalize flows to use off-peak electricity, recover waste heat, and monitor and optimize chemical dose rates. Expert systems, a branch of artificial intelligence, can be designed to provide assistance to POTW personnel charged with operating and maintaining complicated wastewater treatment processes. Prototype systems have been developed to diagnose problems associated with activated sludge treatment plant operations. Since studies have shown that treatment plants exhibit more problems due to faulty operation than any other cause, expert systems might prove useful in closing the gap between design capability and operational performance.

Planning and Management Tools

Reclaiming or reusing treated wastewater, primarily for nonpotable purposes, is not a new concept; water shortages caused by droughts, the rising costs of developing reliable water supplies, and modem wastewater treatment technologies are making reuse projects more economically attractive than ever.[95] California alone had nearly 400 nonpotable reuse projects by 1985;[96] Florida lists 188 recovered water reuse systems. Nonpotable uses include agricultural irrigation, industrial processing, and toilet flushing. To meet water quality requirements, reused water must be adequately disinfected and a chlorine residual must be present.[97]

Florida adopted a rule in 1988 that includes a mandatory reuse of reclaimed water in critical water supply problem areas.[98] The State's five water management districts will designate critical areas and will implement the program through their permitting program for recovered water. The State has developed comprehensive rules on water reuse, particularly for irrigation in public access areas, of residential property, and of edible crops. Specific requirements have been set for preapplication treatment, reliability, operation control, buffer zones, storage, cross-connection control, and other features. The driving force for water reuse in Florida has been effluent disposal rather than water shortage due to low stream flows. Applicants for surface water discharge permits must demonstrate that reuse of domestic reclaimed water is not economically or technologically feasible for them.[99]

Municipal Solid Waste[100]

Man has long used open dumps and landfills to dispose of solid waste, and early landfills were considered a way to fill in or "reclaim" land areas that were considered unusable otherwise.[101] By the 1970s, hydrogeological investigations showed that in many locations, harmful liquids were leaching through the soil into the groundwater supply, and the search for alternatives for municipal solid waste (MSW) disposal was on. Planning and constructing new landfills began to require extensive subsurface investigations to determine hydrogeological and geotechnical conditions that affect contaminant discharge from waste sites. However, landfill cri-

[94] Gordon Speirs, "Wastewater Treatment Plant Recess Audit," paper presented at the 1989 Municipal Wastewater Treatment Technology Forum, U.S. Environmental Protection Agency, Ann Arbor, MI, June 6-8, 1989.

[95] Daniel A. Okun, "Water Reuse in Developing Countries," paper presented at the Annual Conference of the Water Pollution Control Federation, San Francisco, CA, Oct. 17,1989.

[96] Okun, op. cit., footnote 16, p. 26.

[97] Ibid.

[98] Reclaimed water is water that has received at least secondary treatment and is reused after flowing out of a wastewater treatment plant.

[99] David W. York and James Crook, "Florida's Reuse Program: Paving the Way," paper presented at the 62d National Conference of the Water Pollution Control Federation, San Francisco, CA, Oct. 17, 1989.

[100] This section is based on U.S. Congress, Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Wrote,* OTA-O-424 (Washington, DC: US. Government Printing Office, October 1989).

[101] William L. Rathje, "Rubbish," *The Atlantic Monthly,* December 1989, p. 103.

teria promulgated in 1979 by EPA had little immediate effect on the practices at MSW sites, and almost 80 percent of MSW still ends up in landfills.

Disposal of MSW is primarily a local responsibility. However, new criteria, proposed in 1988 and now under revision, would extend Federal control over landfills and include regulations on location, facility design, operating criteria, groundwater monitoring, financial assurances, and postclosure responsibilities. According to EPA, most MSW landfills do not have equipment to monitor air, surface water, or groundwater for pollutants. As of November 1986, only about 35 percent monitored groundwater, 15 percent monitored surface water, 7 percent monitored methane gas, and 3 percent monitored other air emissions.

The majority of MSW landfills, 86 percent, are publicly owned, and most are small, receiving less than 30 tons per day. Privately owned landfills tend to have more capacity; one representative of private operators estimated that about 50 percent of total landfill capacity may be privately owned,[102] Perhaps because their larger size gives them economies of scale and because of more stringent State regulations promulgated in recent years, privately owned MSW landfills are more likely to have leachate collection systems, groundwater monitoring, and surface water monitoring.

Issues

EPA predicts that about one-third of all existing landfills will close by 1994, and that 80 percent of currently operating landfills will close in the next 25 years.[103] Many of these are old landfills that cannot meet the requirements of the Resource Conservation and Recovery Act. Few new, technologically advanced landfills have opened, accelerating the decline in capacity.[104]

However, raw data on landfill closings does not provide a complete picture. While landfill capacity in many States, such as New Jersey, Florida, Massachusetts, and New Hampshire, is running low, some States have expanded their landfill capacity.

Photoo credlt: Office of Technology Assessment

About 80 percent of municipal solid waste is disposed of in landfills, most of which do not have equipment to monitor air, surface water, or groundwater for pollutants.

Pennsylvania, for example, closed 13 MSW landfills in the last 2 years, but available capacity has actually grown from 4.2 years to 5.5 years, because the State permitted one very large, new facility to open and allowed two others to expand.

Regulatory Concerns

EPA has issued guidance on pollution controls considered to be “Best Available Control Technology." Although regulations regarding emissions were issued in late 1989, those regarding ash will not be issued until Congress clarifies whether or not ash will be managed as hazardous waste. In the absence of clear Federal guidance, several States have issued their own emissions and ash management guidelines and standards. A meeting of leading experts in incinerator technology organized by the U.S. Conference of Mayors endorsed recycling and waste reduction and found that technologies exist today to control pollutants from incinerators to levels of risk

lo%. Prindiville, personal communication, November 1988, as reported in Office of Technology Assessment, Op. cit., footnote 100.

103Most environmentally sound landfills are designed with a lifespan of about 10 years. At any given moment, one-half of these landfills will be full in 5 years.

104Howard Levenson, senior associate, Office of Technology Assessment, personal communication, Dee. 7, 1989. In addition, finding new sites for new landfills is a major problem, particularly in Northeastern States.

below regulatory concern.[105] Mercury and chromium, however, remain vexing problems in emissions and in incinerator ash.

Recognizing the limitations of current knowledge, EPA is coordinating with industry, States, and universities to develop a research and development R&D) agenda. Study areas are likely to include emerging commercial technologies, appropriate MSW incinerator operating conditions and emissions control technology, ash management, landfill design and operation, siting and monitoring methods, recycling techniques, and toxic products substitutes.[106]

Institutional Concerns

About 10 percent of U.S. solid waste is recycled, and most observers believe more MSW could be recycled. The major roadblocks are not technologies, although some technical refinements could provide measurable increases. EPA is promoting a national recycling goal of 25 percent by the year 1992, although the goal does not appear to be based on a quantitative evaluation of the market potential of individual MSW components. Some components, such as office paper and aluminum, are "supply-limited," that is, they are not collected in sufficient amounts or are too highly contaminated for current manufacturing processes. Others, such as used oil and newspapers, are "demand-limited," because markets for them are insufficient, even though supplies may be available. These distinctions are not constant and may change due to many factors.

Pricing is the other serious market consideration, one made complex by fluctuations in markets for recycled products. Increased public sector collection of recycled materials provides a supply of materials that is not sensitive to demand. Municipal collectors can even afford to pay manufacturers to take materials, if doing so is less expensive than disposal. This means that private sector suppliers may have difficulty marketing their recycled goods, which would drive down profits and reduce the employment and tax revenue they generate. Municipalities must thus consider their recycling policies and programs carefully.

Although MSW is primarily a local responsibility, States have begun promoting incentives for multicommunity facilities or for nonlandfill waste disposal, and some States are providing financial assistance to communities. Maryland's Solid Waste Facilities Loan Program provides loans to local governments to improve environmental and human health aspects of their solid waste programs. Since 1983, over $1.4 million has been obligated for loans from State general obligation bonds.

Minnesota established the Solid Waste Processing Facilities Capital Assistance Program in 1980 to assist counties in moving from landfills to recycling and resource recovery for solid waste. Priority is given to programs developed under joint powers agreement between counties. Grants totaling $20.2 million have been awarded from the General Fund since 1980. Minnesota also established the Waste Management Board in 1980 as an independent agency of the State. Its purpose is to provide technical, financial, and planning assistance for solid and hazardous waste management to communities and technical assistance to industry in recycling, resource recovery, and hazardous waste management. The Legislative Commission of Waste Management provides oversight of the board's grantmaking and advocacy to facilitate waste management.

MSW Technologies

MSW technologies include landfill liner materials, collection and treatment of leachate, monitoring and controlling landfill gas and other potential contaminants, comporting and other processing equipment, and techniques and equipment for better subsurface analysis.[107]

Landfill Liners

Liners are used at the bottom of a landfill to prevent or reduce migration of leachate (liquids that percolate through the landfill carrying contaminants) into groundwater beneath the site or away

[105] Water Schaub, U.S. Conference of Mayors, personal communication, Oct. 13, 1989. Regulatory concern relates to a one-in-a-million chance of a person over a lifetime developing a health problem linked to an incinerator.

[106] U.S. Environmental Protection Agency, office of Solid Waste, *The Solid Waste Dilemma: An Agenda for Action* (Washington, DC: February 1989), p. 31.

[107] Jeffrey Clunie and R.W. Beck& Associates, *The Nation's Public Works: Report on Solid Waste* (Washington, DC: National Council on Public Works Improvement, May 1987), p. 49.

from it laterally. About 66 percent of U.S. landfills use a soil liner such as clay. Many of these, however, were not constructed using sound soil engineering techniques (compacting and remolding). A soil or clay liner can use compacted and uncompacted soil to absorb the chemicals leached into them. However, certain chemicals, xylene or carbon tetrachloride, for example, dehydrate the soil, causing water to migrate downward. The dehydrated soil may crack, forming pathways for liquids to leach into deeper soil.

Presently, only 1 percent of landfills use synthetic membrane liners, and only 6 percent of planned landfills will use them. Other less common liners include paving asphalt, sprayed liners of liquid rubber, and soil sealants. Synthetic membrane liners are typically made of rubber, polyvinyl chloride, or various polyethylene. Most synthetic liners are virtually impermeable to water; their permeability to other chemicals varies.[108] Data suggest that the toughest liner is made of high-density polyethylene, though some experiments show it was easily permeated by trichloroethylene. The lack of definitive data indicates that additional research is needed on the frequency with which synthetic liners are actually exposed to high concentrations of volatile organic chemicals and on long-term performance of the liners under these conditions.

The effectiveness of synthetic liners also depends on how well the seams of the different liner segments are joined together. The chemical compatibility of liner materials is critical in determiningg bond strength, and liner manufacturers' recommendations on compatible materials must be followed to assure proper bonding. Composite liners, or engineered soil overlain with a synthetic flexible membrane, combine the best qualities of both types by being nearly impervious to most leachate while providing an absorbent layer should the synthetic liner rupture.

Covers

During the useful life of a landfill, some type of cover, usually about 6 inches of compacted earth, is applied on a daily basis to control against mosquitoes and vermin, prevent odors and fires, and discourage scavenging. Proposed EPA regulations would require this.[109] When a landfill is closed, it is covered to reduce water infiltration. Unlike daily cover, the final cover needs to be of an easily compacted soil type and should be sloped to increase runoff and reduce infiltration. EPA estimated that almost all active and planned units have or will have some type of earth cover of soil, sand, or clay, but only about 2 percent have or will have a synthetic membrane cover.

Although for the most part, MSW is placed below ground level, the concept of confining waste above ground was developed for hazardous waste. If a sloped, above-ground storage mound is used, complete with liners and requisite drainage and gas collection equipment, simple gravity will aid in a more reliable leachate control system, and leaks can be found more easily before they contaminate groundwater.

Leachate Collection and Removal Systems

Leachate collection and removal involves placing a series of perforated collection pipes in drainage layers filled with sand or gravel, or above the liner, to collect leachate. If the landfill is designed with a slope, leachate will drain into a central collection point. The collected leachate can be recirculated back into the landfill, but in most cases it is trucked to a municipal sewage treatment plant or sewer, discharged to a treatment plant through a sewer, or treated onsite with biological treatment processes. However, only 11 percent of existing landfills use leachate control systems, and available data do not allow a determination of how much leachate is collected.

Gas Production, Collection, and Use

Gas produced by decomposition in landfills is primarily equal parts methane and carbon dioxide, with a few trace organic chemicals. Landfill gas can be allowed to escape into the atmosphere through vents, or it can be "flared" or burned as it leaves collection pipes. More expensive and complicated pumping and collection systems are used only when a landfill has been at least partially closed and a cap

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[108] Permeability is one performance measure of a liner. One measure of the rate at which leachate permeates a liner is in centimeters per second. A clay liner is relatively permeable, allowing water to seep through it at 1 millionth to 10 millionths of a centimeter per second. Synthetic liners resist seepage and pass water much more slowly—between 100 millionths and 10 trillionths of a centimeter per second. While clay liners are more porous, they do have the ability to absorb and hold organic chemicals.

[109] Currently, 45 States require that cover be applied daily. The Environmental Protection Agency's proposed landfill regulations also would require the application of daily cover. 53 *Federal Register 33314* (Aug. 30, 1988).

installed. Active pumping systems are the most effective means for collecting landfill gas and can recover from 60 to 90 percent of methane produced.

While over 1,500 MSW landfills use venting, flaring, or collection and recovery of methane, only 123 landfills collect methane for energy recovery. Wells are dug into landfills or adjacent soil, and pipes are laid to collect the landfill gas. Contaminants, such as carbon dioxide, are removed, and the methane is injected into natural gas systems pipelines and can fuel an internal-combustion engine or gas turbine that generates electricity for general use.[110] If all methane emissions were collected and processed for energy recovery, the energy recovery potential would amount to 5 percent of all natural gas consumption or 1 percent of all energy demand in the United States.

Enhancing Degradation Rates

Landfills for waste disposal are based on the premise that what is buried will eventually decompose. Core samples taken recently from various landfills indicate that all kinds of waste can remain virtually intact even after 50 years; buried newspapers were used to verify the dates. Thus even biodegradable wastes decompose much differently and more slowly than expected.[111] Appropriate landfill design requires additional research on subjects such as the conditions under which different components degrade, how rapidly they degrade, whether degradable plastics would have much effect on landfill capacity, and what environmental problems they might create.

The idea of recycling leachate to enhance degradation has been examined in the laboratory, and several MSW landfills in the United States are using this technology in some way. The potential benefits of this system include reducing decomposition time from 15 to 20 years to only a few years, increased methane production, and reduced amounts of leachate to dispose of or treat. However, current EPA regulatory proposals would ban addition of any liquid to landfills, and careful controls to prevent offsite migration would be essential.

Incineration Technologies

Three basic types of incinerators are used today: mass bum, refuse derived fuel, and modular. Mass bum facilities are designed to bum unsorted MSW, and require only a small amount of handling of MSW. They generally have only one combustion chamber, and they operate using more air than would be needed to complete combustion if the fuel could be uniformly burned. Some incorporate combustion grates that vibrate, reciprocate, or pulsate to agitate MSW for better combustion.

Refuse derived fuel (RDF) facilities process or separate MSW mechanically before burning. The separation can be done at curbside or at a central processing center. The remaining waste is shredded and sometimes mixed with other fuel, such as oil, and injected into the combustion chamber. Waste coming into these plants is sometimes compacted under pressure for easier handling and burning. Many mass burn and RDF facilities are designed to recover energy, which can be used or sold; these are known as waste-to-energy facilities.[112]

Modular facilities are small and often factory fabricated for disposing of manufacturing-related byproducts. A ram is used to advance MSW through a two-combustion-chamber arrangement. The first chamber has a ‘‘starved” or oxygen deprived condition and the second chamber is oxygen rich to promote burning of uncombusted gases. This type of facility uses unsorted MSW, and its units are smaller than those for mass bum facilities and thus better for small communities. Disadvantages include incomplete burning and generally low efficiency for energy recovery.

Every incinerator must shut down periodically for maintenance. Mass bum incinerator manufacturers claim 85 percent reliability. Early RDF facilities had mechanical problems that caused frequent shutdowns, but recent changes in design have improved their reliability considerably. Occasional combustion "upsets," or temporary changes in combustion quality caused by changes in MSW composition, sometimes cause shutdowns. Air supply adjustments controlled by computer monitoring systems

[110] Philip R. O'Leary et al., "Managing Solid Waste," *Scientific American*, vol. 2S9, No. 6, December 1988, p, 42.

[111] W.L. Rathje et al., "Source Reduction and Landfill Mytbs,' paper presented at NASSWMO National Solid Waste Forum unintegrated Municipal Solid Waste Management, Lake Buena Vista, PL, July 17-20, 1988.

[112] Energy recovery facilities were given a boost by the Public Utilities Regulatory Policies Act of 1978, which requires power companies to buy electricity generated from an incinerator at a price equal to what it would cost the company to generate the same power.

can help avoid these problems. Although most new facilities utilize computer monitoring technologies, mass burn facilities remain simpler and more reliable than RDF units.

Several other incineration technologies are in current use generally in small commercial settings. Fluidized bed combustion is a process in which burning waste is entrained with very hot particles of sand in an upward flow of turbulent air. Both "bubbling," where material stays at the bottom of the furnace, and 'circulating' designs, where waste is allowed to move upward and then returned to the bed for further combustion, are utilized.

Pyrolysis is heating the MSW in the absence of oxygen. It produces a solid residue, which must be managed, and liquid tar and gas, which can be used as fuels. Although pyrolysis plants are operated in some European countries and Japan, U.S. experience is limited.

Controlling Air Emissions

The major types of flue gas pollutants generated by MSW incinerators are: carbon monoxide, particulate matter, nitrogen oxides (NOx), chlorinated hydrocarbons (e.g., dioxins), acid gases (e.g., hydrogen chloride), and metals such as lead and mercury. Problem emissions result from incomplete combustion and combustion temperatures that are either too high or too low.

Three basic technologies are commonly used for controlling incinerator emissions: 1) preseparation of materials from MSW before combustion, 2) destruction of harmful elements during combustion, and 3) removal of pollutants from flue gases by control equipment after combustion. The effectiveness of each of these approaches varies for each of the different categories of air emissions. Preseparation effects are hard to measure. Removing a hazardous material before it gets to the incinerator will prevent it from creating a harmful emission, but its ultimate disposal may be equally dangerous. Limited data show that preseparation has little effect on the production of dioxins/furans. However, at some older facilities, presorting for certain materials, such as aluminum, iron, glass/grit, and auto batteries, has reduced hydrocarbon emissions.

Metals in flue gas and ash can be reduced as much as 25 percent by sorting out certain items such as car batteries. Presorting can increase the combustion temperature (because of a more uniform fuel), lower ash content by about one-half, and decrease carbon monoxide emissions by a factor of two to three. Removing yard wastes from incinerator input can significantly reduce NOx emissions.

Combustion management using computer controls can yield improvements by regulating heat and MSW flow. Sensors monitor combustion temperature, output emissions, and adjust MSW flow to promote complete burning.

Three combustion and postcombustion controls are used to manage NOx emissions. Combustion improvements can be achieved through better grate and furnace design and flue gas recirculation. Selective catalytic reduction, which involves injecting ammonia into flue gases to preclude formation of NOx, can reduce emissions. A proprietary noncatalytic process, Thermal DeNOx,[113] involves the injection of ammonia into the upper furnace where it reacts to produce nitrogen and water. Three U.S. facilities are currently using this technology, and reductions in NOx emissions have been as high as 45 percent.

Postcombustion gases are controlled by devices called scrubbers. These devices fall into two categories and several types. The first category applies to postboiler scrubbers and includes wet, or "quench," scrubbers; dry scrubbers; and spray dry scrubbers. The second category includes dry injection scrubbers used in a preboiler location. In the mid-1980s, because of increased concern for the impact of acid gases on the environment, many new facilities were constructed with acid gas scrubbers.[114]

Wet scrubbers add alkaline absorbents in the boiler, which react with exhaust emissions to form salts, which are then landfilled. Although capable of removing most of the pollutants, wet scrubbers use large amounts of water, which must be treated before disposal. Dry scrubbers spray a solid alkaline powder into the flue gas to react with exhaust emissions. Because dry scrubbers use no water, they avoid water pollution and some corrosion problems. However, they do increase both the capital and

[113] This is a trade name.

[114] Clunie and R.W. Beck & Associates, op. cit., footnote 107, p. 46.

operating costs of waste-to-energy facilities by as much as $5 to $10 per ton.[115]

Other systems inject a solid dry absorbent directly into the boiler or onto original MSW prior to the production of flue gases; lower flue gas temperatures to as low as 40 degrees C to condense acid gases, organics, and volatile metals; or spray an atomized slurry into the flue gases and collect the dry particulates after the water in the slurry evaporates.

The majority of volatilized metals are caught in scrubbers. Metals are condensed onto fly ash particles, which are then picked up by the scrubbers. Low flue temperature has been found to be critical in this process. For example, below 285 degrees F up to 99 percent of cadmium is removed, and a 53 percent reduction of copper was achieved with flue temperatures of between 230 to 260 degrees F.

Precipitators and fabric containers called "baghouses" are commonly used to control particulate emissions from incinerators. Electrostatic precipitators (ESPs), located in the exhaust area of the facility, electronically charge particles and then pass them between parallel plates of opposite charge, drawing the particles to the plates. The plates are unloaded periodically and the residue landfilled. Multiple "fields" of plates can be used to increase efficiency, and ESPs work best when plates are large and gas flow is relatively slow. Efficiency has been shown to be as high as 99.7 percent.

Fabric/bag filters are installed over incinerator exhaust outlets to trap particulate matter in the flue gases. The bags are designed to "cake up" with particulate, adding to their efficiency. A combination of fabric filters and a scrubber has proven to be the most effective at controlling emissions. The scrubber reduces acid gases (which degrade the bag filters), reduces "blinding" the bag filters by sticky particles, and cools the exhaust gases.

Cooling flue gases before they reach pollution controls will condense most dioxin and furans into fly ash particles, which can then be controlled by scrubbers. The combination of scrubbers and fabric filters has been shown to remove 97 to 99 percent of total dioxins in postcombustion flue gases, and most new facilities have these controls.

Incinerator Ash

Incinerators produce both bottom ash and fly ash, the light particles that are carried off the grate by turbulence or that condense and form in the flue gas in the boiler section. Each year the United States generates 2.8 to 5.5 million tons of ash, or 25 to 35 percent by weight and 5 to 15 percent by volume of the original MSW.

Over 50 percent of fly and bottom ash is estimated to be disposed together with MSW in landfills, where rainwater can leach out toxic chemicals from the ash, including metallic compounds and acids. The toxicity of incinerator ash can be predicted through laboratory tests,[116] and ash residues can be treated chemically or thermally to decrease the likelihood of leaching.

Untreated ash can be stabilized or solidified and then used in road or artificial reef construction, construction blocks, and landfill cover, for example. Questions about the long-term effects of reused ash hinder more extensive use, however.

Reduction Tech Techniques[117]

Waste reduction techniques focus on reducing the amount and toxicity of materials before they become waste, to lower the demand for capacity increases and requirements for technologies. Fewer toxics in MSW would reduce the amounts and types of chemicals in landfills that create toxic air emissions and toxic leachate. Packaging accounts for 30 percent of the weight of all solid waste, paper products make up over 40 percent, and yard wastes comprise another 20 percent, making all of them candidates for waste reduction.

Toxicity Reduction

Toxics are found in many household products that end up as MSW. In fact, household maintenance and cleaning products are estimated to make up almost one-half of the household hazardous waste discarded from residences. Lead, cadmium, and mercury are used as coatings-in light bulbs, in cables and electrical products, and in batteries. Such items are major contributors to the residues of these chemicals in MSW. Identifying substances in MSW that pose the greatest risks to humans and removing or

[115] Ibid., p. 47.

[116] Office of Technology Assessment, op. cit., footnote 100, p. 251.

[117] This section is based on ibid., ch. 4, "MSW Prevention."

substantially reducing them from products that enter the waste stream is an effective way to reduce toxicity.

Many organic chemicals are used, often intentionally, in common consumer products. Examples include formaldehyde in particle board, toluene in inks, chlorobenzene in cleaners, and methylene chloride in spray propellants. Industry has successfully reformulated a number of products to reduce or eliminate hazardous components. The substitution of chloroflourocaxbons (CFCs) with hydrocarbons as a propellant in aerosol spray cans after a ban on CFCs by EPA and the Food and Drug Administration in 1978 and the substitution of titanium and zinc pigments for lead in exterior house paints are examples. However, reformulating products is time-consuming and costly; R&D leading to approval of one new pesticide can take 10 to 15 years and cost up to $10 million.

Studies have shown that consumers favor buying products that pose fewer potential risks when discarded and that providing information on the toxicity content of a product will affect purchasing decisions. Making such information available is one way public officials can affect the amount of toxic substances in the waste stream and reduce costs of MSW disposal.

Recycling[118]

Recycling is another method of reducing waste management costs, increasing landfill capacity, and reducing incinerator emissions. MSW recycling is carried out principally by private entrepreneurs in the scrap industries, nonprofit groups, and scavengers. Municipalities, however, usually initiate curbside collection programs, drop-off centers, and buy-back centers. The preparation of collected materials involves both manual and automated methods and takes place at central facilities, commonly referred to as material recovery facilities.

The type of equipment used depends on the type of MSW that is being handled: mixed waste, commingled, or separated. Mixed waste facilities separate recyclable from other waste that is then landfilled or incinerated. In some areas, several types of recyclable (e.g., glass, aluminum, and paper) are collected together and later separated. This commingled waste is easier to manage than mixed waste, because items that could pose a hazard, such as disposable razors or diapers are excluded. However, a different collection system than for the rest of MSW is needed, and the program depends on public participation. Even items separated at curbside need some preparation to meet the needs of commercial buyers. Equipment may include scales, conveyors, and balers, as well as other processes for separating different types of materials that are collected together.

Technical Difficu!ties in Recycling

Paper and paperboard waste represent 41 percent of total MSW discard, and estimates indicate a 22 to 28 percent recovery rate. Some short-term opportunities exist to increase recycling paper and paperboard, but technical and capacity barriers may preclude dramatic increases. Since most high-quality waste paper is already collected, additional supplies from new sources and de-inking of lesser quality waste will be more costly. Contaminants in recycled waste paper limit its use in making newsprint, and consumer preference limits increased use of recycled paperboard.

Glass recycling rates are in the neighborhood of 10 percent. Presently, because of chemical differences, certain types of glass, such as flat glass, safety glass, pressed and blown glass, optical glass, and industrial glass, cannot be manufactured with recycled waste glass (known as cullet). The largest use of virgin materials, primarily silica sand, is for containers, accounting for 68 percent of U.S. silica sand production in 1986. While cullet is 100 percent recyclable, color separation processes are not as efficient and limit its use. Technologies have yet to be developed to reprocess non-color-sorted glass.

Less than 200 million pounds of postconsumer plastic discards (less than 1 percent of the amount in MSW) were recycled in 1986. Plastics are resilient materials not easily crushed; thus, plastic bottles take up more space on a collection truck than other MSW components, making household collection difficult.

The large variety of plastics in MSW poses other problems. Presently, only containers made from two types of plastic (high-density polyethylene and polyethylene tetraphalate) are being recycled in substantial amounts, because these containers are

118 This section is based on ibid., ch. 5, "Recycling."

not degraded significantly by processing. The Food and Drug Administration restricts the use of recycled plastic in food packaging because of the risk of contaminants migrating into the food.

Finally, the presence of contaminants and the effects of natural degradation processes affect plastics recycling. Separating plastics from paper, metals, adhesives, pigments, and dirt is necessary but difficult. While proven separation technologies are commercially available, automated separation techniques (primarily based on differences in density) do not work well for complex mixtures of products containing many types of plastics. The performance of recycled resins is not as good as that of virgin materials, and since reprocessing accelerates the degradation process, durability and dimensional stability are reduced.

Hazardous Waste[119]

Public works officials must comply with EPA's hazardous waste regulations. The most effective way to minimize the risks associated with hazardous wastes would be to reduce the production of the materials and the wastes. Once hazardous wastes are generated, they must be managed by one of two broad categories of technologies: 1) treatment by one or more steps to reduce the hazard level of the waste, or 2) disposal through containment or dispersal on land or in the oceans.[120] Treatment technologies reduce the hazard level directly or facilitate reduction in other steps by changing the physical or chemical nature of the waste, by separating waste constituents, or by reducing the concentration of hazardous substances in the waste. The treatment technologies include chemical, thermal, and biological treatments.

Containment technologies, such as landfills, surface impoundments, and underground injection wells, hold waste in a manner that inhibits release of hazardous components into the environment or keeps releases to acceptable levels. With most centainment options, releases are likely to occur at some time. Some surface impoundments are designed, in fact, to transfer material to the ground. Dispersal techniques, such as land treatment (spreading waste on the land) or ocean dumping, rely on naturally occurring processes to reduce the hazard level of waste constituents, or to transport them into and through the environment thereby diluting concentration to acceptable levels, or both. Some geographical locations are considered good sites for land disposal facilities because their hydrogeological characteristics make releases unlikely and because the probability that people or sensitive elements of the environment would be exposed to releases is extremely low.

The feasibility and appropriateness of a management technology for a specific waste depends on many factors, including the characteristics of the waste and the environmental features of the facility site. Regulatory requirements and the goals and economic calculations of waste generators and handlers will also influence technology choices.

Waste type is an important determinant in choosing treatment technology; for example, some wastes are incompatible with a specific technology because they would damage the equipment. Well-established chemical and physical treatments are available for wastes characterized as hazardous because of their reactivity, corrosiveness, and ignitability. However, the choices are not clear for a waste for which toxicity is the major hazardous characteristic. Toxic constituents may be organic, inorganic, or metallic, and many technologies could be used. The major issue is whether to use a treatment or containment approach; treatment is preferable in most cases, if it is technically feasible.

In general, the kinds of waste most suitable for land-based containment are residuals from treatment operations, pretreated or stabilized waste, untreatable waste, and relatively low-hazard waste. However, some untreatable wastes, such as polychlorinated biphenyls (PCBs), are so highly toxic that land disposal is unacceptable, and waste elimination is the only feasible alternative.

Technology Alternatives

The goal for a hazardous waste treatment and disposal technology is to reduce the probability of release of hazardous constituents, but no technology can eliminate this probability entirely, because

[119] This section is based on several OTA publications—*Technologies* and *Management Strategies for Hazardous Waste Control,* summary, OTA-M-197 *(Washington DC:* March 1983); *Superfund Strategy, summary,* OTA-ITE-253 *(Washington DC:* March 1985); and Serious *Reduction of Hazardous Waste, summary,* OTA-ITE-318 (Washington, *DC:* September 1986).

[120] Office of Technology Assessment, Technologies *and Management Strategies for Hazardous Waste Control*, op. Cit., footnote 119, pp. 19-20.

toxics in waste usually affect more than one medium. For example, high-temperature incinerators destroy most of the toxins in waste, but some air pollution may occur, and the incinerator ash must be disposed of. Chemical treatment, such as dechlorination, detoxifies the waste itself, but may produce some residue requiring additional treatment or disposal. Treatment efficiencies, such as degree of destruction, degree of containment, degree of stabilization, and reliability, also differ. Emerging thermal, physical, and chemical treatment technologies offer the potential for preventing emissions of hazardous constituents, providing resource recovery, and reducing toxicity.[121]

EPA has emphasized cleanup for control of hazardous substances.[122] Resource Conservation and Recovery Act (RCRA) regulations emphasize keeping landfill costs low by not requiring comprehensive, stringent monitoring at landfills, or retrofitting of existing, active landfills. The agency has exempted from some of the new regulations portions of existing landfills that do not yet contain wastes, has limited postclosure monitoring requirements to 30 years, and has not required locating waste management facilities so as to protect drinking water sources. The Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) is aimed at the cleanup of uncontrolled hazardous waste sites abandoned by industry and municipalities; in many cases there were no formal mechanisms or funds to respond to the hazardous spills and leaks at these sites.

Reducing Hazardous Wastes

Because many hazardous wastes cannot be destroyed by known pollution control methods, reducing the production of hazardous wastes brings higher benefits to environmental protection and public health. Source segregation or separation, widely used in industry, is usually the easiest and cheapest way to reduce wastes before they require management by communities as hazardous waste. The basic principle is to keep waste in concentrated, isolated forms rather than to produce large amounts of indiscriminate mixtures that must be separated later.

End-product substitution may bring long-term benefits if the substitute product is adopted in many industrial sectors and markets. Changing only one product or application is likely to have a relatively small effect on hazardous waste generation. Moreover, waste reduction is likely to be a secondary benefit of such changes, since product performance improvements are the main driving forces. However, as hazardous waste management becomes more expensive and costs are passed on to consumers, public awareness of the amount of hazardous waste in products may contribute more to end-product substitutions.

Monitoring Strategies and Technologies

Monitoring is essential to environmental protection and public health to establish baseline data and data for setting regulatory standards, verifying compliance with regulations, helping identify R&D priorities, and assessing contamination. Surveillance monitoring can verify compliance with regulatory requirements and provide limited data about changes in environmental quality. Assessment monitoring helps determine the extent of deterioration in environmental quality and provides data that indicate cause-effect relationships for specific hazards. Sampling procedures, data comparability, and limitations in available analytical methodologies must be developed for both types of monitoring. Difficult choices are necessary about the location and number of sampling sites and the frequency with which the samples are taken.

Even though monitoring is essential to controlling risks, RCRA regulations call for only limited monitoring activities for incinerators and land disposal facilities. Such an approach can lead to delays in detecting releases of harmful contaminants.

Treatment

Although industry and Federal officials are more likely to use them than local public works officials, several innovative technologies to deal with serious hazardous waste sites are on the horizon. A new process, known as in-situ radio frequency heating, has been developed to decontaminate soil tainted with volatile or semivolatile waste. This process

[121] Ocean disposal appears to be technically feasible, but adequate scientific information is unavailable for deciding what the appropriate locations are for specific wastes. Ibid., p. 20.

[122] The Resource Conservation and Recovery Act Of 1975 (R_) regulates the management and disposal of newly created industrial hazardous waste. The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 finances the cleanup of waste spills and the uncontrolled disposal sites of past industrial practices.

uses microwave technology to heat contaminated soil from 200 to 1,000 degrees F, incinerating the toxins. Up to 5,000 tons can rehandled at a time, and preliminary tests show costs to be 60 percent less than for other types of thermal incineration.[123]

An electrochemical oxidation process is being developed and tested at the United Kingdom's Atomic Energy Authority. The technique converts PCBs, pesticides, and other hazardous materials to carbon dioxide and water through feeding a solution or slurry of the chemical into an electrochemical cell. The rapid oxidation in the chamber is achieved at atmospheric pressure and with temperatures at or below 100 degrees C. It may also be possible to dispose of CFCs with this process.[124]

Issues and Concerns

Public perceptions of environmental risks are shaped almost entirely by the common understanding of health and environmental effects from past management practices and failures. Risks and potential damages-the direct harmful effects of pollution and contamination, as well as indirect effects, such as losses in property values-are borne largely by local communities. Although the public calls for better management, citizens also frequently oppose the siting of specific environmental public works facilities, such as waste treatment plants.

Coping With an Anxious Public

Public works officials can build public confidence and expand understanding of the risks involved by: 1) improving the quality of information dissemination to the public to better describe facility needs, uses, characteristics, and risks; 2) using decision processes based on sound technical criteria to ensure that specific technologies and locations have been chosen to reduce present and future risks as well as to satisfy waste generator and management needs; and 3) increasing efforts to promote demand management, conservation, and alternatives such as source reduction and recycling. Although both technical and institutional approaches can be used to address public concerns, a combination of nontechnical and institutional approaches, especially at the State and local level, may be more effective. Siting concerns can never be completely eliminated, but they may be resolvable through compromise.

Small Systems

Small systems are modest undertakings; a system serving **5,000** persons is likely to have limited budgets, yet must meet the same regulations as larger systems with greater economic capability. Small systems cannot benefit from economies of scale as do larger systems; certain processes and functions-for example, maintaining a chlorinator—in water treatment must be provided regardless of the number of connections.[125] Lacking sufficient technical and financial resources, many small system operators have had to defer capital outlays, and cannot meet the investment required for growth and system upgrading. The amount of capital they can access is limited and their financing costs are relatively high. Finally, the sheer number of small water systems, which are the most likely type of public services to be private sector operations, and what has been steady growth in that number, complicate the task of State agencies charged with regulating this industry. In many States, small systems find it difficult to retain employees with the skills necessary to deal effectively with new standards, with operating problems associated with decaying infrastructure, with expansion requirements, with fair and equitable rate-setting practices, or with some types of financing problems. (See box 4-E for information about the circuit rider program to assist small systems operations.)

State legislatures can adopt clear statutory authority for State regulatory agencies to deny appropriations and operating permits to new systems unless they comply with minimum design, operating, and construction standards and undergo financial, operational, and management evaluations.[126] Washington State initiated the first nationally known program for controlling potentially nonviable small systems. Connecticut has authority to require proposed sys-

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[123] "Weston to Microwave Toxics," *Engineering News Record,* vol. *222, No. 25,* June *22, 1989,* pp. 17-18.

[124] Dermot O'Sullivan, "Electrolytic Oxidation Destroys Toxic Wastes,'" *Chemical and Engineering News,* vol. 67, No. 24, June 12, 1989, p. 27.

[125] Robert M. Clark, "Package Plants: A Cost-Effective Solution to Small Water Systems Treatment Needs," *Journal of the American Water Works Association,* January 1981, pp. 24-30.

[126] John J. Boland and Daniel Serrs, The Johns Hopkins University, "Improving the Management of Community Water Systems: Survey and Recommendations," prepared for the Maryland Department of State Planning, February 1988.

Box 4-E--Circuit Riders: Helping America's Rural Water Operators

More than 55,000 water treatment systems in the United States serve populations under 10,000 persons. Small communities often cannot afford an experienced highly trained, full-time public works engineer. To assist such systems, most of them rural, nearly every State has a visiting engineer who can provide advice, trouble-shoot problems, and ensure proper operation and compliance with Federal and State regulations. These engineers, or circuit riders, as they are called traditionally provided technical support in emergencies; however, now they also provide financial and management guidance, technical training, and technology transfer.

In 1980, the Farmers Home Administration (FmHA) began funding a comprehensive national program for circuit riders,[1] expanding an existing program of 16 circuit riders in 22 to 24 States. By 1989 there were circuit riders working in all the contiguous 48 States. Most States have one circuit rider, five States, Arkansas, Texas, Oklahoma, Louisiana and Mississippi have two. Some small States, especially in the Northeast, share circuit riders. FmHA provided $2.8 million in fiscal year 1989 to the National Rural Water Association (NRWA) which, in turn, has agreements with its State affiliates to provide the State circuit riders. The appropriation for fiscal year 1991 is $3.25 million. A State circuit rider office is not large, usually consisting of the circuit rider, a program manager, and a secretary. In some cases, U.S. Environmental Protection Agency and State environmental agency money helps supplement State office costs.

FmHA regulations require at least 35 half-day site visits per month, and a typical circuit rider will spend around 20 days per month on the road. Newer circuit riders may make as many as 70 visits a month to meet as many operators as possible and demonstrate their utility to those unfamiliar with the service. The program is attractive for young engineers, and experienced circuit riders are actively recruited by larger urban systems that can provide higher salaries.[2]

The services provided by circuit riders are free, and any small water system serving under 10,000 persons can request a visit, although priority is given to water systems with outstanding FmHA loans. Assistance can be requested by calling the State NRWA office or through the State environmental agency. Circuit riders are on call 24 hours every day, and the hard work and long hours cause high turnover.

South Dakota has an active rural water program that supported a State circuit rider before the NRWA'S program.[3] The State's Rural Water Office is staffed by six full-time employees, including a program manager and a circuit rider, paid by NRWA. The South Dakota Rural Water Association (SDRWA) supports staff for lobbying, group insurance, and extra training services for managers, operators, and clerical workers. Technical training courses in subjects such as electricity and chemistry frequently are contracted to area vocational/technical schools and paid for through State membership dues, and SDRWA also provides onsite technical training.

In the last several years, South Dakota has constructed many new, technically complex, regional water systems, which provide piped water to towns, homesteads, and farms in up to seven counties. Because many of the State's system operators are still uncertified, SDRWA is working with the State environmental agency to improve the skills of these rural operators so that they can be certified

[1] The Farmers Home Administration is a credit source for eligible rural communities for various kinds of projects, including water supply and wastewater treatment, which together account for about 50 percent of loans and 55 percent of grants. Congress appropriated $440 million for water and wastewater projects in fiscal year 1989.

[2] Larry Bowman, project officer, Farmers Home Administration, personal communication, Sept. 28, 1989.

[3] Denis Davis, executive director, Rural Water Association, South Dakota, personal communication, Oct. 2, 1989.

terns to interconnect with an existing system, if feasible.[127]

States can also support regionalization, consolidation, and satellite systems, in which a large system agrees to assume ownership, management, or operation of a small system. However, small systems have successfully blocked consolidation efforts,[128] and EPA has the legal authority to exempt small systems from the SDWA provisions, if the exemption does not pose an unreasonable health risk. The program

[127] ***U.S. Environmental Protection*** Agency, ***Ensuring the Viability of New, Small Drinking Water Systems: A Study of State Systems, EPA Report 570/9-89-004*** (Washington, DC: April 1989).

[128] Suffolk County, Long Island, NY residents believed that improved water service would generate unwanted development and blocked efforts to consolidate their system with others. Cirola, op. cit., footnote 44.

has never been an active one and EPA is currently preparing a new set of procedures for it.[129]

Small systems also need information about low-cost, simple wastewater treatment technology. While alternative systems for application in small communities are available,[130] they are not widely used. Conventional collection systems often represent more than 80 percent of the capital cost for the wastewater system in small and rural communities[131] and are rarely cost-effective.[132] Communities find that available funds are quickly consumed for operations and maintenance expenses, and some are considering deliberate noncompliance because they are unable to meet the requirements of their discharge permits.

Financing and Management

Consumer demands and stricter Federal and State regulations have raised costs of environmental public works dramatically, and the upward trend is expected to continue through the 1990s. In addition to mounting outlays for new construction and major upgrading, costs for operations and maintenance, administration, and monitoring are climbing rapidly. In 1987, EPA and State and local governments spent $40 billion for environmental protection, and EPA estimates that just to maintain standards current in 1987 will cost $56 billion per year by 2000. The amount climbs to $61 billion, if costs for selected new regulations described later in this chapter are included.[133] However, a high degree of uncertainty surrounds these cost estimates; if costs were calculated for ***all*** prospective regulations, the price would be significantly higher.

The burden of these rising costs will fall predominantly on local governments, In 2000, local government outlays for sewers, drinking water, and waste management are expected to total almost $54 billion, or 87 percent of all governmental spending for these services, up from almost $33 billion or 82 percent in 1987 (see table 4-4). The State share-mainly for administrative and technical assistance-will remain steady at 5 percent, while the Federal portion is anticipated to decrease from 13 to 8 percent, primarily because of the phase-out of EPA's wastewater treatment facility grants.

Capital Costs

By **2000,** local governments will have to raise an estimated $19 billion per year in new capital—mainly through bond issues—for waste and drinking water and solid waste projects.[134] However, costs can double once projects are designed and the backlogs of deferred maintenance are taken into account. The need for expensive capital improvements will put particularly heavy pressure on small, low-income communities that have limited resources and poor access to capital markets, and on older cities already burdened with large debt and where competition for revenues is acute.

Operating and Maintenance Costs

More sophisticated and energy- and chemical-intensive treatment processes required by new governmental regulations will add substantially to local operating and maintenance costs. Expenses are expected to climb steadily from $23 billion in 1987 to $35 billion in 2000.[135] To cover these increased operating costs, many utilities will have to raise rates substantially. Ironically, one result will be that issuance of new debt for capital outlays will be somewhat more difficult. In addition, the careful and frequent system monitoring required by new regulations will add to local costs, especially if the utility is unequipped to do complex chemical testing in-house, or if private laboratories are not easily accessible.

[129] David Schnare, U.S. Environmental Protection Agency, personal Communication Apr. 27, 1990.

[130] For examples, see the following pamphlets from the U.S. Environmental Protection Agency, "Emerging Technologies: Alternative Wastewater Collection Systems," December 1983; "OverlandFlow: An Update," October 1984; "Less Costly WastewaterTreatment for Your Town," September 1983; and "Land Treatment: Rapid Infiltration," June 1984.

[131] U.S. Environmental Protection Agency, "Emerging Technologies: Alternative Wastewater Collection Systems," Op. cit., footnote 130.

[132] Kreissl, op. cit., footnote 60.

[133] U.S. Environmental Protection Agency, Administration and Resources Management, *A Preliminary Analysis of the Public Costs of Environmental Protection: 1981-2000* (Washington, DC: 1990), p. ii.

[134] Ibid., p. 15.

[135] Ibid., p. 54

Table 4-4-Summary of Local Government Environmental Expenditures by Media
(In billions of 1988 dollars)

Program	1987	Percent of total	2000[a]	Percent of total	Percent increase 1987-2000
Water quality	$11.4	35.0%	$21.1	39.3%	85%
Drinking water	14.8	45.4	22.2	41.4	50
Solid waste		18.7	9.7	18.0	59
Others	0.3	0.9	0.7	1.3	133
Total local spending	32.6	100.0	53.7	100.0	65

a Cost of maintaining 1987 levels of environmental quality plus costs Of new regulations.
b Includes costs to deliver services.

SOURCE: Apogee Research from U.S. Bureau of the Census and data prepared in 1988 by the Environmental Law institute from Environmental Protection Agency Regulatory impact Analyses.

Table 4-5-Average Annual Household Payments for Environmental Services for a Sample of 8,032 Cities, Towns, and Townships **(in 1988 dollars)**

City size	Average payments in 1987	Additional payments to maintain current levels of environmental quality in 2000	Additional payments to comply with new environmental and service standards in 2000	Total estimated household payments for environmental protection in 2000
500 or less	$670	$593	$317	$1,580
501 -2,500	473	223	67	763
2,501 - 10,000	433	143	29	605
10,001 - 50,000	444	197	24	665
50,001- 100,000	373	142	24	539
100,001 - 250,000	291	111	34	436
250,001 - 500,000	335	126	68	529
500,001 or more	393	140	93	626
Population weighted average . . .	419	180	48	647

SOURCE: Apogee Research, inc., from data compiled by the U.S. Bureau of the Census, and 1986 Survey of Community Water Systems, conducted by the Research Triangle institute for the Environmental Protection Agency, Office of Drinking Water, Oct. *23, 1987.*

Impacts on Households

Although some communities will continue to subsidize environmental public works, the major financial impact of regulatory compliance will fall on individual households through higher rates. If current trends continue through 2000, the average household will spend about $650 a year on chinking water, wastewater treatment, and solid waste management, or 54 percent more than in 1987[136] (see table 4-5). However, rates and increases will vary substantially from community to community. For example, Boston is anticipating a tripling of sewer and water rates to finance the mandated cleanup of Boston Harbor. In Cedar Park, Texas, a recently developed suburb of Austin, rates are now relatively high, but are not expected to increase much because capital requirements are low, and no expenditures are anticipated for compliance with new regulations. In recently built communities, rate increases tend to be lower, because facilities are newer and more efficient.

Across the board, system size is the major determinant of rate increases (see table 4-5 again). Utility charges in very small systems are anticipated to increase about 135 percent compared to 50 percent in mid-size cities and 60 percent in large jurisdictions. Small system costs are high because they lack economies of scale and technical and management expertise and usually pay more for credit.

Wastewater Issues

In 1988 EPA estimated that $84 billion in capital investment would be needed to bring all municipal wastewater treatment facilities into compliance with the Clean Water Act standards.1[37] These estimates are probably low, because many of the regulations are not in final form. In addition to construction and upgrading facilities to comply with secondary treat-

[136] **Ibid.,** p. 29.

[137] **Ibid.,** p. 3.

Table 4-S-New Regulations That Will Impose Local Costs

Regulation	Status
A. Drinking water	
Inorganic compounds (IOCs)	in development
Soluble organic compounds (SOCs)	in development
Volatile organic compounds (VOCs)	Promulgated
Fluorides	Promulgated
Lead and copper corrosion control	Proposed
Lead and copper maximum containment level	Proposed
Coliform monitoring	Proposed
Surface water treatment rule: filtered	Proposed
Surface water treatment rule: unfiltered	Proposed
Radionuclides	in development
Disinfections	in development
B. *Wastewater treatment*	
Secondary treatment of municipal wastewater	Promulgated
Pretreatment requirements	Promulgated
Sewage sludge disposal-technical regulations for use and disposal	In development
Storm water management	In development
C. *Solid waste disposal*	
Municipal landfill Subtitle D	Proposed
Municipal waste combusters-air standards	in development
Municipal waste combusters-ash disposal	in development
D. *Miscellaneous regulations*	
Underground storage tanks-technical standards	Promulgated
Underground storage tanks-f inancial standards	In development
Asbestos in schools rule	Promulgated
Superfund Amendments and Reauthorization Act Title iii requirements	Promulgated

SOURCE: U.S. Environmental Protection Agency, Administration and Resources Management, *A Preliminary Analysis of the Public Costs of Environmental Protection: 1981-2000* (Washington, DC: 1990), p. 44.

ment requirements, communities are mandated to solve other problems such as combined sewer overflow (CSO). (See wastewater treatment section of this chapter for details.) Elimination of CSOs in large cities like Boston and Chicago will cost billions of dollars. Costs are likely to be proportionally large for mid-size jurisdictions. Nashville, for example, anticipates spending $633 million on construction of deep tunnels and storage tanks in the city's downtown to hold CSOs and to expand treatment capacity.[138] Prospective governmental regulations on sludge disposal, toxics, nonpoint source pollution, and wetland protection may impose additional costs.

Federal grants have played a key role in financing wastewater treatment facilities. During the early 1980s, Federal construction grants, averaging $4 billion a year, supplied roughly one-half of all investment in wastewater facilities;[139] municipal bonds, general fund revenues, and States provided the rest. Beginning in 1989, construction grants were replaced by grants capitalizing State Revolving Loan Funds (SRFs). Authorization for the program, which was designed as a transitional effort to establish self-sufficient State loan programs, expires in 1994. While all 50 States and Puerto Rico have established SRFs and each has received at least one capitalization grant, SRFs will fall far short of meeting local investment needs. Even if capitalization grants are leveraged, at least 20 States face combined financing needs of nearly $57 billion.[140]

Drinking Water Issues

Detailed costs of compliance with the SDWA are just beginning to be calculated, because final rules are in place for only a handful of regulations. At a minimum, local governments will have to absorb an anticipated 50 percent increase in annual outlays for water. The majority of costs will be imposed by efforts to comply with EPA regulations for filtering surface water, controlling contaminants, providing

[138]"Nashville Plan Hits $633 Million," *Engineering News*, Aug. 9, 1990, p. 11.

[139]Environmental protection Agency, op. cit., footnote 133, p. 19.

[140]Ibid., p. 19.

Table 4-7—Total National Cost Impact of Compliance With Office of Drinking Water Regulations (In millions of 1986 dollars)

Rule	Number of systems affected	Capital cost	Annual O&M cost	Annualized capital and O&M cost	Average annual monitoring cost	Total annual compliance cost
Final:						
Fluoride	385	$ 32.5	$ 3.0	$ 6.8	$ 0.2	$ 7.0
Volatile organic compounds	1,824	164.4	13.4	32.7	23.1	55.8
Surface water treatment	10,288	2,938.5	166.4	511.6	17.1	528.6
Total coliforms	200,183	0.0	0.0	0.0	75.2	75.2
Proposed:						
Phase II soluble organic compounds	2,284	288.4	11.5	45.4	32.2	77.5
Phase II inorganic compounds	192	79.6	6.6	15.9	6.0	21.9
Lead and copper:						
Maximum contaminant level rule	947	333.7	35.4	74.6	0.9	75.5
Corrosion byproducts	42,980	599.0	157.3	227.6	32.0	259.7
Prospective:[a]						
Radionuclides	22,867	3,771.1	347.4	790.3	2.6	792.9
Disinfection requirement	103,354	1,352.0	316.0	474.8	12.8	487.7
Phase V sulfates	1,089	214.0	33.2	77.0	6.2	83.2
Arsenic	230	59.0	5.1	23.5		23.5
Total		*9,832.2*	*1,095.3*	*2,280.2*	*208.3:*	*2,488.5*

KEY: O&M = operations and maintenance.

[a]Mandated by the U.S. Environmental Protective Agency; has not yet developed proposed regulations.

SOURCE: U.S. Environmental Protective Agency, Office of Drinking Water, *Estimates of the Total Benefits and Total Costs Associated With Implementation of the* 1986 *Amendments to the Safe Drinking* Water Act(Washington, DC: Nov. 27, 1989), p. 12.

adequate supply and storage capacity, and replacing corroded and leaking distribution systems (see table 4-6).

The impact of EPA's drinking water standards will vary among systems depending on what rules apply (see table 4-7). Nationally, regulating radionuclides has the highest price tag-about $793 million annually-because of high capital costs and the relatively large number of systems affected. However, the per-system cost of meeting surface water treatment regulations (SWTR) will be greater, because fewer systems are out of compliance now. SWTR, controlling total coliforms and meeting disinfection requirements, comprises 40 percent of all local compliance costs, because the problems are pervasive and costly to address. Expected rules for well-head protection and regulating disinfection byproducts are likely to add significantly to compliance costs.

System size is also important in determining compliance costs, since large systems benefit from economies of scale. Over one-half of total capital requirements are attributed to small systems serving less than 10,000 persons, and within that group one-half of the costs fall on systems serving fewer than 3,300 persons.[141] In Pennsylvania, 90 percent of drinking water violations occur in small systems.[142]

Solid Waste Management Issues

The cost of solid waste collection and construction and operation of landfills and incinerators is expected to rise to about 60 percent from approximately $6 billion per year in 1987 to $10 billion in 2000 and will account for 18 percent of environmental spending (see table 4-4 again). Existing landfills are rapidly reaching capacity, and bitter siting disputes are forcing new facilities further out and increasing per-unit disposal costs. While waste-to-energy plants and incinerators are preferred by local governments, they are more expensive to build and operate and also face siting problems. Rules for controlling gas pollutants and ash from incinerators, under development by EPA, are likely to increase costs.

[141]U.S. Environmental Protection Agency, Mice of Drinking Water, Estimates *of the Total Benefits and Total Costs Associated With Implementation of the 1986 Amendments to the Safe Drinking Water Act* (Washington DC: 1989), p. 19.

[142]Commonwealth of Pennsylvania, Department of Environmental Resources, Division of Water Supplies, *Community Waler Supply: Issues and Policy Options* (Harrisburg, PA: February 1990), p. 6.

Financing and Management Strategies

The impact of sharply rising operating and capital costs can be reduced by increasing revenues and more cost-effective management. Historically, municipal sewer and water services and, to a lesser extent, waste disposal have been underpriced. The difference between the rates users pay and full costs, including maintenance, depreciation, and capital improvement reserves, has been subsidized by General Fund revenues and intergovernmental aid, in the case of wastewater treatment. Loca1 officials have been reluctant to raise rates, fearing a political backlash from consumers who think of environmental public works as rights, rather than as capital intensive services. Through the years, underpricing, coupled with rising costs, has led utilities to cut investment in system maintenance and improvement, a major cause of the deteriorated condition of many municipal systems. A rational methodology for rate-setting would seek to cover marginal or incremental costs rather than average costs, which can lead to excessive demand and inflated estimates of future needs.

Full-Cost Pricing

In response to tightening local budgets, some communities are raising sewer, water, and trash collection charges to cover full costs and adopting new rate structures. Rate structure options include raising seasonal or peak rates when demand is high, and block rates that charge a higher or lower per-unit rate for each additional block, depending on the local policy objectives to conserve or use excess capacity. Encouragement to raise rates is coming from many sources, from environmentalists to private and governmental creditors, who insist on full-cost pricing to ensure debt repayment. Independent sewer and water authorities, removed from political pressure and with mandates to be fiscally self-sufficient, are in a better position than local elected officials to carry out rate reforms.[143] The American Water Works Association is in the process of developing a new manual on alternative rate structures that will help local systems determine their best approach. [144]

Attracting Private Capital

Where State laws permit, local jurisdictions can charge developers impact fees to pay for construction of sewer and water improvements required by their development. In some communities, officials have raised capital funds by selling developers access rights to prospective water or wastewater plants. These strategies and their variations provide public works departments with upfront capital and ensure that facilities are built to local standards and can be easily integrated into the larger community system. Because the real estate market must be strong to attract developers willing to pay impact fees or purchase access rights, these strategies are used most frequently in high growth areas, such as California, Florida, and Colorado.

Operating service contracts are another form of private sector participation. While they do not lower capital needs for local governments, they can cut operating costs and allow a buildup of revenues for capital outlays.

Although enthusiasm for private ownership of environmental facilities has waned since the passage of the 1984, 1986, and 1988 Tax Reform Acts, solid waste management is one of the few areas in which private ownership is still considered profitable. However, private investment is more likely to be in collection, recycling, and resource recovery than in ownership of landfills.

Demand Reduction

Raising user rates is an effective way to reduce demand and system expansion costs, but few communities have consistently used rate increases to manage demand. However, in 1987, officials in Orange County, Florida, added a 50 percent premium for drinking water above 15,000 gallons per month; as a result, demand dropped by amounts ranging from 11 to 25 percent within the county service areas. Experience in California indicates that price changes must be substantial to reduce demand; moderate increases do not change behavior. Furthermore, over time users adjust to price changes and return to former use patterns unless rates are increased steadily.[145]

[143] Apogee Research, Inc., "Wastewater Management," a report prepared for the National Council on Public Works Improvement, 1987, p. 153.

[144] Christopher Woodcock, Camp, Dresser& McKee, Inc., personal communication, Mar. 5, 1990.

[145] Claudia Copeland, Water *Conservation: Options for the Residential Sector* (Washington DC: Congressional Research Service, September 1989), p. 41.

Consumer education about costs can reduce demand. Most consumers are unaware of how much water they use, but when they are informed, by advertisements and inserts in utility bills, their usage can decrease as much as 15 percent. Moreover, providing consumers with retrofit kits for shower heads and toilets can result in a 5 to 9 percent water savings, although over time 15 to 20 percent of those who install the equipment remove it.[146] In solid waste management, controlling demand through public education about source reduction and recycling are promising strategies, although only about 10 percent of U.S. solid waste is recycled. The unpredictable nature of the market and prices thwarts development of the industry at present.

Timely maintenance of sewer and water pipes can reduce demand by minimizing water loss and preventing the contamination of drinking water sources. Dual systems offer an alternative to the high cost of treating all water to drinking water quality, and water reuse can reduce demand.

Regional Planning

European experience shows that regional planning can improve the efficiency of water supply development and wastewater and solid waste management,[147] but few regions in the United States can boast of such achievements. Uncoordinated development of land use and public works plans and lack of integration of drinking water, wastewater, and solid waste plans ignore cross-media impacts and lead to inefficiency and increasing operating and capital costs. To be effective regional planning needs reliable funding and a strong State legislative mandate coupled with financial leverage to encourage local cooperation.[148]

Groundwater protection is an important planning and management issue. Sources of groundwater contamination include many types of waste disposal (including septic systems and hazardous waste) leaking storage tanks, fuel transportation and spills, well operations, agricultural practices, road salting, and urban runoff, as well as mine drainage. Groundwater standards ".. . can be used. . . to establish limits on contaminants in effluents (that is discharges), evaluate ambient groundwater quality, define the level of protection to be achieved, establish a goal for remedial clean-up, trigger enforcement, and help establish preventive programs to protect groundwater.' '[149] Other measures to control sources of contamination include reducing the disposal of wastes on or in the land, enforcing strict standards for sources of contamination, and prohibiting the placement of potential contamination sources above aquifers that are particularly vulnerable to contamination.

Conclusions

Air, earth, and water are parts of the Nation's common resources. They are essential to human health and to community development and deserve protection by far-sighted and well-integrated policy. However, governmental policy tools for providing the protection are the products of numerous, disparate laws, EPA regulations, State actions, and court rulings. In the aggregate, these address obvious pollution problems from specific sources, but do not comprise comprehensive policy guidance for environmental stewardship. For example, relatively little is known about groundwater movement and the intrusion of pollutants into drinking water supplies from landfills, sewer overflows, and other manmade facilities. Although about two-thirds of stream pollutants are from nonpoint sources, primarily from agriculture, data about these pollutants are inadequate and regulatory tools are scarce for controlling the contamination. It is extremely hard to shape good policy and legislation and to justify the costs of meeting standards when problems are so poorly understood.

EPA has recently released a report from its Science Advisory Board that urges the agency to focus on the environment as an integrated whole.[150] Congress could help State and local agencies that

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146 Ibid., p. 42.

147 Apogee Research, Inc., op. cit., footnote 143, pp.130-145.

148 For details, see U.S. Congress, Office of Technology Assessment, *Rebuilding the Foundations: A Special Report on State and Local Public Works Financing and Management, OTA-SET-447 (Washington DC:* U.S. Government Printing Office, March 1990).

149 U.S. General Accounting Office, *Groundwater Quality: State Activities To Guard Against Contaminants,* Report to the Chairman, subcommittee on Hazardous Wastes and Toxic Substances, Committee on Environment and Public Works, United States Senate (Washington.L DC: U.S. Government printing Office, February 1988), p. 12.

150 U.S. Environmental Protection Agency, *Reducing* Risk: *Setting Priorities and Strategies for Environmental Protection,* Report by the Science Advisory Board to the Administrator (Washington, DC: September 1990).

must comply with EPA standards by articulating the Nation's goals for environmental policy in a comprehensive mandate for the agency, and by directing it to undertake research to improve its data and analysis of environmental risk so it can set achievable standards. If EPA standards were based on their overall impact on water quality and on their potential health effects, local decisionmakers might have wider choices for treatment technologies. Consulting more frequently with State and local operating officials during the standard setting process could help identify alternative approaches and avoid future problems.

Adequate financial resources must also be provided for the agency. If Congress considers legislation to elevate EPA to Cabinet status, it would be timely to consider a clearly stated mission to preserve environmental quality from degradation across media as part of the legislation.

Changes at EPA

The Nation does not have an estimate of the overall improvements in water quality since the 1972 amendments to the Clean Water Act. Insufficient data and lack of a methodology to measure improvements to water quality and health effects make estimates of the benefits of standards very difficult. The high costs of regulatory compliance indicate that EPA should make developing data to support estimates of benefits and to direct future regulations a top priority.

Information on local environmental conditions is also limited. Data are lacking on types and amounts of sludge produced, about the purity of water at the tap, about the condition of underground pipe systems in many cities, and the efficiency of specific treatment plants. Some cities do not even have an accurate inventory of their systems. Local inventory and condition assessment information is sparse; many system managers do not have the resources to initiate a program to accumulate the information, and cannot correlate the information they do have with a preventive maintenance program. Federal or State technical assistance programs and incentives are needed to address these problems.

Communities adopt new EPA standards slowly, because their experience has shown that EPA is likely to change pollutant standards as more data accumulate. The cost of meeting EPA regulations is already high, and frequent and inconsistent changes in standards impose enormous hardships on the operating agencies that must implement them.

Environmental regulations focus on single-media effects, and environmental research has followed the same course, although recognition of cross-media effects and interest in research in this field are growing (see chapter 6 for further details). Continued research on a hazard, such as lead in drinking water or dioxin, usually brings better understanding of the risks. Once regulations or standards have been issued and if subsequent research shows that the risks have been overestimated, it is extremely difficult to roll back or change the standard. The costs of reducing many hazards to levels indicated by early estimates may be excessive. Informed regulatory and policy decisions can be made only after extensive research, testing, and evaluation. Although it can ensure that standards are set, requiring EPA to develop standards by a specific date may result in unworkable requirements.

Standards and Regulations

State and local officials responsible for compliance contend that EPA standards afford uneven protection and can create difficult interjurisdictional issues, when pollutants from one jurisdiction cause a neighboring municipality to violate regulatory standards, for example.

EPA's wastewater treatment regulations are based on strict definitions of primary and secondary treatment and biochemical oxygen demand and suspended solids in outflow. Despite the fact that the standards are intended to specify performance, their effect is often to steer jurisdictions to a specific facility design that has a proven record of meeting effluent standards (in the case of wastewater treatment). Absent effective incentives for trying new technologies, regulations based on best available technology tend to stifle the search for innovative alternatives. Many State and local agencies lack the technical ability to consider and weigh treatment and disposal alternatives for different circumstances. Moreover, standards for environmental public works often limit options for local authorities, since the burden of proving that an alternate but untried treatment method or facility falls on the requesting agency, which lacks data to show its effectiveness.

EPA could seek ways to develop regulations that are more likely to have the effect of improving and measuring protection performance, rather than controlling end-of-the pipe pollutants. Such standards could provide localities and equipment suppliers with flexibility to meet health and environmental goals and to reward improved system performance. In addition, methodologies for setting risk-based regulations and better methods for assessing the consequences of regulations are needed.

Protecting Public Works Investments

OTA concludes that the Nation's enormous investment in environmental public works can best be protected by upgrading existing infrastructure to obtain optimal performance and to meet new standards. Other priorities include rehabilitating systems to ensure against water loss or contamination due to leaks, initiating programs to prevent the intrusion of contaminants into supplies and treatment facilities, preventive maintenance, and education and training for personnel. With some notable exceptions, localities can meet many of the costs for these activities by pricing services at full cost.

Costs of maintaining and upgrading facilities to ensure compliance fall disproportionately heavily on small systems because of their small scale and high unit costs. Many small treatment systems are not in compliance with current regulations, and those with limited financial resources will have difficulty meeting new environmental standards, even using known technologies. Although EPA and some States have initiated programs to slow the formation of new, small systems and to provide technical assistance to existing systems, these efforts are not sufficient. Congress could encourage EPA to develop incentives for States to establish consolidation programs and for manufacturers to focus on equipment for small systems. Large, older jurisdictions with declining populations and shrinking economic bases may also have fiscal difficulty renewing and upgrading their public works to meet Federal standards. Congress may wish to address the issue of environmental enforcement policy, given the wide discrepancies in financial resources, technical information, and management capabilities. OTA concludes that such difficulties are likely to result in noncompliance in large numbers of jurisdictions, with small systems having particular problems. Additional Federal fiscal assistance would help States and jurisdictions with low economic bases to avoid this alternative.

Federal tools for affecting State and local rehabilitation, conservation, and maintenance policies are limited, but can be focused through standards and incentives. Since pollution prevention is far less costly than cleanup, Congress could stiffen measures that identify and penalize polluters. The manufacture, sale, and use of consumer products that pollute through use or disposal could be limited, and attempts to measure the environmental costs of products as well as the potential economic loss of nonproduction could be encouraged. A pollution remediation fee on items that pollute on use or on disposal is one possible source of income for Federal assistance to State and local governments to support compliance efforts.

Training and Education

Already complex, environmental technologies are becoming more complicated and more dependent on highly trained personnel. Environmental infrastructure utilizes a host of highly sophisticated electronic communications, electrical, and mechanical equipment as well as intricate microbiological and chemical testing apparatus. Yet the Nation's supply of well-trained managers, engineers, and technicians to install, operate, and maintain advanced treatment facilities is inadequate. Even at the State level, filling positions with well-trained personnel is a constant struggle; smaller systems, while required to meet the same standards as larger systems, do not have the resources to train their staff or to hire already-trained personnel. Existing technical assistance, such as the circuit rider programs, have provided some assistance, but more needs to be done. Congress could support programs for training and education of State environmental agency personnel and provide incentives to operating systems that undertake training. Professional organizations could assist by developing and carrying out mentor programs for young and/or inexperienced agency personnel. Any Federal financial assistance could be tied to ratemaking that covers the costs of staffing for operations and maintenance.

Technological Innovation

New and innovative technologies can address many public works problems and can help agencies design, construct, operate, and maintain complex systems more efficiently and productively. For example, instrumentation and measurement technologies are available to monitor contaminants entering or leaving a facility and eliminate the guesswork now associated with operations and maintenance.

However, public works managers are slow to introduce new technologies, because they lack information, funding, training, and incentives to change. New technologies often address only one part of a system's problems; they must also fit into the existing staffing and infrastructure framework. Market characteristics do not encourage manufacturers to develop innovative equipment for small systems, and consequently new technologies are aimed mainly at large and medium systems. The demonstration of innovative treatment technologies is stifled without a Federal program to support risk-sharing arrangements among public and private participants; engineering firms and local decision-makers will continue to choose technology with a long track record. Federal actions to provide financial incentives for development of innovative technology, and to stimulate evaluation of new technologies through applied R&D **programs, technical assistance, and information dissemination, could improve the efficiency and productivity of environmental public works.**

Environmental problems are very complex, and technology choices are often costly and inflexible. The speed with which manufacturers create new products that degrade the environment once in the waste stream puts great pressure on those responsible for dealing with the results. Because environmental technologies are often developed as solutions for a specific medium and not to address the root cause of the problem, they may create new and unexpected difficulties. The rapid pace of change means that a technology choice often represents both a financial and a facility commitment that does not allow much adjustment once implementation begins. Incentives to discourage waste generation should encourage manufacturers to avoid products that have adverse effects on the environment. If properly designed, **such incentives would affect the raw materials, the manufacturing process, manufacturing byproducts, and/or the ultimate disposal of the product.**