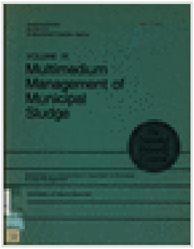

Multimedium Management of Municipal Sludge: A Report to the U.S. Environmental Protection Agency From the Committee on a Multimedium Approach to Municipal Sludge Management (1978)

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Analytical Studies
for the U.S.
Environmental Protection Agency

VOLUME IX

Multimedium Management of Municipal Sludge

A Report to the
U.S. Environmental Protection Agency
from the
Committee on a Multimedium Approach
to Municipal Sludge Management

Commission on Natural Resources
National Research Council

NATIONAL ACADEMY OF SCIENCES
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NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This study was supported by the
Environmental Protection Agency.

CHAIRMAN'S NOTE

This report is a review of the options available for managing the residuals of municipal wastewater treatment in the context of the municipal wastewater management system in its entirety. It discusses the various processes by which sludge can be disposed of or reused in the three environmental media: ocean, land, or atmosphere. Sludge management options are compared in terms of their primary impacts, intermedium effects, risk of environmental damage, technical reliability, costs (direct and indirect), and status in regard to present environmental regulation. Findings from such comparisons are drawn together in Chapter 6 to outline a general approach to decision making on sludge management on a multimedium basis.

In accordance with the assigned scope of study, the report is not intended to serve as a handbook or technical manual for municipalities having sludge management problems, nor does it deal with specific sociological or behavioral issues involved in sludge management such as intermunicipal agreements, areawide land use planning, and public relations.

Harvey O. Banks, Chairman
Committee on a Multimedium Approach
to Municipal Sludge Management

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FOREWORD

This report is one of a series prepared by the National Research Council for the U.S. Environmental Protection Agency.

In June 1973 the Subcommittee on Agriculture, Environmental, and Consumer Protection of the Appropriations Committee of the U.S. House of Representatives held extensive hearings on the activities of the EPA. The ensuing appropriations bill for fiscal year 1974 directed the Agency to contract with the National Academy of Sciences for a series of analytical advisory studies (87 Stat. 468, PL 93-135). EPA and the Academy agreed upon a program that would respond to the Congressional intent by exploring two major areas: the process of acquisition and use of scientific and technical information in environmental regulatory decision making; and the analysis of selected current environmental problems. The Academy directed the National Research Council to formulate an approach to the analytical studies, and the National Research Council in turn designated the Commission on Natural Resources as the unit responsible for supervising the program.

The inside front cover of this volume lists the other studies in the series, and the inside back cover presents a diagram of the structure of the program. Each of the component studies has issued a report of its findings. Volume I of the series, Perspectives on Technical Information for Environmental Protection, is the report of the Steering Committee for Analytical Studies and the Commission on Natural Resources. It describes in detail the origins of the program and summarizes and comments on the more detailed findings and judgments in the other reports.

This typescript edition is an interim printing made in limited quantity. The report will be published in a typeset version during 1977, along with the rest of the series, and distributed for sale by the Printing and Publishing Office of the National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

CHAPTER 1

INTRODUCTION AND SUMMARY

The vastly increasing quantities and complex changes in quality of sludge from municipal sewage treatment plants, accelerated by the requirements of the Federal Water Pollution Control Act Amendments (FWPCA) of 1972, have created an urgent need for a comprehensive review of the options available for managing this residual material. This report has been prepared in response to that need.

The present study examines ecological, technical, economic, and social data on which regulatory decisions for sludge management are founded; legal and institutional constraints on EPA; research on sludge management; and decision making in future sludge management. While primarily addressing the final stages of the wastewater treatment system as it applies to sludge treatment and disposal or reuse, the study also examines the potential for lowering the concentration of metals and other toxic materials in sludge through source control and pretreatment of industrial wastes.

In analyzing its findings, the Committee considered whether new legislation specifically designed to regulate sludge management, disposal, and reuse is necessary to achieve a multimedium approach. The Committee concluded that several federal environmental laws are broad enough to constitute a basis for the multimedium approach to sludge management. These acts provide an opportunity for agency initiative in developing a sludge management program that can resolve such administrative problems as the maintenance of site-specificity within a nationwide regulatory apparatus.

The Committee is keenly aware of the necessity for comprehensive policy formulation by EPA. As sludge generation increases daily, it becomes clear that postponing decisions on its disposition is in fact tantamount to deciding in favor of possible environmental damage and certain management frustration. To avoid this outcome, the timely development and implementation of a definitive, coherent federal sludge management policy should be undertaken in accordance with the recommendations of this report. Such a policy will require review and revision as conditions warrant, and should at all times explicitly recognize the adequacy of the information upon which it is based.

The basic message of the report is that effective sludge management demands a holistic approach: today's fragmented approach is inappropriate to the nature of the material and inadequate to the size of the problem. Only when sludge is managed as an integral element of the whole environmental protection effort can economic, environmental, and social costs be validly compared with benefits, or all risks be effectively assessed.

The recommendations to EPA that follow are designed to alleviate the mounting severity of the nation's municipal sludge problems. The specific actions suggested would relate sludge properly to: (a) the wastewater management system of which it is a product; (b) the issue of efficient use of resources on which it impinges; (c) the media for disposal or reuse, on all of which it may have impacts; and (d) the social and economic complex, whose constraints and demands must be considered at all stages in the decision-making process. Suggestions on management of risk and the need for public acceptance are made in this framework.

I. THE HOLISTIC APPROACH

A. Comprehensive Environmental Management

- EPA should incorporate into its water pollution control program the concept of comprehensive environmental management of municipal wastewater systems. Policies and procedures should be formulated that make it possible to base decisions among options on optimum environmental benefits, rather than on improving receiving water quality alone. To this end:

    - The environmental effects, adverse or beneficial, of municipal wastewater management systems should be considered in their entirety, including the effects of disposal and reuse both of sludge and of residuals from source control and industrial pretreatment (see Chapter 3).

    - Federal funding of improvements should be targeted at the total wastewater management system rather than specific parts. In that regard we recommend that EPA include in grant evaluation adequate consideration of the most cost-effective manner of meeting the total environmental quality and public health goals discussed in this report (see Chapters 3, 4, and 5).

•• EPA offices with responsibilities related to sludge management should be coordinated so that coherent policy on management of municipal sludge may be developed and implemented (see Chapter 5).

Discussion

The need for greater attention to management of sludge will become acute as water quality goals are achieved. Up to five-fold increases in sludge generation in some regions are expected (see Chapter 2, Figure 2.3), since most of the wastewater treatment processes used to improve effluents produce greater amounts of sludge. The average national increase is expected to be more than two-fold (see Chapter 2, Figure 2.2). Thus, realistic estimation of benefits to water quality resulting from wastewater treatment must include in the equation the costs and risks of coping with the sludge that is generated.

Sludge is a product of the treatment of wastewater (see Chapter 2, Figure 2.1) to control effluent quality as required by the Federal Water Pollution Control Act Amendments of 1972. The Act, in concentrating on the primary goal of improving the quality of receiving surface waters, pays less attention to the amount and characteristics of the sludge produced and to the potential impacts of sludge on the environment (see Chapter 5). Disposal of sludge is also within the purview of the new Solid Waste Disposal Act. Any evaluation of the success of the water quality improvement program that gives inadequate consideration to the effects of that program's byproducts can only be misleading; the effects of the program on all parts of the environment must be compared, and the net results evaluated.

A first requirement for comprehensive environmental management is flexibility of choice among the options, allowing a rapid changeover from one method to another if unacceptable levels of environmental damage are indicated by monitoring. One constraint on such freedom of choice would be a heavy capital investment in any particular sludge handling technology. Another would be to prohibit consideration of a medium (e.g., the ocean) for sludge disposal, implying that disposal to air or land is always safer (see recommendation on multimedium environmental management below). The existing program of government grants to cover significant portions of the capital costs of sludge management imposes limits on flexibility of choice. Analysis of financial support of wastewater treatment improvements (Chapter 4) shows that these programs may lead to selection of capital-intensive sludge management schemes that may not have the lowest overall direct, indirect, and social costs. Consideration of related legal and institutional issues (Chapter 5) further indicates that implementation of a policy or program may come through grants which influence a municipality's choice of options.

Several offices at EPA have been assigned tasks related to sludge management in the Action Plan for Residual Sludge Management (Chapter 5, Figure 5.1). These different offices should be coordinated in a way that permits development of coherent EPA policy and guidelines on management of municipal sludge and consideration of the total environment.

B. Multimedium Environmental Management

- EPA should review and revise current policies for disposing of sludge in order to recognize the multimedium nature of environmental impacts and to ensure that the relative merits of available options, environmental and economic, are judiciously weighed. For this purpose:

    - EPA should reexamine current interpretations of the laws that, in limiting disposal of sludge in the ocean or air, may place an unequal burden on the land and its related water resources.

    - Measures to prevent or mitigate impacts not only on the primary medium for disposal or reuse, but also on other media through intermedium transfers should be incorporated in sludge management policies and guidelines.

Discussion

A multimedium view of waste disposal is one that considers the particular characteristics of each environmental medium--ocean, land, and air--and allows for its protection. Since no single medium should bear a disproportionate share of risk, multimedium environmental management requires comparison of the merits and disadvantages of the media, both in general terms and on a site-specific basis. Foremost among the factors to be compared are the risks of direct environmental impacts and of secondary (intermedium) or public health impacts. Other bases for comparison of the three media are discussed following the findings and analysis section at the end of Chapter 3.

If the resource value of sludge is ignored, the ocean may offer a lower-cost, reliable disposal option for coastal cities. Risks of adverse environmental impacts are moderate where sludge has low levels of toxics and can be diffused by currents. Such risks as are known may be attenuated by scientific investigation of the physical, chemical, and biological processes that determine the transport of sludge constituents when discharged into the ocean; however, gathering data for such investigations for site selection or monitoring may add significantly to the cost of ocean disposal.

The land medium offers two routes for disposal of sludge: landspreading and landfill. Landspreading is the only option for which the benefits (recovery of nutrient and related resources of sludge) have been measured. At the same time, such application may carry with it the greatest risk, of irreversible effects of toxic substances and of secondary impacts on the environment and on human health. Landfill is the most effective method of containment of sludge, but only when performed under optimum conditions of site selection and operation. Land acquisition for either landspreading or landfill may be costly for larger municipalities with limited access to land. Monitoring for landspreading must be well regulated and extensive.

Thermal disposal to the air largely eliminates pathogens and synthetic organic compounds. However, the burden placed by thermal disposal on ambient air quality is aggravated where it is used in populous areas and areas that may already have air quality problems. Thermal combustion requires the greatest capital investment and highest level of technical control, and has the added disadvantage of consuming fossil fuels, which involve environmental impacts in their development.

Neither the available scientific and technical information (see Chapters 2 and 3) nor the legal requirements (see Chapter 5) support exclusion of any of the environmental media at the expense of jeopardizing those remaining. Indeed, requirements for a comparative assessment as discussed in Chapter 5, indicate that absolute prohibition of any one of the environmental media is inconsistent with the relevant legislation.

As the findings in Chapter 5 demonstrate, the sludge problem is little recognized in federal or state laws. The federal environmental laws that do have implications for sludge management are broad enough to allow a multimedium approach. Present emphasis in pertinent statutes and administrative regulations is on protection of the ocean and air. The regulations emphasize land disposal, without providing adequate protection for the land and its related water resources. However, permit procedures under sections of PL 92-500 could require a multimedium assessment of sludge management alternatives. Sludge policy that mandates the production of the material but does not adequately consider its disposition in the environment is obviously incomplete.

C. Use of Resources

- In planning sludge management energy and materials requirements should be evaluated with a view to minimizing the use of shrinking resources and the environmental impacts of energy and resource production.

- EPA and state water quality control agencies should actively encourage recovery of resources potentially available in sludge, while ensuring that recovery is accomplished with minimum risk to the environment and to public health. Specifically:

    - State water quality agencies should actively supervise and monitor all resource recovery operations within their jurisdictions. Together with EPA, which should issue guidelines for control, these agencies should require municipal sludge management agencies to control the rate and total amounts of sludge applied in agriculture and silviculture. As a corollary means of effecting control of land application, state water quality agencies should, under EPA guidance, establish limits on allowable concentrations of toxic metals and other hazardous substances in sludge residuals offered for unrestricted sale to the public.

    - EPA should actively sponsor research on the hazards of sludge to health and the environment when it is used as a fertilizer. In particular, studies should be undertaken to establish limits for concentrations of hazardous substances in sludge residuals to allow safe resource recovery under varying conditions of climate, soil, crop, manner of application, and other significant parameters.

Discussion

Effects on resources must also be considered in a comprehensive view of environmental management. Potential environmental effects of a given action must not only be priced in dollars, but also weighed in terms of the energy or resources needed and the impacts of their production on the environment. In addition, the potential value of sludge as a resource (principally as a fertilizer and a soil builder) must be taken into account (see Chapter 3).

Municipal sludge contains nutrients, particularly components of nitrogen and phosphorus, useful in agriculture and silviculture, and in reclamation of strip-mined lands. Sludge humus is a valuable soil amendment. In disposal in the ocean or air, however, no value from sludge has yet become apparent: no measurable benefit, as expressed in increased productivity, has resulted from the dumping of sludge in the ocean, while the low thermal value and high water content of sludge makes its potential as a source of energy dubious.

It is likely, then, that the resources available in sludge may be recoverable with significant economic benefits only on the land. In particular, the estimate that sludge could meet up to 5 percent of the nation's nitrogen fertilizer needs is impressive (see Chapter 3). Recent legislation (the Resource Conservation and Recovery Act of 1976) would be relevant to this aspect of municipal sludge management.

Resource recovery from sludge can only be environmentally acceptable, however, if concentrations and accumulations of toxic metals, persistent organic compounds (such as PCBs), pathogens, and other substances potentially hazardous to the environment and public health are kept within acceptable limits by source control and pretreatment of industrial wastes and adequate sludge treatment. Metals in sludge may accumulate in the soil to levels toxic to crops, although such effects from actual landspreading operations have not yet been documented. Of the metals in sludge, copper, zinc, and nickel are the most phytotoxic, and cadmium and lead most toxic to human or animal consumers. The fate of polychlorinated biphenyls in sludge when applied to soil is not fully known and should be further investigated. Their toxicity is such that allowable limits in sludge must be extremely low.

The municipal sludge agency may recover resources from sludge directly through its own operations (for example, on a municipally owned and operated farm), or under contract with other agricultural or silvicultural users. Potential hazards outlined above make it clear that control must be continuously exercised over quality and amounts of sludge applied in such operations, and the methods of application. Where dried or composted sludge products are produced and packaged for unrestricted sale as fertilizer and soil conditioner, the quality of the material offered for sale must also be controlled and labelled as to possible hazards.

D. Cost and Benefit Evaluation

- <u>Sludge management decisions should be based on consideration of all costs and benefits involved, direct, indirect, and social. To facilitate the analysis:</u>
  - <u>EPA should formulate guidelines for identifying and considering indirect and social costs and benefits, and should require states and sludge management agencies to incorporate these considerations into their decisions on sludge management alternatives.</u>
  - <u>EPA should formulate guidelines that define the assumptions and establish the cost categories to be used in estimating and recording direct costs of wastewater and sludge management, and recommend cost accounting procedures. In addition, the Agency should formulate periodic cost indices for conversion of local cost differences in wastewater and sludge management to a common base and, through the state water quality control agencies, should require municipal sludge management agencies to maintain adequate records of sludge management costs in accordance with state-mandated accounting procedures and to report such costs annually.</u>

Discussion

<u>Direct Cost Data.</u> Analysis of available information on direct costs of sludge management reveals significant variations and inconsistencies. As discussed in the section on direct costs in Chapter 4, some of the variations in direct costs of a process between two facilities of the same capacity are differences in sludge quality, costs of land, labor, and energy, resources available, and facility design.

But different local and regional costs do not alone explain the lack of consistent cost definition. Historical lack of attention to the true direct costs of sludge treatment and disposal, differing assumptions as to cost categories, and differences in cost accounting procedures also contribute to the wide variation among reported direct costs. The variations and inconsistencies are exacerbated by the problems of segregating costs associated with sludge management from those of the overall wastewater management system of which the sludge component is an integral part. The consequence has been to mask the large and growing capital and operational cost increment of the water quality improvement program that is directly attributable to sludge management.

A further problem arising from this segregation is that few data exist on direct costs of pretreatment and source control, because the possibilities for influencing sludge quality through these processes have not generally been addressed in developing sludge management plans. Application of pretreatment to industrial wastewater sources could reduce the overall costs of sludge management.

Indirect and Social Costs. Analyses of engineering studies (Appendix) show that sludge management decisions generally consider only direct costs, with little or no recognition of indirect and social costs. Substantial indirect and social costs may be incurred in connection with any sludge management alternative. There may also be some direct and indirect benefits. Some indirect costs of sludge management are adverse impacts on land values, costs of government such as regulation and monitoring, and potential hazards to health; benefits include inputs to reclamation of land, and production from reclaimed land. Social costs include hazards to health and loss of aesthetic resources; the major social benefit is improvement of water quality. Information in Chapter 4 suggests that although indirect and social costs and benefits cannot be quantified, they are generally identifiable and can and should be considered in sludge management decisions.

II. MANAGEMENT OF RISK

Any method for sludge disposal or reuse entails some risk of damage to the environment, whether the medium directly involved is the atmosphere, the ocean, or the land. Risk can be minimized but never wholly eliminated. The degree of risk entailed is specific to each situation, and can be evaluated at least qualitatively for any particular sludge management alternative. The level of risk and the means for controlling it can be most effectively determined in the context of comprehensive multimedium environmental management already described.

A major element in risk is the inevitable variation in amount and quality of sewage and resultant sludge which depends on the wastewater sources and on treatment processes. Unpredictability of natural phenomena and processes also enter into risk. For example, the fate of sludge discharged into the ocean or released into the atmosphere by incineration is essentially uncontrolled because of the variability of dispersion in those media.

Uncertainty due to lack of information on environmental effects also contributes to risk. Pathogen populations, for instance, constitute an unpredictable risk when sludge is applied to soil. Few reliable data exist on the sensitivity of crops to heavy metals and persistent organics in sludge, particularly as regards long-term effects on productivity and the potential for increased metal concentrations in food crops and in human or animal consumers. Risks in applications in forests are related to nitrate loss into groundwater and the possible eutrophication of downstream water bodies.

The fact that environmental effects can be either reversible or irreversible further complicates assessment. Sludge metals or persistent organics could irreversibly damage soil of a landspreading site even if application ceased. Excess nitrate nitrogen in soil water would, however, return to previous levels in time. Areas for ocean disposal with high dissolved oxygen and strong currents return to nearly original states within a few months after dumping operations cease; but where these conditions do not prevail, bottom conditions and benthic communities may be irreversibly changed.

Available means for minimizing risk include:

a. control and improvement of sludge quality through (i) source control and industrial waste pretreatment, which can lessen the variability in toxic content of sewage sludges by decreasing the amounts of those constituents that cannot be removed or neutralized by treatment (metals, persistent organics, or other industrial chemicals); and (ii) adequate treatment of sludge before disposal or reuse (pasteurization, composting, high-energy irradiation) which will reduce the risk posed by pathogens;

b. proper site selection in all media;

c. monitoring at specific sites; and

d. research on processes and effects.

A key consideration in dealing with risk is public acceptance, an important element of which is a balanced presentation of all costs and benefits involved.

The specific recommendations below suggest means by which the causes of risk just described might best be addressed.

A. Sludge Quality

- <u>EPA should implement its responsibilities and authorities under Section 307 of PL 92-500 by itself issuing specific substantive pretreatment regulations for a variety of industrial wastes including heavy metals and toxics. It should also encourage and allow state and local governments, by statutes and regulations, to add requirements for pretreatment of substances not required to be pretreated by EPA or to adopt more stringent regulations for pretreatment than those contained in federal regulations where state or local considerations or policies make it appropriate.</u>

    - <u>EPA, the states, and local waste management agencies should insure that residual wastes resulting from source control and pretreatment of industrial wastes are disposed of in an environmentally acceptable manner.</u>

Discussion

To ensure that the full range of disposal and resource recovery options is open to the sludge management agency, improvement of sludge quality should be undertaken as one step in managing the total wastewater system. In this context, the first move would be to place enforceable controls prohibiting release of toxic wastes to the wastewater collection system in amounts that would adversely affect sludge quality, thus effectively mandating source control and pretreatment of industrial waste (see Chapters 2 and 3). Other characteristics of sludge can then be improved or maintained through additional treatment; the risk of environmental damage is thus diminished at all stages in the process, provided that safe disposal of residuals resulting from source control and pretreatment is assured. A large percentage of the hazardous constituents introduced by industrial or other sources into the municipal wastewater system (those metals and organics listed in Chapter 2, Table 2.2) remain in sludge after wastewater treatment. All media are subject to risk from these materials, particularly from uncontrolled disposal, for instance, in the ocean. In landfill disposal, heavy metals and other hazardous materials may appear in the leachate from the sludges or residues from oxidation; these can be transported into groundwater. In landspreading, metals can also contaminate ground or surface waters, and both metals and synthetic organics such as PCBs may endanger soils, crops, and consumers.

Experience has shown that a high proportion of substances can be kept out of the system (and hence out of the sludge) through a combination of: control of the processes and materials used in production at the industrial source; removal and controlled disposal of hazardous constituents before they reach the waste stream; and pretreatment of the wastes before they are discharged to the municipal collection system. The costs of this source control and pretreatment do not appear to be prohibitive. Pretreatment of industrial wastewater has been successfully practiced in the past to protect the publicly-owned treatment works from harmful substances; such pretreatment is also technically feasible for reducing toxic substances in municipal sludges, according to the limited data available (see Chapter 2, Table 2.3). In the context of the total costs of wastewater and sludge management, costs of source control and pretreatment do not seem prohibitive (see Chapter 4); they are offset by the reduced costs of managing the resulting better quality sludge.

Section 307 of PL 92-500 mandates and authorizes EPA to require pretreatment of industrial wastewater discharged to municipal collection systems. The language of the present general pretreatment guideline does not, however, indicate a specific means for consistent control of municipal sludge quality (see Chapter 2). Such controls could be implemented through the NPDES permit system and enforcement of existing state or local laws.

B. Site Selection

- EPA should require thorough investigations and evaluations of proposed sites for disposal or reuse of sludge residuals by sludge management agencies as a prerequisite for grants.

- EPA should issue guidelines for site investigation and evaluation for federally aided projects. EPA should encourage the states to develop guidelines for all other sites and facilities.

- Sludge management agencies should be required to take all reasonable measures to prevent or mitigate possible adverse environmental impacts at the disposal or reuse site selected.

Discussion

Specific procedures for site selection in each of the environmental media, as described in Chapter 3, can diminish risk. In coastal waters, a survey properly designed to minimize adverse impacts would assess the present biological communities and physical, chemical, and biological processes that determine movement and fate of sludge constituents. Such site investigations are costly in this medium, and new ocean disposal operations should be undertaken only after careful study of the possibilities. Likewise, landfill site selection requires geologic and hydrologic investigation to avoid impairing quality of water supplies by transport of leachate. Investigation of soil, topography, drainage, climate, hydrology, and chemical interaction with the biota is required for landspreading of sludge to protect the soil, surface water, and groundwater from contamination with pathogens, excess nitrates, or other sludge constituents. Necessary factors in selection of thermal oxidation sites are atmospheric flow patterns, land uses, demographic patterns, and public acceptability. Site considerations for disposal of thermal oxidation residues will resemble those for other types of landfill.

C. Monitoring

- Carefully-designed and continuing monitoring programs to identify and evaluate environmental impacts of sludge disposal or reuse should be an integral part of operation of the total municipal wastewater management system. The monitoring program must: (1) establish baseline conditions against which environmental changes can be assessed; (2) identify effects that might endanger human health or ecosystems; (3) identify and provide information for evaluating changes in the disposal medium and inter-medium movements of sludge constituents; (4) assessing the potential effects of these changes; and (5) continue long enough to account for both natural and induced variations. To this effect:
    - EPA should prepare and issue guidelines for sludge management monitoring for each disposal medium;

•• <u>EPA should use results of monitoring in analyses of sludge management decisions to provide the basis for continuing evaluation of Agency policies.</u>

Discussion

Effects of sludge disposal or reuse operations on the environment may be of short duration, or they may be cumulative with long-term and in some cases irreversible consequences. Most of these effects cannot be predicted in advance given the current state of scientific knowledge and technical data. Technology, is, however, sufficiently advanced to permit identification and evaluation of these effects through monitoring. Design of a monitoring program requires understanding of the dynamic processes and characteristics of the environmental medium into which the sludge is placed, and of the potential primary impacts and intermedium transfers of sludge constituents (see Chapter 3).

Monitoring for each medium should include baseline assessment and estimation of natural variation in addition to measurement of alterations in the environment caused by sludge disposal. Monitoring programs for documenting conditions and trends in the marine environment could include measurement of fish and shellfish quality, water quality, and sediments. In the case of landfill, quality and movement of leachate and effects on surface and groundwater should be monitored. Monitoring of landspreading operations may be used to confirm judgments on rates of application. Some relevant parameters would be pathogen kinetics, toxic materials, and nitrate levels in crops and surface or groundwater. Records of the quality of the sludge and where it has been spread on the land should be maintained. For incineration, emission parameters should be periodically measured.

Regulation by a responsible level of government with appropriate and adequate authority for monitoring should be required for any sustained disposal or use of sludge on land. In each medium, monitoring should indicate whether a change in operation or method of disposal is necessary.

D. Synthesis of Information

• <u>EPA should solicit the views of municipal sludge management agencies, engineering experts, the states, and the academic community to identify sludge management research and data needs.</u>

- EPA should set priorities for sludge management research and data accumulation and estimate time and costs in meeting them so that these elements can be given proper consideration.

- EPA should establish an orderly process of information handling to assure that decision making by EPA in Washington, EPA regional offices, the states, and municipal sludge management agencies is based on the best available research results and data.

Discussion

Our knowledge of the impacts of sludge on a given medium and of the processes of transfer from one medium to another is too limited to support a conclusion that disposal to any one medium is always either less risky or less expensive than disposal to another. Awareness of the adverse and pervasive effects on the environment and human health of metals and persistent organic compounds is relatively recent, and information for evaluating those effects is as yet incomplete.

Decision making on sludge management must therefore be based on the limited information available and guided by a best perception of risks and trade-offs on the part of the decision maker. These necessary judgments are useful in shedding light on areas of research and data gathering that deserve priority.

Information now available within EPA on public health, the environment, and economic and social institutions should be synthesized to help sludge managers decide among disposal to ocean, land, or atmosphere.

The findings and analysis sections of Chapter 3 that discuss research identify deficiencies in information significant to management of risk in sludge disposal and reuse. For example, little is known about possible transfers of pathogens and synthetic organic compounds from ocean to atmosphere. Present understanding of ocean processes does not permit prediction of the effects of most sludge constituents on water quality. Research is needed on specific disposal operations to quantify the environmental impacts on coastal ocean waters. The possibility of infection from aerosols generated and inhaled needs to be studied. Research is needed in these and other areas, but the need for such knowledge should not delay action. Decisions must be made based on the information that is now available.

E. Public Acceptance

- EPA should initiate a program to inform decision makers in Congress, the states, and the public about sludge management problems. Specifically:
  - Information should be disseminated about the size of the problem and the options for disposal and reuse that are available.
  - The kinds and levels of risk associated with each option should be identified and presented in light of total costs and benefits involved in overall management. This information should help the public to define acceptable levels of risk.

Public determination to clean up the nation's waters through rigorous requirements for wastewater treatment appears to remain strong. At the same time, the public remains ill-informed about the increase in the volume of sludge that will be produced, about the costs and complexities of sludge management, and about problems inherent in using or disposing of sludge. In most areas, proposals for sludge disposal are strongly opposed by people who live close to the site. Because the generation of sludge is an inevitable consequence of the processes for treating municipal wastewater, and because disposal sites and options will inevitably affect some segment of the public, information should be disseminated to improve public information about the problems of sludge management. Such dissemination is especially important because of the extent to which social attitudes shape the programs that may be implemented (see Chapter 5).

CHAPTER 2

TREATMENT PROCESSES FOR MUNICIPAL WASTEWATERS AND SLUDGES

The avenues for disposal and the impacts of sludge on the environment are largely controlled by its volume and composition. Sludge characteristics are, in turn, determined by inputs and treatment processes. This chapter analyzes the aspects of source and treatment that control the properties and amounts of sludge, and suggests the effects that possible change in water quality standards may have on systems of wastewater management.

THE MUNICIPAL WASTEWATER SYSTEM

Sludge derived from municipal wastewater is a product of both collection and process inputs (Figure 2.1). The process inputs to the system shown in Figure 2.1 include chemicals and energy, used in the separation processes involved in wastewater treatment.

Each type of input may also be considered in relation to its sequence in the full system. The wastewater treatment plant receives influent from point sources (e.g., industry) and nonpoint sources (e.g., street runoff in combined sewer systems). Components of these streams are separated and solid, liquid, or gas outputs or residuals are produced. Effluent waters are discharged to the environment while the sludge, a suspension with approximately 5 percent or less solids, may proceed through additional treatment before reuse or disposal.

Environmental impacts occur not only at the final disposition of sludge, but at virtually every stage in the process outlined above. A complete environmental analysis of the system would entail evaluation of the aggregated impacts that ensue from wastewater inputs, process inputs from physical installation and operation of the treatment facilities, and the system's outputs.

Other relationships are clarified by tracing the flows through Figure 2.1. The higher levels of wastewater

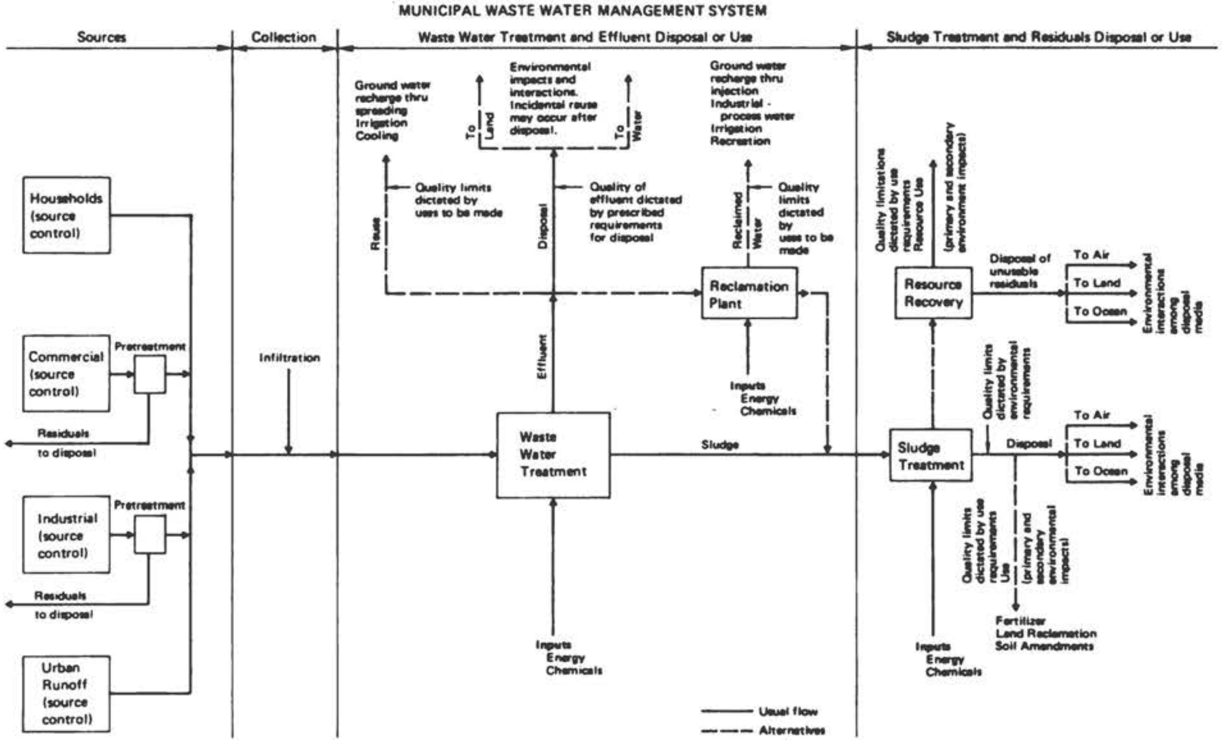


FIGURE 2.1 The municipal wastewater system.

The system includes inputs from domestic, commercial, and industrial sources of wastewater; infiltration; urban runoff (in combined systems); process inputs of chemicals and energy used in wastewater treatment. The flow chart illustrates that all inputs to the system, including toxic substances, ultimately must be directed to the air, land, or water. Outputs from the processes are liquids, gases, and residual sludges. As the quality of the liquid effluents is increased to meet higher receiving water quality standards, additional burdens may be placed on land, water, and air, and other resources in treating the resulting sludge.

treatment, using more efficient processes, larger collection systems, more process inputs to upgrade treatment, or a combination of these, produce higher quality effluents for discharge to receiving waters. Such processes may also produce more sludge. In the context of the entire wastewater management matrix, sludge is only one of many outputs and impacts of an interrelated system.

Figure 2.1 also illustrates that any option or set of options in the wastewater management system entails environmental costs. For example, fresh waters may be protected at some cost to the land, or land may be protected at some cost to the ocean. In constructing the physical system, it is important to weigh comparative physical, economic, and social impacts and benefits of alternatives.

WASTEWATER TREATMENT PROCESSES

Wastewater is treated by a sequence of processes designed to remove undesirable components, and to release a liquid effluent that meets prescribed requirements. Undesirable components include pathogens, debris, suspended solids, oxygen-demanding organic materials, persistent organics, and hazardous metals. The wastewater treatment itself produces residues, including big objects, such as rags and wood, which are removed by large screens or bar racks, and smaller solid materials such as grit, sand, and silt. Organic residues include scum-forming greases, organic sludges created by the removal of suspended solids from the wastewater, and biological solids produced from oxygen-demanding organic materials. Chemical precipitates are formed when lime or other metal salts are added during treatment.

Removal efficiencies, biological systems employed, and possible chemical additions strongly influence the amount of sludge produced by the various processes. Typical amounts are shown in Table 2.1. More extensive treatment, from primary sludge processes (screening and sedimentation) to activated ones (containing microorganisms capable of aerobically stabilizing a waste), approximately doubles the amount of sludge produced per unit of wastewater.

Table 2.1 shows the distribution of publicly-owned treatment works by type of treatment employed. Since plant capacity may vary considerably, the percentages shown are not indicative of absolute amounts of sludge produced. During the year for which figures in the first two columns were compiled, 21,118 treatment plants were operating. Activated sludge and trickling filter were each used by approximately 20 percent of the plants (Table 2.1). Primary treatment alone accounted for about 15 percent of the total;

TABLE 2.1 Volumes of Sludge Produced by Different Wastewater Treatment Processes, Distribution of Types of Wastewater Treatment, and Estimated Amounts of Each Type of Sludge

There is a large variation in amounts of sludge per unit volume of wastewater produced by primary treatment (removal of substances from wastewater by mechanical screening or sedimentation), secondary biological treatment (oxidation of organic material by microorganisms), and chemical treatment (addition of metal salts to remove suspended solids and phosphorus). Chemical precipitation produces the most sludge per unit volume of wastewater, but is now used in only 5 percent of treatment facilities. Most secondary sludge is produced by biological treatment (activated sludge and trickling filter). Estimates of the total amounts of each type of sludge expected in 1985 are shown in the third column. These data are from a third source and are not calculated from the first two columns. Dashes indicate where data are unavailable.

Treatment Process	Sludge Dry Solids, Grams per Cubic Meter of Wastewater[1]	Percent of Total Facilities Using Treatment Process[2]	Total Amounts of Sludge,[3] 1985 Estimate, MT × 10^6
None	0	11.6	–
Primary Sedimentation	150	14.2	3.4
Activated Sludge	270	20.3	1.4
Trickling Filter	57.0	20.4	0.92
Chemical Precipitation	395	5.0	0.41
Secondary–Other	–	2.4	–
Advanced	–	2.3	–
Pond	0	22.3	0
Land Disposal	0	0.7	0

[1] Metcalf and Eddy, Inc. (1972).
[2] U.S. EPA (1975).
[3] Farrell (1974).

no treatment and the combination of other processes each accounted for approximately 10 percent.

SLUDGE TREATMENT PROCESSES

The ultimate disposal or reuse of sludges and residues from municipal wastewater treatment will determine the specific processes required in handling and treating the sludges. These processes may include, for example, concentration, stabilization conditioning, and drying (Metcalf and Eddy, Inc. 1972).

Throughout treatment, the solids may be dewatered to reduce sludge volume, size of treatment units, and transportation costs. Sludges are frequently concentrated before anaerobic digestion; any of several means of thickening may be used. Gravity thickening permits the solids to settle and withdraw from the bottom of the tank as a more concentrated slurry, while the supernatant liquid is returned to the wastewater treatment process. Typically, combined primary and activated sludge might be thickened to from 4 to 6 percent total suspended solids on a dry weight basis.

Anaerobic digestion, a possible second step in the sequence summarized above, involves the microbiological decomposition of much of the organic material in the sludge. The products are methane, carbon dioxide, and a stabilized sludge. For the process to work efficiently, the sludge must be well mixed, maintained at favorable temperature and pH values, and devoid of excessive concentrations of toxic materials (Malina 1971). The sludge leaving the process contains stabilized solids and carrier liquid composed of organic material, suspended solids, nitrogen, and phosphorus. Some liquid may be separated in a second stage digestion tank.

Anaerobic digestion reduces the number of pathogens in sludge (Peterson et al. 1973, McWhorter 1974). Digestion periods of 12 to 49 days removed from 85 to about 100 percent of four types of bacteria (U.S. EPA 1974). Enteric viruses are largely inactivated during anaerobic digestion (Lund and Ronne 1973, Bertucci et al. 1975, Malina et al. 1975). Pathogenic organisms that may survive digestion include _Entamoeba histolitica_, _Ascaris_ eggs, _Salmonella_, and helminth cysts.

In contrast to anaerobic waste treatment, the aerobic process stabilizes wastes with aerobic and facultative microorganisms (Metcalf and Eddy, Inc. 1972). Other treatment processes, not now common in the United States, may be employed to reduce the pathogen content of sludge:

pasteurization, irradiation, and composting of sludge with shredded solid waste or wood chips. Composting yields a product with nutrient content and soil building properties valuable for soil application (Epstein and Wilson 1974). In composting systems, fungi and facultative bacteria are responsible for waste degradation under controlled moisture and oxygen conditions.

SLUDGE PROPERTIES

Some of the properties of various sludges are shown in Table 2.2. In general, primary sludges are unstable and may decay, causing odor, but are easier to thicken and dewater than activated sludges. Four sludge constituents with important possible environmental impacts are metals, persistent organics, fertilizer or nutrient content, and pathogen populations.

The concentrations of potentially hazardous metals such as cadmium (5-2000 ppm dry weight), lead (50-30,000 ppm), and zinc (500-50,000 ppm) are variable (Table 2.2). Mercury levels in sludge are usually low (Furr et al. 1976). Persistent organics show similar variability, with a median polychlorinated biphenyl (PCB) concentration of 3.8 ppm dry weight of sludge (Furr et al. 1976). The percentage of fertilizer constituents in dry solids is shown in Table 2.2. If the supernatant liquid is separated, the resulting digested sludge is comparatively lower in nitrogen and phosphoric oxide but has a similar potassium oxide content to that of the undigested sludge.

Other treatment processes which use chemicals to stabilize the wastes result in sludges with different properties. These chemical sludges from municipal wastewater treatment at present account for a relatively small amount of the total sludge produced in the country. A variety of chemicals (e.g., iron, aluminium, or carbonates) may be used in wastewater treatment and the nature of the resultant sludge could vary widely. Owing to lack of data on composition of these chemical sludges and the relatively small amount of such materials at present, this report's evaluation of impacts refers only to organic sludges.

FUTURE INCREASES IN MUNICIPAL SLUDGE

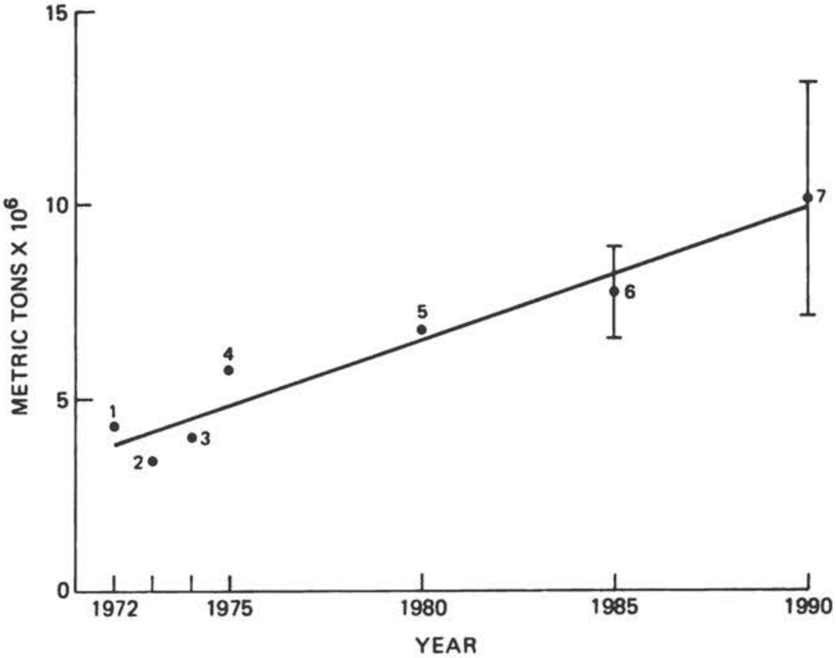
Some estimates of past and future amounts of municipal sludge in the country are presented in Figure 2.2. Amounts will increase as new, upgraded, or expanded plants serve more and more people. Upgrading includes procedural changes that make removal more efficient and, depending on the processes used, create more sludge. Various methods of

TABLE 2.2 Properties of Various Sludges

Raw primary sludge results from sedimentation of wastewater solids, activated sludge from biomass of suspended microorganisms, and trickling filter humus from biomass of attached microorganisms. Stabilization of organic matter in these sludges by aerobic or anaerobic biological processes produces digested sludge. Levels of metals, persistent organics, and pathogens affect the reuse of sludges. Digestion reduces virus and bacteria from levels found in raw sludges, but does not affect metals or persistent organics. Nutrient content of digested sludge can be used by crops. Thermal content determines how easily sludge can be oxidized after sufficient dewatering.

	Raw Primary Sludge		Raw Activated Sludge		Trickling Filter Humus		Digested Sludge		
	Range	Median	Range	Median	Range	Median	Range	Median	Reference
Total Solids (TS) (%)	3-7	5	1-2	1	2-7	4	6-12	10	(1)
Volatile Solids (% TS)	60-80	70	60-80		50-80		30-60	40	(1)
Thermal Content (kJ/kg) × 10^4	1.6-2.3						0.72-1.6		(1)
Nutrients (% dry weight)									
Nitrogen	1.5-8	3	4.8-6	5.6	1.5-5	3	1.6-6	3.7	(1)
Phosphorus	0.8-2.7	1.6	3.1-7.4	5.7	1.4-4	3	0.9-6.1	1.7	(1)
Potassium	0-1	0.4	0.3-0.6		0-1		0.1-0.7		(1)
pH	5-8	6					6.5-7.5	7	(1)
Alkalinity (ppm $CaCO_3$)	500-1,500	600					2,500-3,500	3,000	(1)
Metals (ppm dry weight)									
Arsenic							3-30	14	(2)
Cadmium							5-2,000	15	(3)
Chromium							50-30,000	1,000	(3)
Copper			385-1,500	916			250-17,000	1,000	(3)
Lead							136-7,600	1,500	(2)
Mercury							3.4-18	6.9	(2)
Nickel							25-8,000	200	(2)
Selenium							1.7-8.7		(2)
Zinc			950-3,650	2,500			500-50,000	2,000	(2)
Persistent Organics (ppm dry weight)									
PCBs							1.2-105	3.2	(3)
Chlordane							3-30		(3)
Dieldrin							0.3-2.2	0.16	(3)
Pathogens									
Virus (PFU/100ml)		7.9						0.85	(4)
Coliform (10^6/100ml)	11.0-11.4		2-2.8			11.5		0.4	(5)
Salmonella (per 100ml)		460	74-23,000			93		29	(5)
Pseudomonas (per 100ml)		46,000	1,100-24,000			11,000		34	(5)

[1] Metcalf and Eddy, Inc. (1972).
[2] Furr et al. (1976).
[3] Farrell and Salotto (1973).
[4] Palfi (1973).
[5] Farrell (1974).



[1]Farrell (1974).
[2]Ehreth (1975).
[3]U.S. EPA (1976).
[4]NCWQ (1975).
[5]Ehreth (1975).
[6]NCWQ (1975), U.S. EPA (1976).
[7]NCWQ (1975), U.S. EPA (1976), Ehreth (1975).

FIGURE 2.2 Estimates of present total U.S. sludge production and predictions for future sludge production.

Values for metric tons dry weight produced in the years from 1972 to 1975 are based on estimates of population served by wastewater treatment and per capita solids production. Projections for 1980, 1985, and 1990 reflect the increase of sludge expected to arise from institution of secondary wastewater treatment at all facilities where it is not now in effect, and from construction of new facilities. Ranges are given for 1985 and 1990 estimates. Data presented here indicate that between 1972 and 1990 the amount of sludge produced per capita in the United States may more than double.

estimation (see Figure 2.2) have been used to project future amounts. A comparison of 1972 and 1990 amounts indicates that total sludge production may more than double by 1990.

These future increases ultimately depend upon changes in individual plants. For example, the amount of sludge produced by municipal facilities now conducting primary treatment will increase when biological treatment is installed.

Changes in individual plants are aggregated in the projected national increase, which may not be evenly distributed by geographic area. Some regions will face sludge management problems considerably larger than the national average increase. Projected wastewater treatment needs were used to estimate expected increases in various Water Resource Regions (WRR), from 1973 to 1990 (Figure 2.3). The New England area (WRR 1) and parts of the Rocky Mountain states (WRR 14), the Southwest (WRR 15), and California (WRR 18), show the greatest percentage increases over present amounts. Regions along the Atlantic Coast (WRR 2, 3), in the Midwest (WRR 5), and in the North Central States (WRR 9) show significant increases.

SOURCE CONTROL AND PRETREATMENT

Source control and pretreatment technology may well alleviate some of the problems caused by the projected sludge increases. Source control is defined here as the exclusion at source of material that would harm the collection or treatment process or limit sludge reuse or disposal options. These exclusions may occur through modification of either the industrial processes or the product. Pretreatment of industrial wastewater is defined as the removal of toxic materials at the industrial plant before the wastewater is released to the municipal sewer. The main goal of these processes has been to protect the wastewater collection and treatment system against high organic load, and flammable, corrosive, and toxic substances. The processes are also intended to protect the biological systems affected by the ultimate disposal or reuse of the sludge.

Hazardous metals and persistent organics could be limited by pretreatment and source control. These constituents are contributed by a variety of point and nonpoint sources, but a substantial portion may be attributed to industries that discharge into municipal sewers. Since pretreatment provisions exclude toxic materials from the wastewater system, the outstanding regulatory issues become the effectiveness of such exclusion as well as the possible complications and environmental

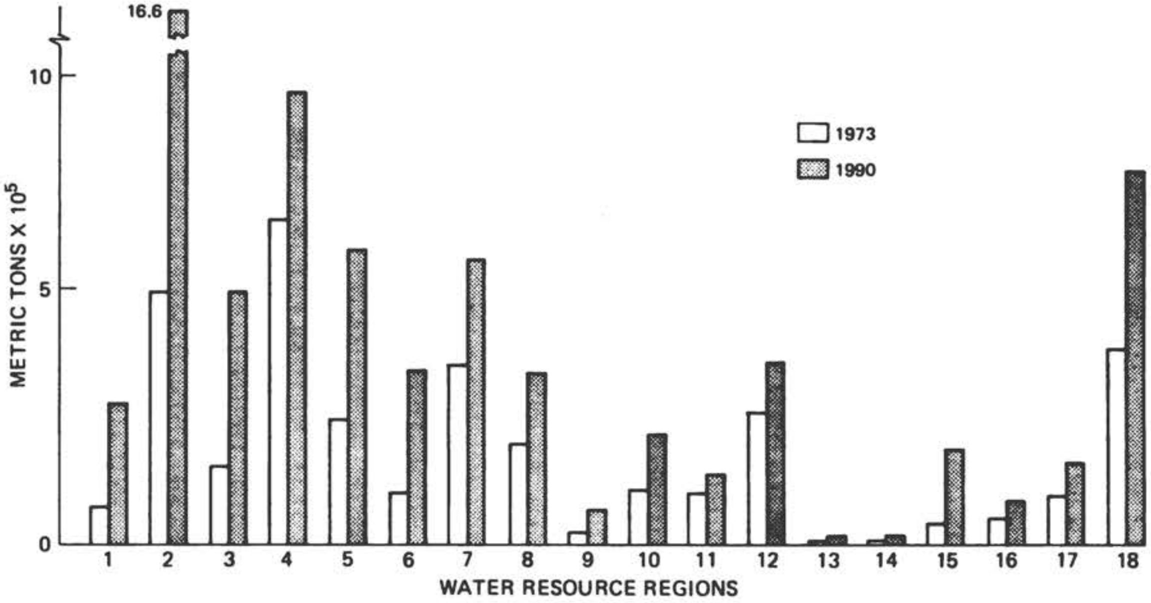
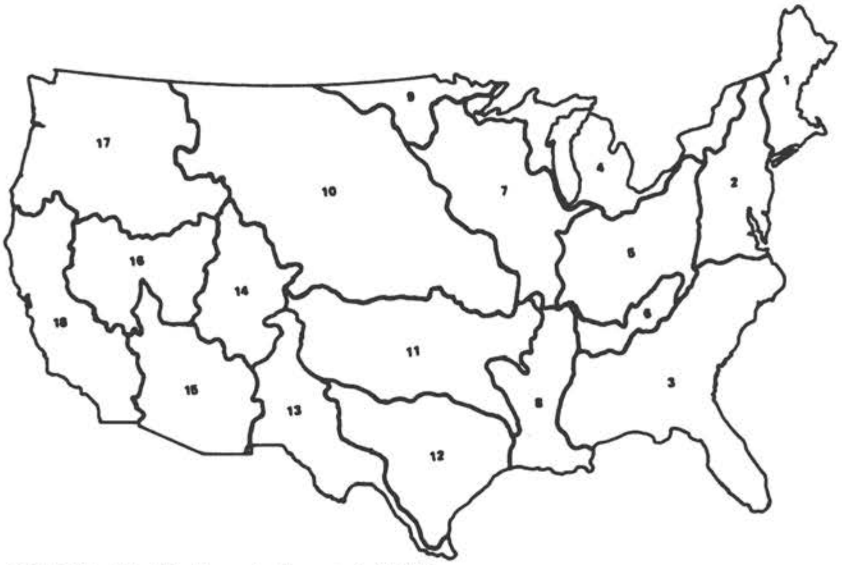


FIGURE 2.3 Estimates of sludge production in 1973 and predictions for sludge production in 1990, by Water Resource Region.

Values for tons of sludge in 1973 were computed from data on suspended solids and percentage reduction of solids, compiled for the National Residuals Discharge Inventory (Luken et al. 1976). Estimates for 1990 are based on increased solids produced by upgrading all facilities to secondary treatment, and construction of new facilities. Regional estimates of the volumes of municipal sludge will be more useful in area planning than will national estimates. Water Resource Region boundaries are shown in Figure 2.4.



SOURCE: Modified from Luken et al. (1976).

FIGURE 2.4 Water Resource Regions of the United States.

Boundaries are shown of the Water Resource Regions whose sludge production data are provided in Figure 2.3. A Water Resource Region is made up of 1 to 9 Aggregated Sub-Areas (ASAs) with similar water management characteristics. An ASA includes an area drained by a river system, a closed basin system, or a coastal drainage area.

impacts of handling and disposing of the isolated toxic materials.

In general, industrial liquid wastes are more varied and more concentrated than municipal wastewaters (Fair et al. 1968). Acids, alkalis, chemical contaminants, oils, coarse solids, and other constituents are included in industrial wastewater. Material that once polluted the air has been converted into water pollutants by scrubbing of stack emissions.

Industrial wastewaters can be pretreated by the same processes as those used for municipal wastewater, or by processes to remove specific chemical constituents (Fair et al. 1968). For example, sedimentation and flotation are used to remove solids and oil or grease, while biological treatment, such as activated sludge and trickling filters, are used to reduce organics. Highly acidic or alkaline waste can be neutralized, either by adding alkali or acid, or by mixing acid and alkaline waste streams. Pretreatment for incompatible (toxic) pollutants usually entails a chemical process. Metals are removed by chemical precipitation followed by removal of precipitates, chemical reduction, ion exchange, or other techniques.

Treatment technology for industry can include process modification and separate treatment of different process wastewaters (Fair et al. 1968). For example, in metal finishing, cyanide wastewaters are chlorinated separately before mixing with wastewater containing metal. A possible benefit of industrial pretreatment and process modification is conservation of water, which can be recycled for cooling and reclamation of materials.

In cases where pretreatment rather than source control is used, toxic materials are isolated at the industrial plant (Fair et al. 1968). Ideally, they are recycled or reused in the industrial process. If recycling is not feasible, the materials require special regulatory oversight to ensure that they are not improperly discarded.

Potential benefits of source control have been examined for New York, Chicago, and Buffalo. The expected and actual metal removals reported in relevant literature are presented in Table 2.3. In Chicago and Buffalo, 50 percent or more of the cadmium, chromium, copper, nickel, lead, and zinc appears to be removable through source controls. Less promising results were estimated for New York City (Klein et al. 1974). If these limited findings may be extrapolated, the potential for significant reductions throughout the country may become important in reducing future problems related to hazardous metal content.

TABLE 2.3 Metal Reduction in Sludge by Industrial Pretreatment

Data on industrial wastewater pretreatment and resulting metals removal, actual or expected, are shown for three industrial cities. Actual levels of metals in sludge before and after implementing a pretreatment ordinance, and the calculated percentage of removals, are shown for Chicago. Percentages of removals observed in the Buffalo pilot plant are used to calculate levels of metals remaining in sludge after pretreatment. Expected removals for New York City are based on the percentage of industrial contribution of metals to municipal wastewater, determined by survey. In each case, reductions of metals can be demonstrated for pretreatment of industrial wastewaters.

		Chicago[1] Level (ppm)			Buffalo[2] Level (ppm)		New York City[3]
Metal	Removal %	Before	After	Removal %	Before	After	Removal %
Cadmium	71.6	190	54	50.0	100	50	39
Chromium	62.4	2,100	790	79.0	2,540	1,040	52
Copper	81.2	1,500	282	59.1	1,570	330	19
Lead	73.0	1,800	486	66.4	1,800	605	–
Nickel	92.3	1,000	77	63.5	315	115	65
Zinc	49.1	5,500	2800	84.0	2,275	364	20

[1] Data from Zenz et al. (1975).
[2] Data from R. S. Kerr Environmental Research Laboratory (1977).
[3] Data from Klein et al. (1974).

Implementation of source control systems in the past has relied upon four conditions. First, where wastes had to be controlled at the source, the discharger was required to construct and operate the facilities. Second, where wastes were totally excluded from the municipal system the discharger had to finance the process. Third, where wastes from industry could be treated and safely disposed of in the municipal system, wastes of unusual quantity or strength were handled by surcharges. Finally, in the past, industry had the responsibility for monitoring its waste streams.

The present EPA guideline for industrial pretreatment (U.S. EPA 1977) in the first place limits discharges of toxics to levels which will not interfere with waste treatment by the municipal facility, or pass through into the municipal effluent. The guidelines are further tied to the removal efficiencies of both the pretreatment process and the municipal treatment works. That is, the removal rate of the latter may be such that higher levels of toxics may be permitted in the industrial discharge than would ordinarily be permitted. However, this strategy does not specifically prevent the introduction into municipal sewage sludge of those contaminants that limit sludge disposal.

FINDINGS AND ANALYSIS

1. The municipal wastewater management system currently designed to separate potentially harmful constituents from effluents includes wastewater inputs (industrial, commercial, and household wastes, runoff, and infiltration) and process inputs (among others, chemicals and energy). For maximum benefit to the environment, the full system, including the sludge management options that are the subject of this report, should incorporate analysis of the multiple relationships between the indirect and direct inputs, levels of treatment, and disposition of gaseous, liquid, and solid residuals. The production of higher quality liquid effluents to meet environmental goals will result in increased environmental impacts in several other parts of the system.

2. Wastewater treatment processes may produce widely varying amounts and characteristics of sludge, depending upon processes used and removal efficiencies sought.

3. Sludge treatment processes alter the material to make it more amenable to handling, disposal, and reuse. Pathogen reduction may be accomplished to varying degrees through anaerobic digestion, composting, pasteurization, radiation, and other methods.

4. Reuse or disposal options will be environmentally acceptable only if metals, persistent organics, nutrient value, thermal or energy content, and pathogen content, and other constituents are, for a given option, kept within certain limits.

5. National figures project that by 1990 the volume of sludge will be more than double the amount produced in 1972. Specific regions may show even greater increases.

6. Source control and pretreatment show potential for a significant reduction of hazardous metals in sludges produced by wastewater treatment in urban areas. Guidelines for pretreatment should specifically deal with levels of toxics in sludge, and not only with levels discharged to the wastewater collection system.

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CHAPTER 3

IMPACTS OF DISPOSAL OR USE OF MUNICIPAL SLUDGE

INTRODUCTION

The sludge produced by municipal wastewater treatment plants in the United States is disposed of in various ways: about 15 percent is dumped in the ocean, 40 percent deposited in landfills, 20 percent used as a resource on land, 5 percent spread on land not in agricultural use, and 25 percent incinerated (Farrell 1974). Ocean disposal, although substantial for some highly populated coastal areas, is employed by comparatively few municipalities. Wastewater facilities with a low flow capacity generally choose landfill; small rural communities tend to prefer landspreading. Incineration is often used by facilities that receive a wastewater flow of more than 5 million gallons per day (mgd) ($1.2. \times 10^4$ m^3/day) (Metcalf and Eddy, Inc. 1976).

This chapter discusses options for disposal and resource recovery from the point of view of the impacts of sludge on the environment and human health. Examination of the impacts--primary, secondary, and human health aspects--is followed by discussion of their relationship to sludge management activities--site selection, technology, and monitoring. The implications for ocean, land, and air are separately considered for each topic, and synthesized in a comparative analysis of options for sludge management at the end of the chapter. Impacts are defined here as any alteration of the existing environment, positive or negative, that may result from placement of the residual material. If recovery of resources is the primary goal, the aim of sludge management should be to enhance the environmental impacts. Conversely, if sludge is considered a waste material, the goal should be to reduce impacts.

PRIMARY ENVIRONMENTAL IMPACTS ON THE OCEAN

Circulation patterns, interaction of water movements with bottom topography, and biological processes control movements and fate of sludges discharged to coastal ocean waters. Data are sufficient to permit general descriptions of the physical behavior of sludge constituents but not of specific biological effects on marine ecosystems (see Table 3.1).

Sludges are mixtures of water and solids which separate into liquid, particulate, and floating components when released to coastal waters (Calloway et al. 1977). Coarse-grained particles in sewage sludges sink rapidly, low-density particles more slowly. While sinking, particles are dispersed and mix with the wind-stirred surface waters. During most of the year, the surface layer is partially isolated from subsurface waters by a highly stable pycnocline zone. The low-density effluent plume may not mix readily with the denser waters below the pycnocline, instead remaining near the surface where it may be moved by winds and surface currents. When river discharge and rainfall exceed evaporation in coastal areas, the net estuarine circulation may move solids toward the shore with the near bottom currents.

Floating Debris, Surface Films

Appreciable quantities of oils, greases, and sewage artifacts may remain on or near the ocean surface after sludge disposal unless the sludge has been adequately treated. These materials may discourage recreational boating, fishing, and other uses of coastal waters. Some floating materials may also wash up on bathing beaches, depending upon the location and characteristics of the disposal site as well as the characteristics of the sludge; however, in many coastal ocean areas, more floating material may be contributed by rivers, storm water runoff, and vessel refuse than by sewage sludge disposal (NOAA 1977).

Dissolved Oxygen Concentration

Substantial quantities of dissolved oxygen are required to oxidize organic matter in sewage sludges. Sediments suspended during and after major storms consume large quantities of oxygen (Drake 1974). It thus seems likely that dumped sewage sludge contributes to the observed low oxygen concentrations of some continental shelf areas during times of a well developed pycnocline in summer. Discharge of sewage effluents from all sources and production of plankton supported by nutrients derived from sludge and other sources can also significantly deplete dissolved oxygen in coastal waters (Segar and Berberian 1977). Oxygen may also be depleted when abnormal wind conditions change currents in coastal areas used for sludge disposal.

TABLE 3.1 Summary of Behavior and Environmental Effects in Coastal Ocean Areas of Various Constituents in Sludge

Behavior of sludge constituents in the ocean and their effects on marine organisms are determined by their physical, chemical, and biological properties. Currently unavailable quantitative data on circulation patterns, interaction of water movements with bottom topography, and biological processes would be necessary for a comparison with land application.

Constituent	Environmental Behavior	Environmental Effect
Pathogens Bacteria Viruses	Associated with particles and surface films	Possible transfers to humans through ingestion (food or liquids) and body contact sports
Metals Lead Cadmium Mercury	Dissolved and/or associated with particles	Concentration by organisms (e.g., shellfish). Possible transfers to humans through shellfish or other seafood.
Polychlorinated biphenyls	Associated with particles	Concentration by organisms
Low-density solids	Easily eroded and transported by currents and wave action	Changed benthic community and abundance of organisms. Possible transport of pathogens and chemical constituents
Nutrients Phosphate Nitrogen compounds	Dissolved in waters, locally concentrated by marine phytoplankton	Increased productivity. Possible depletions of dissolved oxygen in near-bottom waters

Sludge Solids

Whether discharged by pipeline or barge, solids are moved by currents as they settle. Thus the depositional patterns of sewage-derived solids are highly dependent on local currents and on the effects of storms which can erode deposits and transport solids on the continental shelf.

Prediction of sewage sludge accumulation on the continental shelf is difficult for two reasons: (1) data available on currents for most coastal ocean areas are limited, and (2) existing methodologies do not readily lend themselves to quantitative estimation of fine sediment transport. Deposition eventually occurs if fine particles are introduced faster than they can be removed by waves and currents or destroyed by biodegradation, but data on most ocean areas are inadequate to predict the threshold at which sludge particles accumulate. Tidal and wave-generated currents keep fine-grained sediment suspended and even resuspend it after deposition. In deeper waters, sludge particles may be dispersed over large areas of ocean bottom, but are less likely to be resuspended except during severe storms.

Sludge solids normally accumulate first in depressions on the ocean bottom, especially during quiescent periods. Shelf valleys, such as the Hudson Shelf Valley in the New York Bight, are natural sinks for fine sediment and sludge solids.

Sludge particles have been shown to reach the bottom and accumulate in quantities sufficient to increase significantly the metal and organic carbon content of bottom sediments at water depths of up to 300 feet (90 m). Mackay et al. (1972) compared measurements of amounts of organic carbon and metals from sludge in sediments of the Firth of Clyde to those observed in the New York Bight Apex. The similarity of findings was notable because, although the sludge inputs were similar in constituent concentrations, the amounts and water depths involved were very different: the Clyde sludge total was only one fifth the amount dumped in the New York Bight, and the receiving waters are 300 feet (90 m) deep in comparison with water depths of 180 feet (55 m) in the Bight (Mackay and Topping 1970).

In the New York Bight, after 50 years of sludge disposal, deposits now cover about 50 km^2 of ocean bottom near the head of the Hudson Submarine Canyon (Lerner and Wood 1971). Deep currents apparently move both up and down the canyon so that sludge materials may be transported down the canyon axis as well as along the continental shelf (Hatcher and Keister 1977). The deposits are apparently carried short distances by seasonally variable deep currents

(Harris 1977). The bulk of the material is deposited in the Hudson Canyon, where chemical and biological degradation apparently act as a brake on inordinate build-up of material (Swanson 1976).

In the area off the mouth of Delaware Bay used by Philadelphia, Pennsylvania and Camden, New Jersey for disposal of barged sludges, observed concentrations of silver and zinc in sediments indicate that sludge solids move some tens of kilometers shoreward and disperse in a band roughly parallel to the coast (Rutherford and Church 1975). Effects in these sites are markedly less severe than those observed in the New York Bight, apparently because sludge has been deposited there for a shorter time (1973 to 1976) and in smaller quantities, and because currents and waves are more vigorous.

Lear (1976) found that the biotic communities that live on the bottom of the Middle Atlantic continental shelf (depth 35-55 meters) had been affected by the disposal of approximately 25,000 tons of sludge solids from Philadelphia-Camden per year since 1973. The major effect was a shift in population structure. The formerly abundant polychaete worm _Spiophanes bombyx_ had been partially replaced by nematodes more tolerant to pollution. Metals in the sludges--particularly nickel, cadmium, and copper--were taken up by shellfish (_Artica islandica_ mahogany clams and _Placopecten megellanicum_ scallops).

Sludges discharged at the head of Santa Monica Canyon, California have apparently been moved down the canyon from the discharge point. In 1976, about 2 km^2 were affected by high carbon contents (more than five times background) and elevated metal concentrations (five to thirty times background) (Schafer and Bascom 1976). Deposits enriched in silver, cadmium, copper, chromium, lead, mercury, and nickel extended more than 2 kilometers down the canyon (SCCWRP 1975, Schafer and Bascom 1976).

Alteration of Benthic Communities

Large quantities of carbonaceous material in sewage sludge are commonly deposited on the bottom in shallow waters before becoming oxidized, along with silts, clays, and their associated contaminants. Where these fractions accumulate quickly enough, they will probably modify benthic invertebrate communities. Diversity and abundance of benthic fauna on the shallow continental shelf have been greatly modified in the New York Bight near areas of disposal of sludges and dredged materials, and in some places sediments have been emptied of normal benthic macrofauna (NOAA 1976).

Alteration of the physical characteristics of the bottom by compaction of mud and subsequent erosion may change benthic communities significantly (Rhoads 1967). Measurable changes may occur in the chemical and physical properties of the sediments, including increased concentrations of metals, longer-chain hydrocarbons, and increases in organic matter. High concentrations of metals harm marine organisms (NRC 1975a, 1975b) and accumulations of sewage sludge in continental shelf sediments may cause diseases such as shell erosion in crustacea (National Marine Fisheries Service 1972, Young and Pearce 1975) and fin-erosion in fishes (Mahoney et al. 1973, Murchelano 1975, Ziskowski and Murchelano 1975).

Contamination of the water column and sediment water interface by petrochemicals and synthetic organics can be expected to harm populations of some marine organisms (American Petroleum Institute 1975; NRC 1975a, 1975b). Furthermore, the organic fractions of sewage sludges consume seabed oxygen required by benthic communities, and sediments receiving sewage sludges generally support extremely large microbial populations that use the organic matter as a substrate.

Studies of comparable waters indicate that sewage sludges reach the sediment interface and cause changes in species composition of benthic invertebrate assemblages (Mackay et al. 1972) and uptake of metals by invertebrates (Steele et al. 1973). But predictions about the effects of offshore sludge disposal on ocean-floor organisms are tenuous. There is inadequate information about (a) dispersal of sewage sludge solids, (b) areas where sewage solids accumulate, (c) rates of deposition, and (d) nature of benthic fauna on the shelf (especially in topographic lows).

Environmental effects of major sludge constituents (carbon contents, nutrients) are not easily controlled. Unless the sludges are disinfected, pathogens may still be transferred to humans through the eating of shellfish or through water contact sports.

Disposal Operations in Great Britain

Sewage sludges from London have been dumped in the Outer Thames Estuary since 1887 (Shelton 1971, 1973). Major disposal operations were studied at Manchester and Glasgow (Mackay and Topping 1970, Mackay et al. 1972). Dissolved oxygen depletion in sludge disposal areas has not proved a problem in Great Britain, largely because of high dissolved oxygen concentrations, strong tidal currents, and relatively low water temperatures, which favor dispersal of the wastes, re-aeration of sea water, and rapid removal of contaminated waters from the disposal sites. Nutrient input from sludge is small by comparison with input from other sources; only 7 percent of the nitrogen entering the North Sea can be attributed to sewage discharges of all types, and there is little evidence of excess plankton production or eutrophication (Portmann 1974).

Mariculture

Treated sewage effluents and sludges might conceivably be deliberately discharged to alter coastal ocean waters in order to increase production of fish and other food organisms. No experimental work on these potential positive impacts of ocean disposal has been done, however, in United States coastal waters. There are some indications that such reuse might be effective: the productivity of New York Bight waters has apparently surpassed that of nearby continental shelf areas (Malone 1977), benthic biomass near sludge outfalls has increased, and deep water marine organisms now come into shallower waters to feed near outfalls (SCCWRP 1975), leaving when discharges cease.

PRIMARY ENVIRONMENTAL IMPACTS ON THE LAND

In disposal or use of sludge on land, landfilling is used exclusively as a means of disposal, while landspreading is used as a means both of disposal and of resource recovery, principally the latter. The impacts of the two techniques are determined by many of the same variables, among them sludge composition, application rate, soil characteristics, climate, and groundwater hydrology (see Table 3.2). In many important respects, however, the nature and significance of the impacts of landfilling and landspreading differ, as a consequence of the differing practices and functions of the two techniques.

Impacts of Sludge Disposal in Landfills

When properly sited, designed, constructed, operated, and managed, landfilling appears a potentially safe means of containing sludges (Stone 1975). Costs vary with conditions, but in many areas available technology would permit landfilling without harm to the environment. Where sites are not readily available, or do not meet the minimum criteria, costs may be high and environmental risks significant.

TABLE 3.2 Principal Variables in Use of Land for Sludge Management

Of the variables listed, some, such as application method and rate (Table 3.11) and crop management, can be controlled. Composition of sludge can be influenced by choice of treatment and by source control and wastewater pretreatment. Effects of these variables are considered in evaluation of impacts of sludge disposal by landfill or surface spreading, and those involved in resource recovery by landspreading for agricultural use.

Element	Variables
Sludge	1. Composition
	2. Type of treatment
Application	1. Method
	2. Loading rate
Soil	1. Texture[a]
	2. pH
	3. Organic matter content
	4. Cation exchange capacity
	5. Percent base saturation
	6. Depth
	7. Slope
Climate	1. Temperature regime
	2. Precipitation regime
Crop	1. Uptake
	2. Management
Ground Water	1. Depth to zone of saturation
	2. Nature of zone of aeration
	3. Natural quality of ground water
	4. Physical nature of aquifer
	5. Chemical nature of aquifer

[a] This includes infiltration rate, permeability, and available moisture capacity, each of which could well be considered as a separate variable.

SOURCE: Wilson (1975).

Substandard landfill site selection, preparation, or operation can cause excessive odors, unsightliness, pollution of surface and groundwaters, and proliferation of disease vectors such as rodents and flies. Covering the landfill daily with soil mitigates odor and vector problems. Equipment noise, spillage, and dust can be lessened by tight fencing, watering, and barrier vegetation (Stone 1975).

Improper siting and excavation of landfills can significantly alter patterns of erosion and sedimentation. Measures such as gradient limitation, drainage diversion, and the use of sedimentation basins are required to reduce erosion.

Leachate from a landfill (consisting of sludge moisture, infiltrating rain, and ground and surface waters) may transport metals and pathogens to other water supplies, including drinking water (Wilson 1975). Constituents of concern in the leachate include nitrate (derived from organic and other forms of nitrogen in the sludge), gases, pathogens, and toxic metals.

Wilson (1975) identified constituents of a representative sludge percolate from a landfill disposal (Table 3.3). The amounts of these constituents in leachate depend on the moisture in the landfill, the proximity to groundwater, and the soil characteristics. An upper level aquifer may subsequently transport leachate to surface waters (Wilson 1975). Of the constituents listed, the heavy metals (lead, cadmium, mercury, and zinc) may be strongly attenuated by a clay lining (Griffin et al. 1976). Iron, magnesium, potassium, and ammonium ion would be only moderately attenuated. Chloride, sodium, and water-soluble organics are little attenuated by clay. Chemical or biological activity in surrounding soils may improve the quality of water leaching from sludge deposited in landfills.

Impacts of Landspreading

Nearly all the sludges produced by secondary treatment and advanced chemical treatment can be applied to the land surface or upper soil layers. At present, anaerobically digested sludge is applied most frequently.

Soils may be harmed by chemical sludges, because of the use of lime, alum, or iron salts to remove solids or phosphates (Carroll et al. 1975). Because of their low nitrogen concentration, some chemical sludges are not considered valuable as fertilizers.

TABLE 3.3 Constituents of Sludge Percolate

A significant potential impact of landfills results from the generation of leachate, made up of sludge moisture and infiltration of precipitation and ground and surface waters. The chemical nature of this percolate derives from the properties of the sludge and the products of decomposition. Constituents that may exceed limits for drinking water include iron, manganese, nitrate, cadmium, and lead.

Constituent	Percolate concentration mg/l
Iron	0.04 - 5.40
Manganese	0.05 - 0.68
Calcium	8 - 107
Magnesium	3 - 152
Sodium	0.90 - 47
Potassium	0.70 - 11
Sulfate	2.4 - 156
Chloride	0.35 - 59
Ammonium	0.40 - 1.28
Nitrate	8 - 15
Total Nitrogen	8 - 25
Phosphate	0 - 1.2
Organic Carbon	7 - 12
Boron	0.40 - 2.0
Cadmium	0.04 - 1.20
Chromium	0.01 - 0.04
Cobalt	0.02 - 0.04
Copper	0 - 0.25
Lead	0.05 - 0.22
Mercury	0.001 - 0.0014
Molybdenum	0.01 - 0.05
Nickel	0.006 - 2.00
Silver	0.01 - 0.30
Vanadium	0.03 - 0.04
Zinc	0.006 - 0.27

SOURCE: Modified from Wilson (1975).

Positive Impacts

The available literature indicates that the principal benefits of spreading liquid sludge on the land may be improved soil quality (structure, humus content, water-holding capacity), and addition of nutrients to the soil. Both of these impacts increase fertility and plant growth (Carroll et al. 1975, Knezek and Miller 1976). Results from various studies are difficult to compare because of soil and other regional differences and wide variation in sludge characteristics; nevertheless, there is general agreement that sludge has potential as an agricultural and silvicultural resource and may well be an aid in reclamation of land.

Improved Soil Structure. Humus in soil is dynamic, and is continuously broken down by microorganisms. It provides many of the nutrients for crops. Application of sludge increases the humus content of the soil, may alleviate the unfavorable structural characteristics of some clay soils, and promote soil aggregation and add chemical reaction sites for nutrient exchanges in sandy soil. Thus the organic matter added from sludge generally improves soil tilth. For example, one study has shown digested sludge applied on a sandy soil and a loam soil increased field moisture capacity, noncapillary porosity, and cation exchange capacity (Carroll et al. 1975). Organic matter content, total nitrogen, and soil aggregation increased significantly. Benefits were found to be greater in the sandy soil than in loam.

Nutrient Addition. Concentrations of nitrogen, phosphorus, and potassium in sludge depend on initial inputs into the wastewater system, type of treatment, and management of the sludge between treatment and incorporation into the soil. The solids portion of the sludge contains much of the nitrogen and phosphorus, the liquid portion some nitrogen and most of the potassium. Therefore the sludge needs to be applied in liquid form in order to realize the complete value as a fertilizer (Carroll et al. 1975).

Since concentrations of the nutrients that increase soil fertility are considerably lower in sludge than in commercial fertilizers, sludge needs to be applied very heavily in comparison to inorganic fertilizers. For example, the nutrient content of sewage sludge, in the usual fertilizer terminology, is approximately 2-4-0.5 (N, P, K), totaling 6.5 percent on a dry weight basis (Keeney et al. 1975). This total may be compared with an average total analysis of 43.2 percent for chemical fertilizers used in the United States in 1972.

Much of the nitrogen in sludge is organic and only slowly available to plants (Keeney et al. 1975). Phosphorus and potassium are considered to be as available in sludges as in chemical fertilizers.

Applications of sludge and commercial fertilizer to various crops have been compared in several studies. The results of a study by Walsh et al. (1975) are shown in Table 3.4: while a smaller application of commercial fertilizer produced yields in the first year similar to those from land treated with the highest sludge applications, the following year the yield of the commercially treated plots dropped more markedly than that of the sludge-treated plots, because of the delayed release of nitrogen and phosphorus from sludge.

Because different crops use different amounts of nutrients, the benefits of using sewage sludge depend on the crop (Knezek and Miller 1976). Much of the nitrogen content is organic and must therefore be mineralized to inorganic form before it is available to plants. With slow release, nitrogen may be insufficient to meet the needs of some crops. If additional sludge is added to compensate for the slow rate of release, heavy mineralization of nitrogen may continue after harvest, leaving in the soil nitrate capable of leaching. On the other hand, the slow-release of the nitrogen can be an advantage on sites such as forest land, where application is infrequent.

Sewage sludge also contains considerable quantities of calcium and magnesium, which are important plant nutrients. High applications of most sludges will tend to buffer the pH of soils. This is particularly valuable for very acid soils such as those found in mine spoil banks.

Sludge should not be applied to soils bearing root crops or vegetables that are consumed uncooked (Keeney et al. 1975). In soils where animal feed is grown, an adequate interval should elapse between final application and consumption.

Forest and Park Application. Fertilizing forests with sludge, although not widely practiced at present, may be beneficial after logging operations. There is, however, danger of nitrate pollution of water when sludge is applied to some forest soils that are low in organic matter and highly permeable to water which will carry nitrate nitrogen. Existing root channels speed infiltration and subsurface flow of water and nitrogen to stream channels (Hall et al. 1976).

Results of a study of sludge used to promote forest growth (Edmonds and Cole 1976) suggest that seeding grasses

TABLE 3.4 Crop Yields as Affected by Liquid Digested Sludge

The value of sludge as a soil amendment and the most effective application rates were determined in a study of crops grown on acreage applied with a range of tons of sludge per acre. Results demonstrated that sludge made phosphorus available, and slowly released nitrogen to the benefit of crop plants.

Treatment[1] Tons Per Acre of Sludge (Dry Weight Basis)	1st Year Corn (1972)	2nd Year Corn (1973)[2]	1st Year Sorghum-Sudan (1972)	2nd Year Sorghum-Sudan (1973)[2]
	bu/acre[a]		tons/acre[b]	
0 Control	55	37	2.06	1.83
3.5	82	53	2.88	2.12
7.0	84	42	3.02	2.25
14.0	101	44	2.94	2.47
21.0	93	48	3.41	2.62
Water[3]	64	45	2.35	1.76
Fertilizer[4]	102	23	3.37	1.79

[1] Sludge was applied in the late fall prior to planting the first year of corn or sorghum-sudan. No additional sludge was applied.

[2] Severe drought lowered yields in the second year.

[3] Water was applied at a rate equivalent to that applied with 10.5 tons/acre of sludge (3 acre-inches).

[4] Plots were treated once with 325 + 220 + 100 lbs/acre of N + P_2O_5 + K_2O commercial fertilizer prior to planting the first year crop.

SOURCE: Modified from Walsh et al. (1975).

[a] bu/acre × 0.90 = m^3/ha.

[b] tons/acre × 2.24 = MT/ha.

after application could reduce nitrate losses. The researchers found that tree growth and foliar nitrogen increased with one application of a sludge containing from 2 to 4 percent nitrogen spread to an average depth of 15 cm. Heavy applications of sludge, however, injured trees. The sludge decomposed rapidly in the forest site (Edmonds and Cole 1976); one year after application it resembled a friable soil. Sludge bacteria did not penetrate more than 3 cm into the soil and therefore did not enter groundwater, but airborne bacteria and fungi presented a potential health hazard. Cadmium, lead, and zinc showed an affinity for the upper soil horizon.

These studies lead to the conclusion that sludge has characteristics which, with careful management, can improve the soil environment for tree growth to an extent limited only by the assimilative capacity of the soil-plant system (Olson and Johnson 1973).

Park land, turf farms, and relatively undeveloped urban property may also offer attractive sites for sludge use. However, public reaction to spreading sludge in parks tends to be unfavorable (Schmid et al. 1975).

Land Reclamation. Sludge application for the rehabilitation of strip-mined or other low-quality land is receiving increasing attention (Halderson et al. 1974). Studies of the use of municipal sludge to treat strip mined areas have shown that organic and nutrient content of the sludge improve poor, sterile soil (Battelle Pacific Northwest Laboratories 1974).

The quantity of sludge needed to restore such areas depends on the nature of the land being treated. For example, reclamation of soil affected by acid drainage required more sludge than calcareous and strongly alkaline soils (Lue-Hing et al. 1974). The benefit of restoring these lands to productive use may offset the temporary high nitrate hazard attending the high rates of application.

Negative Impacts

Phytotoxic Metal Accumulation in Soils. Much research has been concerned with the possible effects of toxic metals and other persistent chemicals that may be present in sludge. Many agronomists are apprehensive that these metals may accumulate in the soil to a level that is toxic to crops (Chaney et al. 1975, Keeney et al. 1975). Research has shown that soil properties such as organic matter, cation exchange capacity, iron and manganese oxides and clay content, and crop species can influence the phytotoxicity of zinc, copper, and nickel.

Phytotoxicity of various metals, and the interactions between soil properties, metals, and plant uptake have been studied (Knezek and Miller 1976). A review of the potential hazards of metals to plants and animals has been made by the Council for Agricultural Science and Technology (CAST 1976). Studies by Simon et al. (1974) demonstrated that leaf content of zinc and cadmium decreased as soil pH increased; Roth et al. (1971) found that copper and nickel influences the phosphorus and iron nutrition of soybean plants.

Walsh and coworkers (1975) conducted experiments with corn and sorghum to determine how much copper and zinc were retained at different levels of sludge application. The levels of metals in the plant tissue were below those recognized as toxic for plants, even at the highest rate of sludge application (see Table 3.5). However, total metal accumulation in soil from a series of sludge applications is a more important consideration.

Various attempts have been made to quantify the potential phytotoxicity of land application of sludges. One approach, first proposed by Chumbley (1971) and elaborated on by Chaney (1973), is based on the relative toxicity of copper, nickel, and zinc. It has been suggested (Chaney 1973, Chaney et al. 1975) that the effect of soil sorption properties be accounted for by limiting the total phytotoxic metals, expressed in "zinc equivalents" (Zn eq) to a percentage of the cation exchange capacity (CEC) of the soil.

More recent information suggests that use of the zinc equivalent relationship for copper, nickel, and zinc underestimates the amounts of sludge-borne metals that can be applied to neutral to calcareous soils (CAST 1976). The maximum safe applications of individual metals can differ among soils owing to differences in cation exchange capacity and the relative toxicities of the various metals (Sommers and Nelson 1976). They suggest eliminating the concept of the zinc-equivalents equation and propose instead limits for each individual metal.

The CAST report also concludes there must be a limit to how much a soil can assimilate metals and still maintain normal crop productivity. The conclusion is based on studies of the effects of adding inorganic salts of metals to soils as well as studies of soils contaminated with metals from mining and smelting activities. Data currently available are not sufficient to determine the maximum amounts of heavy metals that can be tolerated.

Recent research results (Chaney 1976) show that many plants grown on nearly neutral to calcareous soils will tolerate high levels of zinc in the soil and still show

TABLE 3.5 Effects of Sludge Application on the Concentration of Copper and Zinc in Plants

At an experimental farm where liquid digested sludge was applied to crops in amounts up to a one-time application of 28 tons per acre,[a] metal levels in plant tissues were below those recognized as being phytotoxic. Phytotoxicity was not observed in this short-term experiment.

A. Copper

			Crop				
Rate of Application			1st Year Corn		2nd Year Corn		
Sludge	Cu	Rye	Grain	Stover	Grain	Stover	Sorghum-sudan
tons/acre[a]	lbs/acre[b]	ppm Cu[1]					
0	0	3.8	0.4	1.6	0.4	2.1	6.1
3.5	8.6	7.0	0.6	2.2	0.2	2.9	6.4
14.0	34.4	9.4	0.5	2.7	0.5	3.8	6.6
28.0	64.8	11.7	0.4	2.9	0.3	3.9	9.4

B. Zinc

			Crop				
Rate of Application			1st Year Corn		2nd Year Corn		
Sludge	Zn	Rye	Grain	Stover	Grain	Stover	Sorghum-sudan
tons/acre[a]	lbs/acre[b]	ppm Zn[1]					
0	0	21	18	23	21	28	70
3.5	17.8	32	19	24	21	27	102
14.0	71.2	46	22	42	20	42	106
28.0	142.4	56	22	50	22	49	122

[1] Plant growth may be reduced when the level of copper in the plant leaves exceeds 30 ppm and when the level of zinc in the plant leaves exceeds 150 ppm.

SOURCE: Modified from Walsh et al. (1975).

[a] tons/acre × 2.24 = MT/ha.
[b] lbs/acre × 1.12 = kg/ha.

increased concentration of cadmium. The CAST report concludes that it seems advisable to abandon the ratio of zinc to cadmium in sludges as a criterion for limiting or regulating applications of sludge to soil, especially if the pH is above 6.5.

Keeney and coworkers (1975) have noted that metal toxicity to crops from sewage sludge application in the United States has not so far been documented. Chaney (1976), however, has cited examples of such phytotoxicity in Europe. In general, phytotoxicity has been reported from laboratory studies in tests using many times the recommended level of sludge or metal salts.

Cadmium Enrichment. Cadmium appears to be of greater significance for human consumption (a factor considered later in this chapter in the section on human health aspects) than for plants (Braude et al. 1975). Plant uptake of cadmium is extremely complex. If the cadmium level in the soil is constant, soil pH, CEC, organic content, zinc, copper, temperature, plant species, age, and plant part (e.g., grain, leaf) will all affect the cadmium content of the edible portion of a crop (John et al. 1972).

Cadmium is relatively mobile in soil and is not excluded by plant roots (Lagerwerff 1974). Since cadmium occurs commonly in zinc, lead-zinc, and lead-copper-zinc ores and has a number of industrial uses, it is being added to the environment at a significant rate (Page and Bingham 1973). Fleischer (1973) estimates that human activities account for about 90 percent of the cadmium discharged to the atmosphere and to streams.

Walsh et al. (1975) report that cadmium and other hazardous metals such as copper and zinc do not appreciably accumulate in the seed portion of the plant. They suggest that if crops grown on soil amended by sludge are harvested for their seed only, potentially harmful elements will not accumulate in the food chain even when sludge is applied at high rates.

PCBs and Pesticides. Persistent organic contaminants such as polychlorinated biphenyls (PCBs) and chlorinated hydrocarbon pesticides are discharged by industrial effluent sources to many municipal sewage systems. Some sludges with up to 450 ppm of PCBs have been reported where such discharge occurs,[1] but no studies are yet available on fates of PCBs in soil or plant or animal uptake from landspreading of sludges containing PCBs.

A consideration that concerns all the hazards just discussed is the period of time a site may be used for sludge application as a nutrient supplement. The average useful life of sites subjected to intensive application in the past was about 20 years (Schmid et al. 1975). The accumulation of metals and the persistence of chlorinated hydrocarbons in the soils may limit the use of sludge on most soils over time unless the concentrations of such materials in the sludge are minimized through source control and pretreatment of industrial wastes.

Reducing Negative Impacts

Bernard (1974) indicated that 2 to 5 percent of the nitrogen fertilizer needs of the United States might be met by widespread land application of sludge if it were of "fertilizer quality," i.e., if the concentrations of hazardous materials (heavy metals, toxic organics and pathogens) were kept within limits acceptable for widespread and continuous use. With the present rate of increase in sludge production (see Chapter 2), this source of nitrogen fertilizer may be at least doubled within the foreseeable future.

Production of fertilizer-quality sludge requires limits on allowable concentrations of heavy metals and synthetic organics in sludge based on crop tolerances, transfers within the food chain, and soil productivity. If discharges to the municipal wastewater stream are controlled, sludge with concentrations below the limiting values can be produced.

One approach would be to limit the metals in the sludges to nonphytotoxic levels (Chaney 1976, Stewart and Chaney 1975). An alternative measure would be to set limits in sludge at levels that would maintain metals and organics in human food below some specified level. However, as yet no limits have been set for most metals because data on interactions with soils are insufficient (CAST 1976). Relatively few limits have been established for the persistent synthetic organics.

Composting has been used to treat sludge to produce fertilizer. In this biological process, either raw or digested sludge is layered with wood chips or other organic matter that will help decompose it into a relatively stable material with good fertilizer qualities. The temperatures generated during the process greatly reduce or eliminate pathogenic organisms (Epstein and Willson 1975) and the final product is dry and acceptable for use in urban areas or on agricultural land. Composting initially raises sludge pH and stabilizes the organic matter. Both developments serve to reduce metal availability to plants.

PRIMARY ENVIRONMENTAL IMPACTS ON THE AIR

Incineration can significantly contribute to air pollution because of incomplete combustion and formation of intermediate combustion products (Water Pollution Control Federation 1977). As a result, all sludge incinerators must be equipped with scrubbers to meet air quality standards. Even if thermal disposal of sludge meets air quality standards, its use in areas of marginal air quality may not be allowed.

Table 3.6 shows the emission factors for sludge incinerators with and without scrubbers. Emissions are a function more of collector efficiency than of incinerator operation. The intimate mixing of air with sludge solids at high temperature that takes place when sludge is incinerated provides opportunity for the noncombustible fraction of sludge to become gas-borne and to be carried away in the exhaust gases. Accordingly, sludge incineration characteristically emits significant quantities of very fine-grained flyash (U.S. EPA 1975). The EPA New Source Performance Standards (U.S. EPA 1974) limit particulate emissions from new sludge incinerators to no more than 70 mg/Nm^3 (0.031 grains/standard ft^3) and less than 20 percent opacity.

Meeting the particulate performance standards requires a flyash collector, because simple water sprays and baffle or settling chambers are not efficient enouqht to collect such fine dust. Accordingly, high-energy scrubbers, bag houses, or electrostatic precipitators are needed to achieve compliance with the standards.

The high-energy scrubber has a lower initial cost and is simpler to operate and maintain than the other methods. However, scrubber corrosion is a major problem where chlorides are present and disposal of the scrubber wastewater is becoming more difficult, particularly if the wastewater carries soluble metal compounds. In addition, where scrubbers are successful, they may still pollute water because of the dissolved and undissolved solids in the scrubber water. If recycled to the sewage plant, solids may eventually build up to troublesome levels.

Alternatively, a dry collector such as an electrostatic precipitator or fabric filter captures extremely fine ash which, after improperly controlled disposal in a landfill, may become airborne (U.S. EPA 1975). One solution would be to wet the collected ash in a pug-mill and deposit the resulting agglomerated mud in a properly operated landfill.

The EPA Sewage Sludge Incineration Task Force (U.S. EPA 1972) concluded that existing well-designed and properly

TABLE 3.6 Emission Factors for Sewage Sludge Incinerators

Sludge incinerators must be equipped with scrubbers to remove particulates and other combustion products. Particulate and gaseous emissions with and without scrubbers are shown here. Levels indicated after scrubbing will not necessarily meet air quality standards.

	Emissions (Per Unit of Dry Solids Fired)			
	Uncontrolled		After Scrubber	
Pollutant	lb/ton	kg/MT	lb/ton	kg/MT
Particulate	100	50	3	1.5
Sulfur dioxide	1	0.5	0.8	0.4
Carbon monixide	Neg	Neg	Neg	Neg
Nitrogen oxides (as NO_2)	6	3	5	2.5
Hydrocarbons	1.5	0.75	1	0.5
Hydrogen chloride gas	1.5	0.75	0.3	0.15

SOURCE: U.S. EPA (1976).

operated municipal wastewater sludge incinerators have the capacity to meet the most stringent particulate emission control regulation existing in any state or local control agency. The newly promulgated federal New Source Performance Standards are based on demonstrated performance of an operating facility; thus, proper emission controls and proper operation of the incineration system must be used to meet all existing regulations of particulate matter. Although only the venturi scrubber met the promulgated standard in the EPA test, EPA (1975) has stated:

> "Impingement scrubbers tested by EPA did not meet the standard but, in our best judgment, would do so if used in conjunction with an oxygen meter that automatically regulates fuel burning rate. In our best judgment, electrostatic precipitators could also provide more than adequate control. There are no EPA test data on either of these control systems because during the test program there were no existing plants using them."

Gaseous Emissions

Sludge typically has high nitrogen content and can thus form nitrogen oxides (NO_x) during combustion at temperatures attained in incinerators. But, because of cooling of the hot gas leaving the incinerator, the NO_x formed has an opportunity to decompose. Measurements indicate that sludge incinerators are a minor source of NO_x (U.S. EPA 1975).

Synthetic Organic Compounds

EPA (1975) reported on incineration of sludges containing low levels of pesticides and PCBs. Pesticide and PCB determinations were made on sludges collected during tests at three plants; PCBs were found in the sludges at low concentrations (1.2 to 2.5 ppm). Pesticides and PCBs were not found in the ash from either type of incinerator, nor in the inlet or outlet scrubber water. The report infers that the PCBs must either be destroyed by incineration or remain as vapors in the water-scrubbed gas stream, and that their escape as vapors from the incinerators was unlikely. The report goes on to say that 99 percent destruction of PCBs occurs at 1600° to 1800°F (870° to 980°C) in 2.0 seconds. Total destruction of PCBs in municipal sludges was possible when oxidized with an exhaust gas temperature of 1100°F versus 1600°F (595° versus 870°C). Ninety-five percent destruction of PCBs was achieved in a multiple-hearth furnace with no afterburning at the normal exhaust temperature of 700°F (370°C).

Trace Metal Emissions

Flyash from sludge incinerators without high-efficiency particle collectors carries with it various metallic compounds. However, the past practice of installing incinerators without collectors is no longer acceptable. With use of high-efficiency collectors to capture the flyash, the amount of trace metals escaping new plants should be extremely small. Measurements should be made on well-controlled plants to establish what the trace metal emissions actually are.

Mercury is an example of a substance that presents special problems during incineration. High combustion temperatures decompose mercury compounds to volatile mercuric oxide or metallic mercury. Fortunately, the quantity of mercury involved is usually small (see Table 2.2). Limited test data (U.S. EPA 1975) indicate that perhaps only 4 to 35 percent of the mercury entering an incinerator with emission controls would be emitted in nonparticulate form to the atmosphere.

High temperatures cause volatilization and emission of mercury, arsenic, cadmium, and lead. The impact of these emissions on the ambient environment is still being assessed, but seems to be relatively small because their initial quantities are small. Procedures for curtailing emissions found to affect the environment significantly include reducing incineration temperature, as in fluidized bed burning, to decrease volatilization of metallic compounds; and installing equipment to capture the emissions. Each of these options has drawbacks, either in effect, cost, or other complications.

Wet oxidation emits no flyash, but may give off small amounts of organic or odorous gases which to be eliminated would require burning and the use of auxiliary fuel.

Since pyrolysis is still in the developmental stage, comprehensive data are not available on the emissions it entails. Air pollution control, however, is likely to be required (Metcalf and Eddy, Inc. 1976).

Sludge Use as a Fuel

A possible reuse of sludge is its incineration with supplemental fuel to generate steam. Burd (1968) described a system where dried sludge was fed to a boiler furnace. A portion of the steam produced was used in the evaporation stages. Fuel oil was also burned in the furnace. Burd also mentioned that a large chemical company successfully incinerated, for a time, a thickened, waste-activated sludge in a boiler furnace along with conventional fuels. Inorganic deposits, however, accumulated on the boiler tubes so that the technique eventually had to be suspended. Methods of burning sludge with any significant energy recovery are not likely to be developed in the near future.

Wet-air oxidation should be able to consume the organic and carbonaceous components of sludge almost completely, but is a complex process that must be operated by highly skilled personnel (Metcalf and Eddy, Inc. 1976). Maintenance problems and shutdowns have frequently afflicted the high temperature and high pressure systems involved. Some recent installations operate on moderate temperature and pressure; only partial oxidation is achieved. The partially oxidized sludge can be dehydrated easily.

Pyrolysis, which involves destructive distillation at temperatures somewhat lower than those needed for incineration, is being developed as a sludge treatment process. Its feasibility is not yet known.

SECONDARY ENVIRONMENTAL IMPACTS

Transfers from Ocean to Air

To evaluate the effects of sludge disposal in coastal ocean waters, possible transfers of constituents between ocean water and other environmental media (ocean bottom, land, atmosphere) must be identified. Data on these transfers, however, are scarce and usually qualitative; Table 3.7 summarizes available findings.

Most of the sludge is eventually deposited on the bottom around the disposal site. However, low-density particles and aggregates may form surface films and concentrate pathogenic constituents, such as bacteria and viruses. Under the action of waves and strong winds, the surface-active materials may form aerosols and possibly be blown back to land (NRC 1976). The implications for public health of such transfers in coastal areas have not been evaluated.

Transfers from Land to Surface Waters and Groundwaters

Sludge applied by landspreading may cause infiltration of nutrients or contaminants into groundwaters, or runoff of nutrients into adjacent surface waters and eutrophication. Nitrogen is present in sludge as organic nitrogen, ammonia,

TABLE 3.7 Possible Intermedia Transfers of Sludge Constituents Discharged to the Ocean

Data on transfer of sludge constituents between ocean and other environmental media, for evaluation of effects of disposal in coastal ocean waters, are scarce and qualitative in nature. Available data are summarized here. Transfers to atmosphere by aerosols may have public health implications, but these have not been investigated.

From Ocean Water to	Constituent	Process	Remarks
Ocean Bottom	Particles, with associated bacteria, viruses, metals, carbonaceous matter	Gravitational settling	Dominant reservoir of sludge-related materials
Shoreline, beaches	Particles, low-density floatable materials, surface films	Wave action, on-shore winds	Minor amounts of solids
Atmosphere	Surface active bacteria, viruses (?)	Bubble bursting-aerosol formation	Importance unknown
Estuaries, marshes	Particles, low density floatable materials	Estuarine circulation	Importance unknown

and nitrate. Although some ammonia is lost by vaporization, most is converted aerobically to soluble nitrate, which will move with soil water (Page and Pratt 1975). Nitrate in groundwater can be a hazard to the drinking water supply whether introduced by sludge or commercial fertilizer. Soil application tests suggest that metals are quite interactive with soil particles and do not usually move into the ground or into surface water (Ellis 1973).

The downward movement of water and dissolved constituents by infiltration and percolation depends on soil permeability, precipitation, and depth of the water table. Runoff is related to precipitation, soil permeability, slope, and the water content of the sludges.

A study in Minnesota[2] demonstrated that the application of up to 5.2 cm of liquid digested sludge with 3 to 5 percent solids content resulted in nitrate and soluble phosphorus in the soil water at levels normally required for crop production, without significant nitrogen movement below the root zone.

J.M. Walker (1975) determined the nitrogen profile under a field after surface application of digested sludge with 20 percent solids and 2.5 percent nitrogen, and concluded that sludge application rate is limited by nitrogen concentrations in the soil water and their potential effect on groundwater. The actual amount of sludge applied will depend on nitrogen content of the sludge and the amount and rate of nitrogen use by the crop.

Phosphate is readily retained by the soil, and therefore does not significantly move into groundwater. It can, however, be added to adjacent surface waters by soil erosion. Runoff and erosion may be restricted by injecting the sludge into the soil rather than spreading it on the surface.

Transfers from Land to Air

Aerosols are generated by spraying sludge on land. Sludge may also be resuspended as dust by wind. Aerosols and dust may bear pathogenic bacteria and viruses as well as odors, but aerosolized pathogens may be counteracted by natural factors such as evaporation and ultraviolet radiation, and by buffer zones, subsurface injection, and well-designed spray apparatus.

Transfers from Air to Land or Surface Waters

Almost all incinerator particulate emissions are eventually deposited on the land or surface waters. Their impact on air, land, or water should be kept to a minimum if efficient collection systems are uniformly installed and consistently operated so that the emission standards are met.

The residues of thermal reduction methods cause less problems for disposal than the sludges from which they are derived, primarily because the volume of the residues is considerably less than that of the original liquid sludge. Incineration methods produce an ash, and pyrolysis a char residue, both of which are largely inorganic and may be reused, in a variety of applications, or disposed of by landfill (Metcalf and Eddy, Inc. 1976, Interstate Sanitary Commission 1976). Such disposal may have a more serious leaching problem than landfill of sludge, as metals will be more concentrated in the ash than in the original sludge.

PUBLIC HEALTH ASPECTS

Health Aspects of Disposal to the Ocean

Disposal of sewage sludges in coastal ocean waters entails certain, largely unidentified, risks to public health, through possible contamination of fish or through water contact sports (see Perkins [1974] for a review).

There is no compelling evidence that sludge disposal in marine waters in the United States or Great Britain has so far caused detectable public health problems. The dangers of high concentrations of industrial wastes in fish have, however, been demonstrated in Japan, where severe mercury poisoning was reported from fish exposed to industrial waste. More than 4000 cases of methylmercury poisoning from seafood consumption have been reported in Japan (Verber 1976).

Fish and Shellfish

Freshwater fish grown in sewage effluents have been found to affect human health. Skin problems have occurred among workers handling the fish (Mackenzie and Campbell 1963) and fish have been contaminated with typhoid and other bacteria (Brunner 1949). Levels of risk to humans from handling or eating fish in contact with sewage effluents or wastewater treatment sludges seem to have received little or no attention.

There is far more experience of public health risks from eating shellfish from sewage-contaminated marine or estuarine waters. Typhoid fever has been the major disease associated with shellfish; the last United States case recorded was in 1954. Since 1961, infectious hepatitis has been the most common hazard, with the last large outbreak occurring in 1974. Vibrio parahaemolyticus, a marine bacterium causing diarrhea in Japan, has been reported as a probable cause of shellfish-borne gastroenteritis. Salmonella and other disease-causing organisms have also been involved.

The implications for public health of those hazardous metals (mercury, arsenic, and selenium) that are concentrated in fish are not yet thoroughly understood. The mercury poisoning reported in Japan (Verber 1976) has underlined the need for further study.

Although none of these events has involved sewage sludges, they have alerted the public to the danger that materials from sludges may contaminate seafood (Verber 1976). This threat has been discussed in the adjudicatory hearings on disposal of sewage sludges from Philadelphia (Lear 1976).

The earliest studies (1940s) of the environmental effects of sludge disposal in the waters of the Middle Atlantic Bight (New York and Philadelphia) were concerned with possible public health risks through contamination of the sea clam (Spisula solidissima) (Verber 1976). Sites used for disposal and some waters traversed by the barges were closed to commercial harvest of shellfish, but the ban is harder to apply to recreational shellfish harvesting. The disposal site used by Philadelphia from 1961 to 1973 was shifted farther offshore (Guarino 1976). Within a year after disposal operations ceased, the original abandoned site was found to be free of fecal coliform bacteria and was reopened to commercial shellfish production (Verber 1976).

Water Contact Sports

Another way the coastal population may risk exposure is through water contact sports such as swimming or surfing. Although all disposal takes place several miles offshore, low-density solids and liquid effluents may be widely dispersed throughout coastal waters. Substantial concern has been expressed in the New York Metropolitan Region, for example, about possible movement of sewage sludges toward bathing beaches (U.S. Congress, Senate 1974). Subsequent study found no convincing evidence that large volumes of sludge-related materials had moved along the ocean floor onto the beaches (NOAA 1975); monitoring of water quality at the closest beaches also failed to show unacceptable levels of fecal coliforms. However, floating sludge materials have since been found on Long Island beaches (Swanson 1976).

Contamination and closure of public beaches owing to discharges of sewage treatment plant effluents into estuaries and nearshore waters are common in many coastal urban areas in the Eastern United States. Swimming in water contaminated by sewage effluents has been found to cause gastrointestinal disease (Cabelli et al. 1977).

Aerosols are a route of pathogen transmission. In the marine environment, bacteria and viruses might be concentrated in surface films and incorporated in aerosols through breaking waves and bursting bubbles, thus to be transferred through the atmosphere to coastal populations (NRC 1976). No studies of sludge disposal in the ocean were found to relate possible diseases to such an exposure pathway.

Studies of communicable diseases among inhabitants of agricultural settlements using wastewater irrigation (Katzenelson et al. 1976) showed incidence of shigellosis, salmonellosis, typhoid fever, and infectious hepatitis significantly higher than in comparable settlements not using wastewater irrigation. This suggests that a comparable hazard may exist in coastal populations downwind from ocean areas heavily used for wastewater and sludge disposal. Even if such a risk from ocean disposal could be documented, however, it would be difficult to determine the contribution attributable solely to sludge disposal operations. Bacteria exposed to antibiotics discharged in sewage may become resistant and, if transferred, could complicate the treatment of illnesses (Koditschek and Guyre 1974a, 1974b).

Health Aspects of Disposal or Use on Land

The possibility of transmitting disease is a major part of public anxiety about sludge handling operations. Considerable research is required before safe guidelines are established. Many reports have concluded that the hazard is not great (Ewing and Dick 1970), since few incidences of disease have been traced to sludge-disposal operations. The reporting of enteric disease cases is notoriously poor, however, and most investigators feel that sufficient information is not yet available on the epidemiological significance of complex populations of bacteria, viruses, and protozoan and helminth parasites found in sludge (see Table 3.8).

TABLE 3.8 Human Enteric Pathogens Occurring in Wastewater and Sludge, and the Diseases Associated with Them

Bacteria, viruses, and helminth and protozoan parasites in sludge represent a potential source of disease. Although no incidences of disease have been traced to sludge disposal, quantitative data on pathogen populations and kinetics in sludges and in soil are not yet sufficient to allow conclusions concerning health hazards.

	Pathogens	Diseases
Bacteria	*Vibrio cholerae*	Cholera
	Salmonella typhi	Typhoid and other enteric fevers
	Shigella species	Bacterial dysentery
	Proteus species	Diarrhea
	Coliform species	Diarrhea
	Clostridium species	Botulism
	Pseudomonas species	Local infection
Viruses	Infectious hepatitis virus	Hepatitis
	Echoviruses	Enteric and other diseases
	Coxsackie virus	Enteric and other diseases
	Poliovirus	Poliomyelitis
	Epidemic gastroenteritis virus	Gastroenteritis
Parasites	*Entamoeba histolytica*	Amoebic dysentery
	Balantidium coli	Balantidial dysentery
	Iospora hominis & others	Coccidiosis
	Giardia lamblia	Diarrhea
	Pinworms (eggs)	Ascariasis
	Tapeworms	Tapeworm infestation
	Liver & intestinal flukes	Liver or intestinal infestation

SOURCE: Love et al. (1975).

Pathogens

Pathogen populations have been studied under different soil and other physical and environmental conditions and varying sludge treatment methods (Miller 1973). Size of the organism, type of soil, and rate and direction of groundwater movement affect the distance the pathogens can disperse. They may travel for miles in groundwater through solution cavities in limestone areas or may be immobilized near the surface of heavy textured soils. Pathogenic organisms may survive in soil and on crops for periods varying from a few hours to several months, depending upon the type of organism, the soil moisture and pH, and predation by other organisms.

One study (Drewry and Eliassen 1968) demonstrated that virus retention in soils is an adsorptive process that is highly efficient at pH values 7 to 7.5; efficiency decreases at higher pH values. Salmonella and ova of Ascaris (an intestinal parasite) appear to present the greatest risk. The period of survival for these organisms when dispersed from the land into surface or groundwater is also determined by a wide range of physical conditions.

Aerosols are also generated by spray application of sludges to land. Aerosols generated in sewage treatment are known to bear pathogenic bacteria and viruses (Smith 1968, Higgins 1964), and inhalation is an effective route for infection. In Israel, communities irrigating with domestic sewage have shown significantly higher incidences of waterborne diseases than communities that do not (Katzenelson and Teltch 1976). Aerosolized enteric bacteria were detected up to 350 m downwind from the irrigation line (Katzenelson et al. 1976). No study has been published on pathogens in aerosols produced by spray application of liquid sludge. According to a literature review by Hickey and Reist (1975), no correlation has been shown between airborne aerosols from wastewater treatment plants and incidence of disease in nearby populations.

Land disposal can generate gases and aerosols that might be annoying to nearby residents. Odors from land-applied sludge can result from the operation itself or from storage before application. Since, however, the concentrations of pollutants released in this way are too low to measure without difficulty, no data on such releases are available.

Among the many factors that affect the odor problem are individual perception and habituation. Humidity and climate, wind, and topography also affect generation and spread of odors. Type of sludge and moisture content, size of application surface area, rate and method of application can to some extent be controlled to reduce odors.

Buffer zones, vegetation barriers, the design of the spray apparatus, and subsurface injection of liquid sludge could reduce the pathogenic health hazard.

Contamination of food crops has received the most attention. The greatest risk arises from consumption of raw vegetables grown on soil treated with sludge, but even crops eaten only after cooking can represent a risk since they contaminate working surfaces and lead to bacterial multiplication in other foods (Love et al. 1975).

Well-designed and carefully operated anaerobic digesters can reduce the fecal coliforms in sludge by 97 percent or more before application, but the remaining levels of pathogens may still be significant for public health (Love et al. 1975). For certain uses, stabilization processes may not reduce pathogens adequately. Other methods that have been successful in such instances are: pasteurization, treatment with lime, long-term storage of liquid digested sludge, composting, and irradiation. Research is being conducted on the effects of irradiation on the pathogens in liquid sludges. When combined with sludge digestion, irradiation inactivates viruses, reduces bacterial populations, and improves dewatering (Trump 1976).

Metals

Concern over possible hazards to human health from accumulation of certain metals in food crops is relatively recent. Although much research is being done on tolerances of metals in food, complete and precise definitions of tolerances and safe practices for sludge use in agriculture are not yet available (Braude et al. 1975). The U.S. Food and Drug Administration's program on toxic elements in foods (Table 3.9) is at present placing highest priority on assessing hazards of mercury, lead, cadmium, arsenic, selenium, and zinc (Jelinek et al. 1977). For example, the cumulative toxicity of cadmium to the human kidney and liver is well documented (Fleischer et al. 1974, Page and Bingham 1973, Flick et al. 1971). Sanjour (1974) reported work that showed that the average dietary intake of cadmium for the United States population could be greater than the tolerance recommended by FAO/WHO.

Landspreading of municipal sludge may contaminate human food with hazardous metals in several ways. A possible route is from livestock grazing on pasture where sludge has been applied--the sludge contaminants so ingested can be retained and accumulated in animal tissues. It is generally agreed that sludges should never be used where root or leaf crops are to be grown.

TABLE 3.9 Concentrations and Tolerances of Heavy Metals in Foods

Currently, research is being directed toward gathering data for establishing guidelines on safe practices of sludge use in agriculture, and on tolerance levels for metals in food. Such information is necessary to ensure that agricultural use of municipal sludge does not increase the metal burden in the consumer. Cadmium, which occurs in the diet at levels close to the provisional tolerance level, is of particular concern

	Cadmium	Lead	Mercury	Selenium	Arsenic
WHO/FAO (1972) Provisional Tolerances (Adult) Converted to μg/Person/Day	57-71	429	43	Not Establ.	Not Establ.
Total Diet Findings, U.S. Adult μg/Person/Day (1973)	51.2	60.4	2.9	150	10 (As As_2O_3)
Average Concentration in Entire Diet, Including Drinking Water, ppm	0.018	0.021	0.001	0.05	0.003
Most Prevalent In:	Grains & Cereals Leafy Vegetables Fruits Beverages	Legumes Fruits	Meats, Fish & Poultry	Grains & Cereals Meats, Fish & Poultry	Meats, Fish & Poultry

SOURCE: **Braude et al. (1975).**

Nitrate

Application of sludge on land presents a risk of producing high nitrate levels in drinking water. Such levels are known to cause infant methemoglobinemia or gastric nitrosamine formation in adults (Gelperin 1970).

PCBs

Polychlorinated biphenyls are a common constituent of municipal sewage sludges (Table 2.2), particularly where there are industrial sources of wastewater, and can therefore be considered to be a health risk. Concentrations of PCBs and chlorinated hydrocarbons in the sludge are highly variable but present data are adequate to conclude that they represent a significant potential hazard to human health. In sufficient quantities, PCBs are known to cause reproduction failures, gastric disorders, skin lesions, and liver cancer. Because of the low levels at which pathological effects have been observed in various species, and because biomagnification factors of up to 2.7×10^4 have been observed (Massachusetts Audubon Society 1976), EPA has set an ambient water quality standard of one (1) part per trillion (U.S. EPA 1977). Since only sludges with extremely low concentrations of PCBs could be disposed of to ocean or land under this promulgated standard, source control of PCBs and monitoring for them would seem to be necessary.

Health Aspects of Disposal to the Air

Thermal oxidation at temperatures high enough to destroy odorous organic material--1300°F for 1 second--probably also destroys pathogens, although no data are available from sludge incinerators to confirm this assumption. Thermal oxidation does vaporize arsenic, mercury, lead, and other metals, but even mercury, the most prominent of these, is not emitted in quantities sufficient to threaten the ambient environment (U.S. EPA 1975).

Organic chemicals such as organophosphates and persistent chlorinated hydrocarbons have been found to injure health. Rapid thermal degradation of most pesticides begins at approximately 500°C (930°F) with near total destruction of persistent organic substances at 900°C (1950°F) (U.S. EPA 1975). Accordingly, thermal oxidation is probably the surest way to destroy persistent organics in sludge. More data are needed to prove the validity of this assumption.

Other problems are emissions of oxides of nitrogen, particulates, and gases. Incinerators are not expected to be a significant source of atmospheric NO_x. The health impact of particulate and gaseous emissions should be negligible if incinerators are consistently operated such that the New Source Performance Standards are met.

SITE SELECTION

For the purpose of this discussion, site selection and the other aspects of sludge management--technology and monitoring--are analyzed solely in terms of the environmental and health impacts discussed above. Criteria for site selection, as for other management options, depend upon whether the sludge is to be considered a resource or a waste material. Where recovery of the nutrient values for land or sea is the intention, the site should be selected with a view to enhancing the environmental impacts; where sludge is to be disposed of, the site should be selected to reduce impacts. Provision for positive impacts and reduction of negative impacts depends upon thorough investigation of the sites before selection and use.

One way of reducing impact is containment, as by landfilling. Dispersal by discharge into the ocean or atmosphere is less easily controlled, but should also minimize alteration of the existing environment. Whether intended for dispersal or containment, the properties of the site should be the basis for determining its potential usefulness.

Choosing Sites in the Ocean

Sites for sludge disposal in the ocean will generally be selected in coastal waters, but some sites may have to be selected in open ocean waters beyond the edge of the continental shelf to minimize impacts to the shore. To select the best sites, the behavior of sludge in the ocean should be further examined, as should constraints imposed by circulation and by chemical and biological processes in open and coastal areas.

Coastal water movements driven by winds and river discharges vary markedly in space and time and increase the difficulty of predicting the behavior of sludge released in nearshore waters. In general, materials introduced into the nearshore zone are transported away from the point of discharge by tidal currents parallel to the shoreline which are usually the strongest nearshore currents (Gross 1972).

Offshore and longshore winds transport surface waters from the coast and cause subsurface waters to well up, along with any sludge-related materials in them (Gross 1972).

When the wind ceases, the warmer surface layers move shoreward and low-density--including floating--materials can be carried toward the shore.

In most coastal areas where river or sewer discharges exceed local evaporation, an estuarine circulation occurs and influences movements of discharged sewage sludges (Gross 1972). Estuaries are usually not acceptable disposal sites for sludges, because the net effect of estuarine circulation is to circulate particulates and nutrients so that mixing with open ocean waters is inhibited.

Selection of an appropriate site for ocean disposal of sewage sludge requires detailed knowledge of localized ocean processes. Such knowledge is currently unavailable for most and perhaps all coastal ocean areas adjacent to the United States (Gross 1972). For most potential ocean disposal areas, it is therefore impossible to predict physical movements, chemical reactions, or biological interactions without costly, extensive investigation (NOAA 1976).

Ocean disposal is fundamentally a dilution-dispersion strategy. Solids, dissolved constituents, and floating materials will be diluted and moved by currents in directions and at speeds that cannot at present be predicted, although in principle they are predictable (NRC 1976). A few coastal ocean areas offer potential for sludge containment in or near the disposal site. The deep basins off Southern California may provide nearly isolated areas for containing sludges with little or no physical, chemical, or biological transport (Faisst 1976).

No efforts have yet been made to develop criteria for selection of sludge disposal sites in the open ocean, owing to the uncertainties related to developing international regulations for ocean waste disposal and the costs of transportation over long distances.

Choosing Sites on Land

Land Availability

Site selection raises the problem of land availability, whether for landfill disposal or agricultural use. Open land within the United States could in theory readily accommodate all municipal sludges (Carroll et al. 1975), but not enough suitable sites exist near major metropolitan areas. Vacant tracts large enough to be economical for land application may be scarce near municipal areas that have large quantities of sludge (Schmid et al. 1975). Rural areas have been putting their locally generated sludge into land disposal for years with little adverse reaction (Montague 1975), but are often reluctant to accept sludge from large metropolitan areas.

Aside from land availability, landfill disposal and agricultural use require very different considerations. The containment of a waste is the goal of the former; the latter is intended to promote the reuse or recovery of a resource.

Land for sludge disposal must meet a number of requirements, besides being available, in order to be suitable.

Requirements of Landfill Sites

Landfilling disposes of sludge on land or in pits by spreading it in compacted layers, covered with soil (American Society of Civil Engineers [ASCE] 1976).

Siting and design of landfill operations to avoid impairing water quality should be based on geologic and hydrologic considerations (Flawn et al. 1970) including locality, topography, seismicity, soil types, substrate characteristics, permeability, transmissibility, solution-holding capacity, reactivity of host and cover materials, seasonal variations in water table levels, and chemical composition of underlying beds, to determine the extent to which leached materials could travel through either soil layers or into the groundwater. Adequate protective space or barriers should lie or be placed between the site and ground or surface waters; subsurface barriers must be designed and constructed to assure permanence.

Environmental and geologic mapping studies in the Texas coastal zone indicate that conditions under which municipal wastes are generally disposed of are unsatisfactory because geologic and hydrologic factors have not been adequately taken into account (Brown et al. 1972). Study of the physical properties of proposed landfill sites has rarely been adequate to determine if the sites will provide a secure landfill.

With the available technology, careful site selection, and use of advanced techniques in design, construction, maintenance, and water quality monitoring, landfill sites should be established and maintained without substantial danger of groundwater or surface water pollution. However, proper construction and maintenance of landfill sites in many substrates could be economically impractical because of the high costs required to control leaching from the landfill wastes. Where shallow water tables occur below the landfill, the initial design, as well as long-term maintenance, becomes very significant. Data on the underlying geologic units and soil characteristics provide the basic information needed to identify the conditions suitable for landfill operations.

In regions of moderate and heavy precipitation, it is desirable to seal the landfill with a rounded and relatively impervious soil cap to prevent further percolation of surface water into the waste, and essential to control surface runoff and prevent flooding (Walker 1974).

Requirements of Landspreading Sites

Sludge is spread on land surfaces either for agricultural purposes or as a means of disposal. When used agriculturally, sludge is applied in amounts related to crop use of nutrients. In disposal of sludge by landspreading, application far exceeds plant nutrient needs. Site selection for landspreading of sludge must consider soil and subsoil characteristics, topography, drainage, climatological considerations, groundwater hydrology, and interactions with biota.

Soil properties are significant for site suitability because soil is a substrate for the physical, chemical, and biological interactions that result in sludge decomposition (Thomas 1973, Ellis 1973, Miller 1973). The texture of the soil and parent geologic material influences (a) infiltration rates, (b) subsoil percolation rates, (c) moisture-holding capacity, and (d) adsorption reactions for the waste components. Finely-textured soils with a high percentage of clay particles tend to have slow infiltration rates, which may result in short-term anaerobic conditions and odors. Clay holds constituents such as phosphates, metals, and pesticides. Nitrate, however, is not readily held on the clay surfaces and is mobile even in a finely textured soil (Hall et al. 1976). A coarse sandy soil, by contrast, permits rapid infiltration of water and sludge components. Unless an impermeable subsoil or substrate underlies these coarse soils, water carrying the soluble components may move downward and pollute underlying aquifers (Knezek and Miller 1976). Soil pH is also important in selection of landspreading sites because the pH controls metal mobility (Miller 1976).

The topography of a potential site influences movement of both surface and subsurface water and, therefore, of sludge constituents (Schmid et al. 1975). Excessive slope is not desirable for surface spreading, but runoff and erosion hazards can be minimized through the use of contour strips, terraces, and border areas. Natural wetlands remove nutrients efficiently (Schmid et al. 1975), but the potential damage to the biotic communities of these areas by heavy additions of nutrients is likely to restrict greatly their use for sludge disposal.

Climate affects the timing of sludge application, runoff intensity, groundwater recharge, and maintenance of soil pH. Temperature directly affects sludge use in areas where frozen soils and/or snow cover make sludge applications impractical or environmentally unsound. In the northern United States, winter storage facilities for municipal wastes may be necessary; thus, operational costs are increased and land application during the summer is intensified. Temperature also controls the growing season of plants, the period of plant uptake, and the rate at which sludge organics decompose in soil. These factors in turn affect the yearly renovative capability of the soil.[2]

Rainfall must be considered in site selection and in the timing of sludge applications. The heavy equipment used to apply sludge compacts wet soil and consequently reduces crop yields. Precipitation distribution influences the amount of sludge storage required.

Sites must also be selected that afford adequate protection of water supplies from contamination by pathogenic organisms in the sludge by allowing sufficient vertical and horizontal separation between sludge application sites and water supplies or geologic features related to water supplies (Keeney et al. 1975).

All of the previously listed considerations of soil, topography, and drainage considered in agricultural application of sludge apply to landspreading as a disposal practice. With higher loadings, more is demanded of the soil capacity to filter and assimilate the sludge.

When sludge is applied frequently, metals that are initially bound in the soil layer could be transported to groundwater, as will nutrients in the sludge that are not used by plants or soil organisms. Probability of runoff and pollution of surface waters increases with greater application.

Choosing Sites for Thermal Oxidation

Important factors in the design of sludge incinerators are foundation condition, topography, drainage, and atmospheric flow patterns. The assistance of a skilled meteorologist or pollution control specialist is required to determine the chimney height necessary for effective dispersion of exhaust gases (DeMarco 1969).

Although incinerators are theoretically capable of being designed, equipped, and operated according to relatively high emission control standards, incineration places a measurable burden on the atmosphere. Therefore, it would not be acceptable in areas with marginal air quality. Since incinerators are usually zoned as heavy industry, incinerator construction in a largely vacant area should establish industrial zoning so that no residences are subsequently built nearby. In urban areas, siting with due regard for meteorological factors, land uses, demographic patterns, and public concern over the location of major waste processing facilities is extremely complex.

TECHNOLOGY

Ocean Disposal Technology

Coastal cities may be able to dispose of wastewater sludges to the coastal ocean by pipeline or barge. Barges may be towed or self-propelled and use pumps or gravity discharge through valves at the bottom of the vessel.

In the mid-1970s, Philadelphia-Camden and the New York Metropolitan Region were the two largest urban regions in the United States using barges to transport sludges to the ocean. Contract firms in the New York-New Jersey area also hauled wastewater sludges for other municipalities to the New York Bight Apex. Los Angeles was the largest city using an ocean outfall including pipeline transport of sludge.

At Philadelphia, anaerobically digested sludge was pumped to an onsite plant lagoon, where the sludge was thickened and then pumped to the barge by a dredge. The barge discharged at a rate that deposited the sludge on the bottom area under Philadelphia's ocean disposal site at approximately 2 tons (dry solids) per acre of bottom per year (Guarino et al. 1975).

An ocean outfall or pipeline may be laid along the ocean bottom from the shore to the disposal site. The sludge is then pumped through a diffuser to mix with deep water, and rises as a buoyant plume until it reaches a level of comparable density. The plume normally does not penetrate the pycnocline (the layer of marked density change) and thus does not reach the surface (SCCWRP 1973). The plume is then moved as a mass by subsurface currents. (See Faisst [1976] for an example of modelling movement of such a plume.)

Technology for Disposal or Use on Land

The techniques of current landspreading and landfilling practices are determined by the characteristics of the sludge, its ultimate intended use, and the physical constraints of the available sites.

Transportation

Sludge must be transported from the wastewater and sludge treatment plant to the site of the landspreading or landfilling operation. Most sewage sludge applied to land is moved as a wet suspension containing from 1 to 10 percent solids, in the form in which it leaves the digester or settling tank (Keeney et al. 1975), or sometimes as a dry sludge cake containing 15 to 35 percent solids. The form, pretreatment, and origins of land-applied sludge vary greatly. The method of transportation selected depends on the physical characteristics and quantity of the sludge, seasonal variations in climate, delivery distance, the pattern of disposal or use, and planned lifetime of the application site.

Tank trucks are most commonly used to convey sewage sludge from small treatment plants (Keeney et al. 1975). The major advantages of tank truck delivery are its flexibility and the capacity for both transporting and applying sludge with one vehicle. Pipelines can be used to transport sludges but, before committing the large sums required, the useful life of a disposal site should be ascertained. Rail tank cars and river barges are also employed to convey sewage sludges to landspreading sites.

Whatever the transportation method, almost any procedure for using sludge requires some provision for temporary storage. Since weather, crop rotation, and quantity of sludge all vary, storage of sludge in large holding tanks or lagoons permits optimal timing of application (Keeney et al. 1975).

Landfill Technology

Urban processed solid wastes (ASCE 1976) may be mixed with municipal sludge to reduce the amounts of leachate from a landfill site, or sludge may be landfilled without additions.

Chemical treatment of sludges will determine, in part, the characteristics and pH of leachates. Planning for disposal of municipal sludges in sanitary landfills should include consideration of the potential for source control and pretreatment of waste constituents accepted for municipal sewage treatment to minimize damaging pollutants in the leachate.

In a properly operated landfill, leachates must be prevented from reaching groundwater by such means as excavating the surface soil from the site, compacting the base of the landfill before filling, or lining the site with clay or similar material if necessary, and installing tile collection networks to collect leachate accumulation on the lining. Liquid may be pumped out or otherwise diverted and treated.

Overflow from landfills can be prevented by pumping out storm waters, limiting moisture levels in the sludge, or mixing the sludge with refuse that absorbs moisture (Weddle 1975). Surface runoff that might run into landfill sites can be diverted by storm sewer systems or berms around the site.

Other guidelines for proper landfill operation (Wilcomb and Hickman 1971) provide for limited access to the site and safeguards against uncontrolled gas movement and subsidence. Experience with particular landfills indicates that spreading and covering wastes daily with compacted earth has helped to control such objectionable aspects as odors. When the landfill is complete, compacted earth placed over the entire site and seeded with grass to prevent erosion will improve appearance and further reduce possible nuisance. Table 3.10 lists the landfill and dumping disposal methods employed by United States municipalities. Several of these lack the safeguards against leaching necessary to landfilling and should therefore be simply categorized as dumping. According to Weddle (1975) most land disposal sites in the United States in 1973 were in fact dumps rather than proper landfills.

Industrial wastes have been disposed of in deep underground caverns and mines (Stanley Consultants, Inc. 1972). The practicality of such disposal for municipal sludge has not been investigated.

Landspreading Technology

The method chosen for landspreading sludge depends on the physical properties of the site (topography, soil characteristics, and subsurface structure), the properties and quantity of sludge, objective (disposal or use), local crop management practices, and public acceptance. System design varies according to whether sludge is to be disposed of or used as a resource: systems for disposal are designed for repeated application, while systems for use should be

TABLE 3.10 Disposal of Sludge in Landfills and Dumps

Proper landfill operation requires control of leachate and runoff. Not all disposal methods employed by municipalities in the United States listed here can be defined as proper landfill operations: some should be categorized as dumping and therefore unsatisfactory for sludge disposal.

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1. Dumped in sand and gravel within open pits previously dug by bulldozer; pits then filled to control odor and other problems.

2. Dumped at site and leveled.

3. Dumped on top of fill and mixed with refuse during compaction.

4. Dumped into pit.

5. Dewatered by vacuum filtration: moved to landfill, dumped, and immediately buried.

6. Only air-dried digested sludge accepted.

7. City landfill disposal of sludge unregulated.

SOURCE: Derived from Stone (1975).

matched to crop requirements. Systems have been designed for surface spreading or spraying, as well as for subsurface injection (Smith 1974). Liquid sludge may be applied to the surface by spray systems, ridge and furrow irrigation, or by vehicle. In the plow-in method, sludge is usually covered with earth, so that most of the runoff and odor problems are eliminated and drying is accelerated (White et al. 1975). In the ridge-and-furrow method, sludge distributed in furrows provides moisture and nutrients to field crops planted on the ridges. Table 3.11 lists the most common methods of application and considerations for transport, application rate, soil conditions, drainage, slope, field capacity, and type of crop.

Application of concentrated sludge solids involves depositing the sludge and covering it with soil. Trucks or wagons spread the solids, which are then worked into the earth by disk harrowing or rotary tilling.

Sludge can be spread on forest land, but this application entails unique problems since large equipment cannot be used among the trees. For this reason, many studies have been conducted on clear-cut sites. In Michigan, experimental spreading of sludge is being conducted on clear-cut aspen lands where rapid and prolific regrowth can be expected to take up nutrients before they leach into the groundwater.[3]

Technology for Disposal to the Air

Burning waste is a simple and quick way of reducing the bulk of human wastes. Its advantages include (a) nearly complete combustion of organics, (b) large reduction of sludge volumes, (c) relatively easy disposal of an inert ash, and (d) the destruction of microorganisms and potential nuisance-causing materials. Combustion is usually accomplished by feeding the waste into an incandescent chamber (furnace). However, it is usually difficult to burn sewage sludge because of its higher moisture content and the tendency of wet sludge to resist mixing with combustion air. Furthermore, if not properly controlled, incineration often entails annoyance from smoke, odor, and dust emission. To meet new flyash emission standards, new waste incinerators must employ high-efficiency collectors such as precipitators, water scrubbers, or possibly fabric filters.

Thus, although sludge incineration has been used by many cities for decades, the conventional (multiple hearth) method is now being reappraised, both because of new environmental regulations or concerns and because of new thermal technologies. Fluidized bed incineration, first applied commercially in 1962, is now in regular use by 38

TABLE 3.11 Methods of Field Application of Sludge

Irrigation and tank vehicle distribution are the two basic methods of surface application of well-stabilized liquid sludges. Irrigation may be achieved by spray (sprinkler) or by ridge and furrow (pipe) mechanisms. Equipment of subsurface application requires attachment to tank vehicles. Solid sludge spread on the surface can be incorporated by plow or disc. The choice of sludge application method depends on quantity and characteristics of the sludge, site properties, and crop management practice. Land application may be solely for sludge disposal, or matched to crop nutrient needs.

Sludge State and Mode of Transportation	Characteristics	Topographical and Seasonal Suitability	Comments
Liquid (Surface Application)			
Irrigation Spray (sprinkler)	Large orifices required for nozzle. Large power requirement. Wide selection of commercial equipment.	Can be used on rough or steep land. Can be used year-round with provision for draining in winter. Not suitable for application to some crops during growing season. Sludges must be flushed from pipes when irrigation stops.	Application rate not recommended to be over 1/4 in/hr.;[1] less if runoff begins to occur. Permanent irrigation set can be used on pasture and woodlands.
Ridge and Furrow Irrigation	Less power requirement than spray irrigation. Land preparation needed.	Between 1/2 and 1-1/2% slope, depending on percent solids. Can be used in furrows between row crops during growing season. Can be used year-round with provision for draining pipes in winter.	
Tank Truck	Capacity, 500 to 2,000 gals.[2] Larger volume trucks require flotation tires.	Smooth and level or slightly sloping land. Not usable with row crops or on soft ground.	Can be used for transport and disposal.
Farm tractor and Tank Wagon	Capacity 800 to 3,000 gals.[2]	Smooth and level or slightly sloping land. Not usable with row crops or on soft ground.	
Liquid (Subsurface Application)			
Tank Truck with Plow Furrow Cover	Capacity, 500 gals.[2] Single furrow plow mounted.	Smooth and level or slightly sloping land. Not usable on wet or frozen soil.	Not suitable for long transport.
Farm Tractor and Tank Wagon Plow Furrow Cover	Sludge discharge into furrow ahead of single plow. Sludge spread in narrow swath and immediately covered with plows.	Smooth and level or slightly sloping land. Not usable on wet or frozen soil.	Additional tractor power needed to pull plow.

TABLE 3.11 (Continued)

Sludge State and Mode of Transportation	Characteristics	Topographical and Seasonal Suitability	Comments
Subsurface Injection Equipment	Sludge placed in channel opened by tillage tool.	Smooth and level or slightly sloping land. Not usable in wet, hard, or frozen soil.	Additional tractor needed to pull tillage tool. Vehicles should not traverse injected area for a week or more.
Solid			
Spreading, either truck mounted or farm spreaders	Waste spread evenly over ground. Normally followed by soil incorporation, disk or plowing. Use plow or disc large enough to give complete coverage.		Very light applications (less than 2 dry tons/acre[3]) need not be incorporated unless surface runoff is likely to occur.
Reslurry and handle as liquid sludge			Suitable for long hauls where rail transport is available.

SOURCE: White et al. (1975).

[1] in/hr. × 2.54 = cm/hr.
[2] gals. × 0.0038 = m^3.
[3] tons/acre × 2.24 = MT/ha.

cities in the United States, although the flyash emission often exceeds current new source standards and will have to be upgraded by suitable application of high-efficiency particle control equipment (U.S. EPA 1975).

The principal methods for thermal oxidation of sewage sludge now in use or under serious development are incineration (conventional furnace or fluidized bed), wet oxidation, and pyrolysis. In some circumstances, sludge may be combined with municipal refuse, for co-incineration or co-pyrolysis.

Burd (1968) gives a detailed description and evaluation of these methods, the principal characteristics of which are summarized in Table 3.12. In most cases Burd's evaluation of the technology of almost one decade ago is still valid. For more recent significant developments see Balakrishnan et al. (1970).

Sludge Characteristics and the Incineration Process

According to Russell (1964) the four sludge parameters most important to incineration are: (1) moisture, (2) volatiles, (3) inert materials, and (4) thermal value. Of these, moisture is particularly important because of the thermal load it imposes on the incineration process and achievement of self-sustained sludge combustion. (Moisture is generally reduced by mechanical dewatering techniques before incineration.)

Volatile and inert materials affect the heat value of the sludge. They are controlled to some extent by other treatment processes such as degritting, mechanical dewatering, and sludge digestion. Almost all of the combustible substances in sludge are volatile. The volatile percentage and therefore the resulting heat potential may vary widely, so incineration equipment must be designed to handle a broad range of values. Table 3.13 lists the most important incineration parameters for many of the solids generated by a sewage treatment plant.

As a general rule, the thermal value of sewage sludge is considered to be 10,000 BTU per pound (23,000 kJ/kg) of volatile solids. Balakrishnan et al. (1970) confirmed that thermal value is a function of carbon and hydrogen content with a minor correction for oxygen content.

Theory of Incineration

Incineration involves drying and combustion. Fuel, air, time, temperature, and turbulence are necessary for a

TABLE 3.12 Characteristics and Potential Impacts of Thermal Reduction Methods

The impacts on the atmosphere of sludge disposal by thermal reduction can be limited by present emission-control technology. Thermal methods greatly reduce sludge volume, leaving inert ash residues that can be disposed of in landfills. Pathogens are completely destroyed.

Process	Theory and Operation	Comments	Potential Impacts
Multiple Hearth Incineration	Counter-current downward flow by gravity through hot combustion gases from oil or gas burners. Rabble arms gently agitate thin sludge layers on each successive hearth to promote drying, then burning.	Consumes scarce oil or gas. Inherently entrains fine flyash in upward-flowing flue gases. Counter-current principle very effective for drying wet sludge prior to ignition.	Fine flyash emission which should be controlled by available dust collectors.
Flash Drying Incineration	Spraying of sludge into large drying chamber enables subsequent choice of either burning or utilization of dried sludge as low-grade fertilizer.	Justified only where markets for low-grade fertilizer seem promising.	Same as above.
Fluidized Bed Incineration	Upward flow of combustion air through incandescent bed of inert particles gives excellent mixing, good particle-gas contact.	Inherently entrains fine flyash in upward-flowing flue gases.	Same as above.
Wet Oxidation	Use of elevated pressure and temperature in closed reactor tank to promote oxidation of sludge.	Reduces volatilization of metals and organics in sludge. Operation requires uncommon skill.	Minor.
Combined Refuse/Sludge	Mixing of sludge with municipal refuse and then burning mixture on travelling or moving grate.	Many full scale attempts have failed primarily from problems of nonuniform burning because of difficulty of mixing the two dissimilar components.	Same as incineration above.
Pyrolysis	Thermal decomposition of carbonaceous and organic material in a deficiency of air.	Until demonstrated successfully on a full scale plant, the viability of this process for sewage sludge remains uncertain.	Reduce flyash emission less volatilization of metals; smoke and organic emissions have caused some problems.

SOURCE: Burd (1968).

TABLE 3.13 Sludge Incineration Parameters

Thermal values of sludges can vary widely depending on the relative percentages of the combustibles listed here, and on the moisture content. Moisture must be reduced by dewatering techniques prior to incineration. Adequate dewatering may allow self-sustaining incineration. The average thermal value of sewage sludge is 10,000 BTU/lb[1] of volatile solids.

Material	Combustibles (%)	Ash (%)	BTU/lb[1]
Grease and scum	88.5	11.5	16,750
Raw sewage solids	74.0	26.0	10,285
Fine screenings	86.4	13.6	8,990
Ground garbage	84.8	15.2	8,245
Digested sewage solids and ground garbage	49.6	50.4	8,020
Digested sludge	59.6	40.4	5,290
Grit	33.2	69.8	4,000

SOURCE: Owen (1959).

[1] BTU/lb × 2.33 = kJ/kg.

complete reaction. The primary products of combustion are water, carbon dioxide, and ash. The drying step should not be confused with preliminary dewatering, a process usually performed by mechanical means, which precedes the incineration process in most systems. Sludge moisture content for the most common types of incineration needs to be about 75 percent or less; consequently, the heat required to evaporate the water nearly equals the heat available from combustion of the dry solids (Owen 1959).

Drying and combustion may take place in separate pieces of equipment or successively in the same unit. Drying and combustion processes consist of four phases: (1) raising the temperature of the feed sludge to 100°C (212°F), (2) evaporating water from the sludge, (3) increasing the temperature of the water vapor and associated gases, (4) increasing the temperature of the dried sludge volatiles to the ignition point. In some operations gases are elevated to a temperature of at least 700°C (1300°F) for a period of 1 second to eliminate odors (Balakrishnan et al. 1970).

Heat of combustion is absorbed by the furnace, or lost by radiation; a larger portion is lost with stack gases, and a smaller portion with the ash. The difference between the heat generated and the heat lost is available for heating the incoming sludge and air. Self-sustained combustion is only possible with highly dewatered primary sludges and then only after the burning of auxiliary fuel raises incinerator temperatures to the ignition point.

MONITORING

This section concerns monitoring of sludge disposal or reuse. It is presumed that sludge and the processes for producing sludge would have been monitored adequately already. Monitoring programs should be designed for early detection of any significant adverse environmental impacts so that corrective measures may be taken before irreversible damage has occurred.

Ocean Monitoring

Ocean monitoring studies have generally emphasized selected marine organisms and marine ecosystems (Preston and Wood 1971, U.S. Department of the Interior 1976, Goldberg 1976). Organisms and ecosystems for baseline studies and monitoring activities have been selected on the basis of the following considerations: (a) possible implications for public health, (b) importance of organism or ecosystem, (c) probability of adverse impact, (d) feasibility of study (costs, availability of analytical techniques and instrumentation). Using these criteria, several groups of marine organisms have been identified for observation.

Benthic organisms are sessile, sensitive to pollution, available in large quantities, and relatively long-lived. These characteristics provide an opportunity to detect and document environmental changes over periods of one to three years (U.S. Department of the Interior 1976).

Planktonic organisms and communities grow quickly and are especially sensitive to pollution at various (particularly early) life stages. They, therefore, constitute sensitive detectors of changes in environmental conditions over a two-week to two-month time frame. Priorities can be established for monitoring the several plankton communities, among them ichthyoplankton (including shellfish larvae), zooplankton, and phytoplankton.

While causes of changes in the abundance, distribution, or condition of fish, and of disease and potential chemical contamination may be difficult to interpret, observation of these changes is important because of possible effects on public health as well as commercial and recreational implications. Endangered species should be included in monitoring activities, since they are likely to be especially sensitive to changes in the marine environment.

Ocean sites used for disposal of sludges should be regularly monitored to detect transfers of potentially hazardous sludge constituents to regions used to produce seafood or for water contact recreation. Monitoring programs should document natural variability in the physical environment and detect early signs of unacceptable environmental degradation so that control and remedial measures can be planned and implemented.

Waters should be sampled at the surface and near the bottom at the disposal sites; in adjoining areas surface films should receive particular attention. The circulation patterns or processes in the disposal areas should be well understood and models developed to predict movements of waters and particles, using data on tidal currents, winds, and river discharge. Development of reliable predictive models may require extensive field programs for several years.

The physical condition and chemical composition of the bottom deposits in and near the disposal sites should be analyzed periodically. Valuable populations of benthic organisms such as lobsters should be sampled more frequently.

Reliable assessment of environmental changes due to waste disposal operations requires particular attention to planning statistically valid sampling schemes and methods of data analysis. Such analysis requires substantial knowledge of the natural variability of fish and benthic communities in time and space so that sludge disposal effects can be clearly identified and quantified.

Land Monitoring

Landfill

The principal purpose of landfill monitoring is to determine the quantity, constituents, attenuation and movement of leachate (Wilcomb and Hickman 1971). Parameters to be measured include hazardous metals, persistent organics, pathogens, nitrate, dissolved solids, and gases.

Monitoring wells should be located according to local hydrology as well as the dimensions of the site. Upgradient as well as downgradient wells are necessary. Leachate and groundwater may be sampled from existing wells or wells drilled specifically for monitoring, and from any surface waters near the site. Baseline levels or background samples of groundwater should be taken.

Monitoring of landfill sites should include a record-keeping system to control the subsequent use of the site after landfill is closed.

Landspreading

Land application systems should be monitored to confirm decisions on rates of application on agricultural or forest land. Monitoring provides information on system performance, but cannot substitute for a reasonable understanding of the interrelated physical, chemical, and hydrologic factors that should be considered before any project is implemented (Blakeslee 1976).

Factors particularly important in sludge monitoring are: public health risks via disease transmission; toxic materials and their potential impact on plants or animals including man; and nitrogen compounds, because of their possible effects on ground and surface waters. Not only the constituents of the sludge, but the soil characteristics, quality of surface and groundwater, and concentrations of toxic materials in the vegetation produced must be evaluated. Nearby wells can yield baseline data on background concentrations in groundwater (Manson and Merritt 1975).

One method of monitoring is to collect untreated soil samples and compare them with samples taken after application of sludge (Blakeslee 1976), in order to identify important changes in soil characteristics before irreversible damage occurs. Where domestic sludge containing little industrial waste is applied, annual sampling of the soil may be sufficient for this purpose. Sludge can be monitored for coliform bacteria, nutrients (e.g., nitrogen), metals, and pH. Under present practices, not all municipal sludge is suitable for landspreading. The elements to be monitored in the soil will include cadmium, chromium, copper, lead, nickel, zinc, mercury, arsenic, boron, and other harmful metals, or persistent organic compounds such as PCBs.

Monitoring can contribute to control of the cumulative total of heavy metals applied to any given acre. Sites of application and quantities applied can be monitored continuously during application. Such monitoring may require the cooperation of both the distributor of the sludge (usually the municipal agency [Carroll et al. 1975]) and a state agency. The state agency appears to be the most appropriate body to supervise records of land on which the capacity for sludge use is exhausted. The applicator could be required to maintain continuous records on quantities and composition of material applied, the exact site of application, and the crops grown on each site.

Monitoring of Thermal Oxidation Emissions

The pollution control equipment required to meet the New Source Performance Standards for Stationary Sources is well developed (U.S. EPA 1975). Monitoring is required to check on control equipment performance, and to detect trends in emissions. Periodic measurements should be taken of particulates, sulfur and nitrogen oxide, and emissions of mercury compounds.

FINDINGS AND ANALYSIS

Ocean Disposal Practice

1. Current ocean disposal operations transport sludge by barge and pipeline to disposal sites where ocean currents will disperse and dilute sludge constituents in coastal waters. Long-term control or containment of potentially hazardous sludges are precluded by this practice.

2. The amount of dissolved oxygen present in the disposal area is a key consideration for ocean disposal.

where dissolved oxygen is abundant, and sludge is dispersed by strong currents, undesirable environmental effects are least likely; such ocean bottom areas have been observed to return to nearly original conditions within a few months after disposal operations ceased. In ocean areas with restricted circulation, on the other hand, oxygen can be depleted and type, abundance, and distribution of benthic communities altered, as a result of accumulation of sludge and subsequent enrichment of the deposits in metals, pathogens, hydrocarbons, and synthetic organic compounds.

3. At present no improvements to marine ecosystems or seafood production have been found to result from discharge of sewage sludges to ocean waters.

4. Unless removed by treatment, floating sludge constituents such as oil, grease, and sewage artifacts may be blown ashore.

5. Detailed knowledge of currents, winds and wave action in a region would aid in locating disposal sites to reduce possible movements of sludge solids into nearshore waters or on to beaches.

Land Use and Land Disposal Practice

1. Substandard landfill operations generate odors, dust, noise, and leachate, and may contaminate groundwater. Landfills can, however, be an acceptable means of disposing of sludge if sites are properly selected, constructed, operated, and maintained, and adequate measures are taken to prevent groundwater contamination.

2. Present data indicate that a small but significant proportion (not exceeding 5 percent) of the nitrogen fertilizer needs of the United States could be met by land application of sludge, if the quality of the sludge were suitable. Landspreading of liquid digested sludge on agricultural or forest land can improve soil humus content, structure, and water-holding capacity. Use of sludge on crops which are consumed uncooked should be prohibited.

3. Sludge can be used with advantage to strip-mined lands if appropriate safeguards are instituted for protecting ground and surface water. Since heavy applications of sludge are required, significant contamination of both soil and water is more likely than in agricultural landspreading. However, the short-term risk of nitrate contamination may be outweighed by the long-term benefit of land renovation.

4. Application of liquid-digested sludges to forest land can improve the soil environment for tree growth. The potential improvement is limited by the assimilative capacity of the soil-plant system. Risks of forest application include nitrate loss to groundwater and streams, and possible eutrophication downstream.

5. Many municipal sludges contain potentially hazardous metals, which may accumulate in the soil to a level that is toxic to some crops, though so far documented reports of metal toxicity to crops from sludge application under field conditions in the United States have not appeared. Copper, zinc, and nickel are of particular potential concern for crops; other metals such as cadmium and lead may affect consumers. The species of crop and soil properties such as pH, organic matter, cation exchange capacity, iron and manganese oxides, and clay content strongly influence the phytotoxicity potential of copper, zinc, and nickel.

6. The toxic effects and biomagnification factors of PCB compounds are such that only very low concentrations of PCBs can be permitted in sludge use or disposal. Application of source control for PCBs may increase the amount of sludge which could be used on the land. Monitoring of PCB levels will be necessary for all municipal sludges.

Air Disposal Practice

1. Thermal oxidation, though generally the most costly of the available disposal options is the only one that may quickly and completely destroy pathogens and persistent organic materials such as PCBs and pesticides. Such destruction is accomplished through complete oxidation of the hydrocarbons, which are the principal constituents of these hazardous substances. Concurrently, other elements such as sulfur, nitrogen and some volatile metals such as mercury and arsenic are partially or completely converted to gaseous compounds which may, if discharged to the atmosphere, be a source of environmental impact. However, means may exist for controlling these gases, together with the flyash generated by high-temperature combustion. The amounts of sulfur and nitrogen oxides, characteristically produced by sludge incinerators are so small as to have minor impact on the ambient air.

2. Pyrolysis is under active development for sewage sludge disposal. Because it is a relatively low temperature process, it may prove to emit smaller quantities of volatile metallic compounds but may, on the other hand, generate

polycyclic organic material or fail to oxidize completely and thus to destroy organics and pesticides. Afterburning, a form of fuel-supported gaseous incineration, may then become necessary to assure thorough destruction of such substances.

Public Health Effects

1. Present understanding of oceanic processes does not permit quantitative prediction of the effects of most sludge constituents on water quality or marine life, nor does it permit satisfactory assessment of public health risks. However, no cases of human disease resulting from ocean disposal of municipal sewage sludges are as yet known.

2. Monitoring programs can be instituted to document conditions and trends in oceanic environmental conditions and marine life. Such programs, which are expensive, need to continue during and after disposal activities until the deposits of sludge materials have decomposed, been buried, or been dispersed.

3. Pathogenic organisms present in digested sludges may survive in soil and on crops for periods varying from a few hours to several months or a year, depending on the type of organism, soil moisture, pH, and predation by other species.

4. Cadmium is an example of a toxic metal found in sludge. The toxicity of cadmium to man is well documented but is difficult to evaluate because its effects on the kidney and liver are cumulative. The average dietary intake for the United States population is already close to the tolerance recommended by FAO/WHO.

5. Aerosols generated in sewage treatment are known to bear pathogenic bacteria and viruses, and inhalation is a possible route for infection. The most recent of the few existing studies show no correlation between airborne aerosols from wastewater treatment plants and incidence of disease in nearby populations. In any case, recent work with electron beam radiation indicates that elimination of pathogens for sludge reuse is not prohibited by costs.

6. Monitoring is a useful tool for measuring system performance, but it cannot be substituted for these preliminary studies. Analytical procedures for monitoring should test soil, sludge, ground and surface water, and vegetation. Samples should be taken before and after application. Use of suggested tolerances for metals in crops is complicated by differences in crop uptake.

Monitoring should include supervision of records of landspreading sites.

Research Needs

1. Research is needed on critical pathways of sludge constituents that may harm humans through eating seafood, contact with seawater, or breathing sea spray near sludge disposal sites, in order to evaluate the risk to public health from ocean disposal of sludges in comparison with disposal in other media.

2. Research is needed on specific disposal operations to quantify the environmental impacts of sewage sludge disposal on coastal ocean waters in the context of other waste disposal operations or other uses involving the same waters.

3. Results from studies on the sensitivity of some crop species to metals and persistent organics in sludge are conflicting. Long-term risks of a potential increase in the concentration of metals or persistent organics in food as a result of sludge use are unknown. A major program is required for systematically synthesizing current research results to assess overall risks to human health, livestock, crop production levels, and continued productivity of the land resource.

4. Research should be undertaken on scrubbers or other means of capturing metallic compounds, and measurements should be taken of the amount of hazardous metals discharged by typical thermal oxidation processes.

5. Municipal refuse constitutes a potential fuel for wet sludge incineration. However, in the United States, repeated attempts to tap this source of heat have been abandoned. Research is needed to determine why these efforts failed and what must be done to achieve the desired combined disposal.

Comparative Analysis of Sludge Management Options

The Committee's examination of the impacts of sludge disposal on air, land, or water has brought to light many aspects of sludge management that warrant comparative analysis. The comparisons may be conducted along two fundamental lines of inquiry. The first approach, illustrated by the structure of the Environmental Protection Agency, is to concentrate on one environmental medium (air, land, and water) at a time. This strategy results in questions as to whether the Agency should stop all ocean disposal of municipal sludge. A second approach, illustrated by the structure of this chapter, is to examine the necessary functions required to dispose of sludge in a given environmental medium. From this approach, site selection, impacts, and monitoring emerge as particularly important. Using this approach, the environmental medium (air, land, or water) would be selected on the basis of how adequately it performs in the functional steps of site selection, public health protection, or whatever criteria the decision maker wishes to place on it. In the past, tradeoffs have been aggregated by environmental medium. Thus, the ocean was deemed the "best option" for certain communities. Here, an evaluation that disaggregates and examines each of the functional steps is proposed. Hence, the "best option" might be the easiest one for site selection.

These tradeoffs, whether explicit or implicit, are the basis of all sludge management decisions. For example, the decision to exclude sludge from the ocean implies that it may be placed in the other media with less environmental impact. The environmental tradeoff is clearly implied in such a decision; however, there is no basis for such an assumption in the available scientific data on comparative impacts.

There is a variety of issues to be considered for comparative analysis of sludge management. The following examination of some of these issues is descriptive, rather than prescriptive, and aims to illustrate the implications of each. Among the most significant are: flexibility, benefits, risks, public acceptance, knowledge, and reliability. Implicit in individual decision to opt for air, land, or ocean is the aggregate weighing of such considerations. They are individually explored here.

Flexibility here includes the ability to switch sludge management operations both within one medium and among environmental media. This capacity for changing operations when results require it is determined by, among other things, the funds invested and the ability of the environment to recover. An inflexible selection is one that by virtue of its cost or for some other reason precludes its rapid abandonment in favor of a new selection.

Physical constraints on site selection are least for ocean and greater for air and land, since once a site has been selected, it is easier to change its location in the ocean, using barges, and much more difficult for land or air. Between land and air, relocation is likely to be more feasible for the former since a land application system can be moved when land is available whereas the equipment for thermal oxidation is not portable.

The flexibility of technological options within a medium is controlled by the variety of systems available. Ocean systems include pipes or barges; of the various air methods only incineration has had some history of success; land offers the options of landfilling and landspreading. Land provides the greatest and air the least demonstrated technical flexibility.

The capital investment required is also a major determinant of flexibility of options within a medium. Ocean disposal for coastal cities requires the least investment in storage facilities and pipeplines or barges. Technology for air disposal systems is both costly and, for methods other than incineration, uncertain. The capital investment for land methods--if land acquisition costs are included--may equal or exceed that required for air methods. In addition to costs of land acquisition, there are storage, transport, and application system costs. Flexibility decreases for each medium as the cost increases, since municipalities will be less likely to abandon high cost options even if they prove demonstrably ineffective.

The relative reliability and ease of operation of the technology once installed is also a key consideration. Pipelines and barges are relatively simple in their operation and maintenance (though weather conditions may at times limit barge disposal operations). Systems for application of sludge on the land surface, or for subsurface injection, and for transport to disposal sites, will be more complicated. For example, cold weather conditions can affect application systems and the soil. The limitations of technology for landfill would be similar to those of other earth-moving operations. Thermal technologies are highly developed and require skill in operation. Some methods have many technical problems (wet-air oxidation) proportionate to technical sophistication. Others (for example, pyrolysis) have not been extensively proven in operational-sized facilities.

Controllable and recoverable benefits from land application have been demonstrated. For the ocean, however, there are no clearly measurable benefits although nutrients contained in sludge may increase productivity of waters at or near the disposal site. Thermal benefits from sludge combustion cannot as yet be documented, but the method might be expected to eliminate pathogens and synthetic organic compounds which are two of the more hazardous constituents of sludge.

Each of the main options for sludge management have entailed risks from primary and secondary (intermedium) environmental effects. The effects are similar in deriving from the hazardous constituents of sludge, but in other respects, are unique owing to the processes peculiar to each medium. As a result, each medium has means by which risks can be reduced and procedures improved.

All ocean disposal operations entail uncontrolled dispersal and dilution of sludge. The ultimate location of sludge constituents in this medium, transfers to other media, and effects on food chains or public health cannot be predicted with certainty even with optimum knowledge of dispersal processes in the ocean. Improved site selection procedures based on investigation of ocean processes, and allowing more sites for disposal may mean less impact on the ocean environment.

There are two aspects to the risks of land use in sludge management. Whereas landfill provides least risk as the only method to contain sludge, under conditions of proper site selection and operation, landspreading may entail the greatest risk, that of irreversible damage to soil by persistent toxics. Such risk can be lessened by monitoring and record-keeping for landspreading operations, and quality control of sludge fertilizer products sold or given away to the public. Significant transfers from the land surface to ground or surface waters, and to the air via aerosols and dust, are known to occur.

Based on information in this report, thermal disposal to the atmosphere by incineration, except in areas where air quality is marginal, may have the least risk of direct impacts, or intermedium impacts through redeposition of emissions, where operating conditions and technical control are such that particulates, metals and other harmful components are largely captured and the emissions meet the latest standards. However, the number of incinerators operating under those optimum conditions is not known. Even less information is available on pyrolysis or other technologies. Residues of incineration are usually contained in landfills. More information on the characteristics of these residues, and of residues of other thermal methods would be useful in assessing the risk of their disposal.

Sludge disposal methods should be compared in terms of pathways of human exposure. Discharge to the atmosphere will directly affect people through respiration, whereas ocean disposal will require transfer through one or more steps to expose humans.

Knowledge of the risk for each medium can be related to the level of knowledge of the effects of sludge disposal. Information remains inadequate on the basic processes, such as bottom currents, which will determine the transport and effects of sludge constituents in the ocean. This is so even though disposal operations have been used in some coastal ocean waters for decades.

Landspreading has also been used for disposal of sludge for many years. Knowledge of land effects is more advanced than knowledge of effects on the ocean. For example, metal uptake by plants can be measured in the laboratory. Gaps remain in information on the risk to public health that may arise from pathogen survival in soil and the risk of contamination of crops.

Only one of the thermal disposal methods--incineration--has been used for long enough to assess the environmental effects, but little seems to be known about the characteristics of the final residues. The environmental implications for emissions from pyrolysis of the relatively lower operating temperatures in pyrolysis are not known.

Source control and pretreatment of industrial discharges to municipal wastewater systems to minimize hazardous chemical compounds in sludge will reduce risk for all three media. Site selection and monitoring are also means to reduce risk.

Although the ocean offers alternative sites for disposal, sites have been chosen in the past without regard to present environmental concerns. Investigation for site selection will require extensive data on currents, prevailing winds, and chemical and biological processes. Such scientific investigation for site selection, and monitoring of relevant parameters and of effects, is costly and difficult to accomplish, because of the large areas involved, and because disposal to the ocean is a method of dispersal and dilution.

Site selection for land use in sludge management would not be so extensive or costly as for the ocean. It is important for this medium that site selection be based on the criteria of suitability rather than merely land availability. Site selection for the land medium would require particular care for an urban area with large volumes of sludge to manage and limited land available for disposal. Monitoring for landfill, which is a containment method of disposal, would be required for groundwater in the area around the site. Landspreading monitoring must be more extensive because sites are larger and hazardous sludge constituents may be transported by natural processes and taken up by crops and consumers.

Site selection for the air medium requires assessment of ambient air quality and other sources of atmospheric emissions in the area, and compliance with zoning requirements. Routine monitoring is done at the point where emissions are released and should, therefore be relatively easy to accomplish.

Disposal in each of the media meets some degree of public opposition, particularly from the populations that live near proposed or existing sites. Public attitude has also varied according to the choice of sludge management option: public protest, for instance, contributed to the administrative decision to prohibit ocean disposal of sludge. Public acceptance of land application of sludge by small, publicly-owned treatment works that have land available, does not seem to be a major problem, but public resistance has been encountered where urban sludge has been disposed of in landfill or by landspreading at sites far from the source.

Disposal of sludge to the atmosphere is often the option selected for large metropolitan areas where the problem of sludge management is large. In some localities, public opposition has caused sludge incinerators to be closed down. With increasing amounts of sludge being produced in the future, thermal disposal methods may encounter more public opposition.

In summary, the comparative analysis of sludge management options implies comparison along functional lines such as risk reduction, site selection, or other aspects. Only by examining these issues discretely and then finding which medium meets the established goals does the real nature of the tradeoffs emerge. Sound sludge management decision making must explicitly recognize those tradeoffs.

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CHAPTER 4

COSTS AND BENEFITS INVOLVED IN SLUDGE MANAGEMENT

INTRODUCTION

Scope of Analysis

Evaluation of options for treatment, disposal, and reclamation of sludge requires economic assessment which, ideally, should consider both market and nonmarket values. Strict market interpretations would be based on the presumption that the supply of sludge management services and the demand for them could be analyzed in terms of quantities supplied and consumed at money prices. For sludge, this presumption is partially true; however, externalities are present. The decision of one sludge management agent (in this report, a public agency) affects individuals who are not included in the transaction. Stated another way, the full effects of the transactions that enable the management option to be implemented are not internalized by those purchasing the option. Thus, indirect and social costs and benefits involved in sludge management must be included in economic comparisons.

In analysis of direct costs, economies of scale are significant. In addition, large differences in indirect and social costs may exist depending on size, location, and local conditions. Therefore, the responsible public agency will face different conditions from rural to urban settings. Spillover (external) effects are prevalent in either case and create a need for cooperation among spatial units.

This chapter's economic analysis applies to sludges created in wastewater treatment, but not to collection and treatment of the wastewater itself. The provisions of the FWPCA Amendments of 1972 (PL 92-500) require that wastewaters shall be treated before discharge. With present and foreseeable wastewater treatment practices, this requirement means that sludges inevitably will be produced. Consideration of sludge management separately from the wastewater treatment processes which create the sludge deprives the analysis of the greatest benefit associated with sludge treatment, use, and disposal: the fact that wastewater treatment and sludge make clean effluents possible and thus in part create the benefits associated with water quality control. Conversely, if assessment of the costs and benefits of wastewater treatment and of sludge management is integrated, choices about desired environmental quality can be based on the overall costs and benefits associated with the entire wastewater management operation.

The amended Federal Water Pollution Control Act specifies a minimum degree of wastewater treatment and that acceptable surface water quality standards shall be established and met. This constraint impinges on the analysis in that estimates of direct costs are derived from facilities subject to regulatory standards. However, degrees of environmental quality for marine and other media of concern in evaluating alternative sludge management schemes are, in general, not specified. Therefore, for this analysis, no explicit constraints on environmental quality related to the disposal media or reuse option were considered. Because this analysis is not bounded by compliance constraints, each alternative may be evaluated in terms of outcomes. This reopens the choice process and eliminates any degree of "compliance at any cost." Ideally, the identification and quantification of costs and benefits would enable the intelligent exercise of public choice.

Alternatives to be Evaluated

An economic analysis of sludge management should consider all possible disposal media as well as the reclamation of sludge constituents. If it cannot be converted to useful products, municipal sewage sludge can be returned to the environment through entrance into one or more of three media--the air, the ocean, or the land. The various means for disposal or reuse in the three media are discussed in detail in Chapter 3.

Sludge management systems have some unit operations and processes for treatment and transportation in common. It is therefore appropriate, in analysis of direct costs, to consider typical costs of components of sludge management systems. Some of the same indirect and social costs and benefits apply equally to all schemes for sludge management.

Categories of Costs and Benefits

In this analysis, three categories of costs and benefits associated with options for sludge management--direct, indirect, and social--are considered. Because of variations in definition of terms in cost-benefit analysis, the nature of the three categories is discussed in this section.

Direct costs and benefits are concerned with dollars expended and revenues gained as a result of exercising a management option. For purposes of analysis, it is assumed that direct costs represent resources that could be employed in other uses for the benefit of society. In this sense, direct cost items are equated with opportunities foregone. That is, it cannot be assumed that expenditures for sludge management call into use resources that otherwise would lie idle. Therefore, the resources cannot be used without cost. Direct benefits are less frequently associated with sludge management but occur, for example, when digester gas or fertilizer is sold.

Indirect costs and benefits are regarded here as items that surface when a second set of activities occurs that is made possible, or caused by, the management option selected. These benefits and costs may be allocated to a specific set of individuals. Further, their valuation can be approximated by a market price. They differ from direct items in that actual money transfers may not take place. Increases or decreases in land values associated with sludge management practices are examples of indirect costs and benefits.

Social costs and benefits are items that escape a market process. In the case of sludge management, these items are most often impacts on common property resources. Water pollution and air pollution arising from sludge management practices are examples of this type of cost. On the benefit side, one might count the visual improvement associated with reclamation of strip mines using sludge.

Consideration of aesthetics helps to distinguish between indirect and social costs. For example, one might define aesthetics in terms of minimizing the disruption of a natural environment. Disruption of this environment, where compensatory payments cannot be made, has negative impacts on society at large and would be regarded as a social cost. Where the adverse effects are specific to some group of individuals, damages may be evaluated, and the real or potential payment to the injured parties would become an item of indirect cost. Social costs are then indirect costs that defy precise bounding by spatial area, cannot be adequately handled with side payments, and frequently affect common property resources.

The Council on Environmental Quality (CEQ) classifies costs as: damage costs, avoidance costs, abatement costs, and transaction costs (CEQ 1975). The Council's view of environmental economics focuses on the most effective way to assure a level of environmental quality. Benefits are not explicitly raised but are expressed as a fraction of the maximum benefit realizable by returning an environment affected by man to an unspoiled condition.

Damage costs as used by the CEQ are the net losses imposed by activities that produce pollution. This class includes market and social costs. Avoidance costs are taken to mean the expenditures to decrease net losses. Abatement costs are the opportunity costs of resources used directly to control pollutants. Transaction costs are the overhead costs incurred through government intervention, where research, monitoring, planning, administration, and communication activities combine to produce the information network involved in solutions to the pollution problem.

In this analysis, abatement costs are covered under direct items and avoidance and transaction costs under indirect items. The net of costs less benefits will be considered as damage costs with social costs and benefits included in the accounting.

The Water Resources Council (1973) classifies items in terms of meeting the multipart objectives of: (1) national economic development, (2) environmental quality, and (3) social well-being. This discussion will embrace elements of category (1) and (2) in consideration of direct and indirect costs and benefits. Item (3) will be portrayed in varying degrees in consideration of indirect and social costs and benefits. The Water Resources Council, in keeping with Harberger (1971), also recommends an analysis framework using the "with and without" principle in an attempt to isolate the net effects generated by the proposed project. Such an approach is inappropriate here because sludge disposal or reuse is not a matter of choice. The mandate that wastewaters must be treated means that sludges will be produced. As sludge production is a primary constraint, the "with and without" principle was not integrated into this analysis.

Table 4.1 summarizes cost and benefit categories used in this analysis, and illustrates the relationship of the three categories to classifications used by others. The table indicates how costs and benefits may be valued, how the functions underlying the costs and benefits may be approached, the types of exchanges that precipitate the costs and benefits, and the spatial areas that define the incidence of the costs and benefits.

TABLE 4.1 Summary of Characteristics of Costs and Benefits

The cost and benefit categories used in this analysis are related by the table to classifications used in other studies. The table also indicates how costs and benefits may be valued, how underlying functions may be approached, the types of exchanges that occur, and the limiting spatial areas.

	Direct Costs/Benefits	Indirect Costs/Benefits	Social Costs/Benefits
Valuation Standard	$ Expended = opportunities foregone (or captured)	$ Estimates = opportunities foregone (or captured)	Psychic Amenity Aesthetic
Other Terms Used to Classify Items	Abatement costs[1]	Avoidance costs[1] Transactions costs[1] Relevant externality[2,4] Pareto relevant externality[2,4] Spillovers[2,3] Secondary[5]	Intangibles[5]
Method of Exchange	Two-party transaction, e.g., municipality–private contractor(s)	Two-party Transaction, e.g., municipality–farmers, resident–physician, taxpayer–government	Nonmarket spillover
Unit(s) of Analysis	Tons processed	Many; land values, crop yield, health, etc.	Indivisible
Items Impacting on Costs (Benefits)	State of technology Scale of plant Nature of wastewater and wastewater treatment processes Sludge treatment/Disposal/Reuse option selected Access (transport routes) Interest Rate Etc.	State of technology Density of human activities Resource use with "slack" in economy	State of technology Aesthetic perceptions
Spatial Area Involved	Local political jurisdictions National by virtue of federal construction grants	Largely regional–in proximity to sludge treatment, disposal/reuse site Regional impacts not necessarily defined by political jurisdiction National by virtue of governmental monitoring research, etc. Potentially global (for example, food chain effects on health)	Most apparent in proximity to sludge treatment disposal reuse site, but potentially global

[1] CEQ (1975).
[2] Bish (1971).
[3] McKean (1958).
[4] Buchanan and Stubblebine (1962).
[5] Prest and Turvey (1965).

DIRECT COSTS

The direct cost of treatment, reclamation, and/or disposal of municipal sewage sludge is a significant portion of the total direct cost of the municipal wastewater management system. Even though the volume of sludge produced is only a small fraction of the volume of wastewater treated, the expenditures required are of the same order of magnitude as those involved in treating the liquid phase itself (Dick 1972).

Many variables affect the direct cost of sludge treatment and disposal or reuse, among them the characteristics of the wastewater, type of wastewater treatment provided, size of the wastewater treatment facilities, location, type of sludge treatment process, distance to the ultimate disposal or reuse site, local attitudes, and government regulations. All such factors need to be taken into account in an economic analysis of possible sludge management strategies, and all of them complicate attempts to generalize about typical direct costs of various alternative schemes for management of sludges.

The total direct cost of a sludge treatment and disposal or reuse management system consists of two types of expenditures--capital, and operation and maintenance. Capital costs include the purchase price and installation cost of all necessary equipment and instrumentation, construction costs, land costs, contractor's profit, and legal and engineering costs. The operation and maintenance costs for a particular sludge management system include the wages paid to operational and maintenance employees and to supportive and administrative personnel, the cost of materials (such as chemicals or routine replacement parts), the cost of energy (in the form of both electricity and fossil fuel), and various other recurring costs peculiar to individual systems.

To derive a total annual cost for a particular treatment system, the capital cost must be allocated throughout the expected life of the system. This may be done by calculating the annual payment required to repay, with interest, the capital invested in the system. This annual payment, the amortized capital cost, depends on both the interest rate and the anticipated life of the facility. The total annual direct cost of a sludge treatment system is, then, the sum of the amortized capital cost and the operation and maintenance costs.

To establish a comparative basis among facilities of different sizes, the total annual direct cost may be divided by the average yearly sludge production to obtain a unit cost of treatment and disposal per unit weight of solids.

In such comparisons, the weight of sludge is conventionally expressed in terms of dry rather than wet solids to circumvent complications caused by differences in the concentration of sludges from different installations and in different processes. Moreover, overall direct costs are customarily expressed in terms of the amount of sludge originally produced from wastewater treatment, even though some sludge treatment processes result in reduction of the quantity of sludge. Thus, if one ton of sludge enters a $20 per ton treatment process and is reduced to one-half ton of sludge for disposal, the reported cost using this convention will be $20 per ton. However, when a particular process is being considered (for example, vacuum filtration), costs are customarily based on the actual weight of dry solids entering the process. Those conventions are followed here.

Cost information considered in this study was obtained from three sources: (1) municipal and regional engineering reports (the 23 engineering reports listed in the Appendix); (2) previous generalized cost studies; and (3) a mail survey of municipalities. As might be expected, cost information from each source was based on varying assumptions and differing cost accounting practices. Differing local circumstances influenced costs and the time reference changed from study to study.

Eleven of the engineering reports described in the Appendix yielded recent estimates of the cost of alternative means of sludge management. These data are tabulated in Table 4.2. None of the data are older than 1970, and all have been adjusted to a single point in time (January 1, 1976) by use of the Engineering News Record Construction Cost Index (Engineering News Record 1976).

Although some of the variability among the estimated cost data in Table 4.2 is attributable to differing local conditions and to differing size of the cities, scanning the data in the vertical columns in the table suggests significant differences in costs among the engineering studies. Scanning the data in the horizontal rows suggests that estimated direct costs of options differ appreciably, and that significant savings in direct costs will be realized by selecting the option most favorable to a specific situation.

Data from published reports on the costs of sludge management (Metcalf and Eddy, Inc. 1976; Stanley Consultants, Inc. 1972; Wyatt and White 1975; Black and Veatch 1971) were adjusted to a common point in time to evaluate the effect of the size of waste management facilities on capital and operating costs for sludge management and the relative contributions of labor, energy, capital, and chemicals on overall costs. As in the case of

TABLE 4.2 Estimated Costs of Sludge Management at Several U.S. Cities[1]

Eleven of the engineering reports described in the Appendix yielded recent estimates of the costs of alternative sludge management schemes. The data have been adjusted to 1976 by use of a cost index. Data in vertical columns suggest significant differences in estimated costs among the studies. Data in horizontal rows suggest that savings of direct costs can be realized by selection of the most favorable option for a specific situation.

	Cost[2] for Indicated Option for Sludge Management										
City[3]	Pyrolysis	Wet Oxidation	Incineration	Drying	Oil-Dehydration	Composting	Landfill	Liquid Application on Land	Dewatered Application on Land	Ocean Disposal	Lagoon
New York City	51-88	113		87	116						
Washington, D.C.	48-60		57	60-73	41-80	71-86			81-82		
Washington Suburban Sanitary District			69-111				83-99				
Corpus Christi, Texas			111	68				46-59	54-76		
Boston, Massachusetts		59	44				63				
Knoxville, Tennessee			58	67		81	64-78	125			
Southern California Region			33			22	27-53	64		9	
East Bay MUD, California			138	134				117	130	61	138
Denver, Colorado			76-98			135-177		77	87-104		
Sacramento, California			95				60-74	56			
Tampa, Florida			173	101-128			121-141	158-160			

[1] Costs adjusted to January 1976, Engineering News Record Construction Cost Index

[2] Cost in dollars per ton of dry solids.

[3] See Appendix for citations of engineering reports.

Table 4.2, large variations in costs were observed. This was true even though the data were generalized values not reflecting site-specific conditions.

The direct cost comparisons shown in Table 4.2 are based on annual costs per unit weight of sludge. Annual costs include amortization of capital expenditures as well as recurring operation and maintenance costs. It should be noted that each engineering report referred to in Table 4.2 considered several sludge management options feasible. The relative contribution of capital amortization and operation and maintenance expenses could be expected to vary among options.

The distinction between capital and operation and maintenance expenses becomes significant when decisions about sludge management are made within an economic framework in which construction grants from EPA may pay up to 75 percent of the capital cost of sludge management and, in some states, part of the remaining portion may be covered by state grants. This influence of construction grant programs is illustrated by the fact that several of the engineering reports considered in the Appendix included two different analyses of costs, one with and one without government construction grants. Such comparisons imply that allocation of funds through the federal construction grant program could encourage selection of sludge management schemes with low operation and maintenance costs (for which no grants are available), but high capital costs. Thus, the construction grant program for sludge management facilities could serve to minimize costs borne by individual cities but to maximize the direct costs borne by society. In addition, it is conceivable that the availability of construction grants providing most of the capital costs for sludge management facilities could lead to selection of options with indirect and social costs higher than those of alternative solutions that might be selected in a free economy.

Selection of sludge management options with high "front end" costs may be particularly constrained when either the adequacy of the technical solution or its future performance requirement is uncertain. Flexibility for future adaptation is maximized by selection of options that require low capital expenditure.

Variation in Direct Costs

To obtain current data on actual costs of sludge management, questionnaires were sent to 100 medium-sized U.S. cities. Eighteen returns were received, and half of those had some information on costs. None, however, was able to provide an analysis of actual costs, including capital and operating expenses, attributable to sludge management. Accounting procedures to permit such analyses of actual sludge management costs appear to be lacking. Estimates of total direct costs for sludge management from various cities recently tabulated by Sullivan et al.[1] indicate that extremely large variations in reported actual direct costs exist.

Even larger variations in estimated direct costs for sludge treatment and disposal processes are evident in the data taken from engineering reports for specific installations. It might be expected that the *a priori* estimates contained in the engineering reports would tend not to reveal extreme variations from the norm, and that still greater variations would exist in actual operational costs at various installations. Regrettably, few operational data based on an exact accounting of total direct costs for various sludge treatment and disposal processes are available.

Good reasons exist for variations in direct costs of a given sludge treatment process between two installations of the same size. Differences in the quality of sludge, in the costs of land, labor, energy, and resources, and in design of installations are among the factors that could cause such variations. It seems unlikely, however, that such factors alone explain the lack of precise direct cost definition for alternative sludge management practices. Rather, it is likely that the historical lack of attention to sludge treatment and disposal and inadequate cost accounting practices have contributed significantly to the wide variation among reported direct costs.

Direct Costs of Industrial Waste Source Control and Pretreatment

The quality of the sludge influences the viability of particular sludge management options for particular locations, and consequently affects the direct cost of sludge management. Thus, source control or pretreatment of inputs to the municipal wastewater system influences sludge management costs. Ideally, the total of direct costs of source control, pretreatment of wastewater, wastewater treatment, and sludge management should be considered in developing environmental strategies.

Unfortunately, few data exist to permit substantial elaboration of direct cost considerations related to selection, design and operation of source control and pretreatment processes. The data do not exist because the possibilities for influencing sludge quality through source control and pretreatment have not generally been addressed in developing sludge management plans. This is illustrated by the fact that none of the 23 regional/municipal studies described in the Appendix considered pretreatment of industrial wastes as an option to be evaluated in considering alternative sludge management schemes; the influence of alternative wastewater treatment practices on sludge quality and quantity was, similarly, not evaluated. The report prepared for the Interstate Sanitation Commission (Camp Dresser and McKee 1975) did include consideration of the possibility of heavy metal extraction from sludges. Extraction was not, however, considered feasible.

Some indication of the direct cost implications of the pretreatment of industrial wastes to improve sludge quality is available in a report on the influence of regulatory requirements on the treatment of municipal and industrial wastewaters at Buffalo, New York.[2] The wastewater treatment facilities of the Buffalo Sewer Authority serve an area described as "highly industrialized." Secondary (biological) wastewater treatment facilities are being constructed. According to the McPhee et al. report "the high metal concentrations presently in Buffalo's sludge may eliminate any agricultural options.... However, the enforcement of the Buffalo Sewer Authority Sewer Regulations could lower these metal concentrations to levels where the agricultural options could be viable alternatives." An option the report considered suitable for sludge management at Buffalo was incineration followed by landfilling with the ash. Based on the current cost of incinerating primary sludge at Buffalo ($193/metric ton or $176/ton of dry solids) and estimating 1 ton of sludge per million gallons of wastewater from the expanded secondary wastewater treatment facilities, total annual cost for sludge management would be about $12 million/year.

This magnitude of annual expenditure may be compared to the estimated costs of industrial waste pretreatment required to open up other sludge management options which might have lower direct costs. McPhee et al.[2] estimated that the total annual cost of industrial waste pretreatment at Buffalo would be $2.27 million, or less than 20 percent of the costs of sludge management. Benefits from this level of expenditure for industrial waste pretreatment accrue to areas other than sludge management, for example by reducing the suspended solids and carbonaceous oxygen demand of the industrial wastewater. The estimated annual cost for pretreatment of plating industry wastewater was $179,000 or less than 6 percent of the annual cost of sludge management. Clearly, requirement that industrial wastes be pretreated may result in adoption of sludge management options with a total cost lower than would be possible without pretreatment. The distribution of expenditures between public and private sectors would, however, be altered.

INDIRECT COSTS AND BENEFITS

As noted earlier, indirect costs and benefits are those items that enter the accounting framework when spillover effects can be clearly specified in terms of spatial area and resource use affected, and some estimate can be made of dollar values either gained or lost by individuals. To illustrate the nature of indirect costs and benefits, consider that a sludge processing-disposal/reuse entity is identified as economic agent A. In exercising one of the sludge management options, A incurs direct costs and may garner some direct benefits. These costs and benefits are internalized to the extent that a market process correctly measures the value of the benefits and costs, and the sludge management activity does not produce side effects that enter the economic activities of another party (economic agent B). The economic well-being of B may not be taken into account by the activities of A. When this occurs, the possibility arises that externalities may become significant.

In terms of cost-benefit analysis, these side effects (also referred to as externalities, spillovers, or impacts), are regarded as secondary effects. They may involve impacts on productive processes or they may be pecuniary in nature. In terms of the technical process, the spillover should enter the cost-benefit framework in that the activities of A have either disrupted or enhanced the productive output of B. Thus, in terms of an accounting of resource units, A's actions have either increased or decreased B's ability to produce in physical terms, given the resources that B has.

Pecuniary side effects become important when activity by A enters the wealth determination of B but does not affect the use of resources. B may lose all revenues from production as a result of pecuniary effects, but if the resources can be used in another economic activity the loss is regarded as a transfer. Such impacts may be very important locally and to the individuals gaining or losing, but since they do not have national significance, pecuniary side effects are often not regarded as an item entering a cost-benefit framework. This is the result of analyzing costs and benefits from a national perspective. Such effects should not be disregarded in evaluations of sludge management alternatives.

For purposes of discussion, some of the indirect costs and benefits associated with sludge management may be classified as the impact on land values, the costs of government, the potential for health hazards, input requirements in a productive process on reclaimed land, agriculture products produced from reclaimed land, effects on ocean productivity, impact of industrial wastewater pretreatment requirements, and displaced fertilizer production.

Land values may be affected at both the treatment plant and the ultimate disposal site. Land near the treatment plant (sludge processing site) will probably be adversely affected regardless of the management option selected. Processes such as sludge treatment are generally regarded as nuisances, and it seems unlikely that they could ever reasonably be considered otherwise.

Land values at the disposal site would be regarded as adversely affected whenever the disposal method is considered a nuisance. This could be true for incineration, ocean dumping, storing in a lagoon or landfilling, or land application. Values of adjacent land might be expected to increase when strip-mined land is reclaimed by application of sludge.

Land value is influenced by a site's proximity to shopping, work, and recreation opportunities, the difficulty or ease of access to those activities, the size of the plot, and the influence of such neighborhood effects as the location of a facility for sludge processing, disposal, or reuse.

Land value can be ascertained by one of two methods. Regarding land as a productive input, its value can be articulated in terms of its marginal physical product. Consider a productive process combining the resources of land, labor, and capital. Holding the amounts of labor and capital constant while varying the amounts of land serves to determine land's contribution to output. By determining the changes in output given changes in land with all else constant, the marginal physical product may be determined. Affixing a price to output permits a dollar valuation of land's contribution to output.

Land value is more commonly determined by rent bids. For example, businesses locate in commercial centers in an attempt to do as much business as possible and thereby increase their profits. Industrial concerns locate near labor pools and transport installations to ensure steady production. Agriculture locates at a distance from more intense activities because low unit transport costs enable this activity to engage land that has few alternative uses. Households may locate near centers of employment for obvious reasons. The price that buyers are willing to pay for land in order to put it to use for some productive purpose establishes its value.

In a pure resource economics world (where only technological impacts would be considered), the processing of sludge and its disposal or reuse should impose no indirect costs on adjacent land values. While the process may be regarded as a nuisance, this nuisance element presumably does not affect the technological processes of nearby land owners. Because of tastes and preferences, however, this nuisance has an impact on location decisions. These impacts can be reflected in the market place when the parcel near the sludge facility transfers ownership, and hence an indirect cost is attributable to the nuisance created by the sludge management practice.

The costs of government in terms of disposal/reuse options include expenditures for: research, planning, regulation, monitoring, and administration. The continued operations of EPA and the various other agencies at all levels of government that collect and disperse tax monies may be regarded as a common cost. These costs would persist regardless of the choice of sludge management option.

Indirect costs stemming from health hazards may be considered as payments to health services for corrective health care, and lost labor productivity. The particular practices for processing, reusing or disposing of sludge will influence the size of the impact. Quantification of these indirect costs is complicated by the potential of long-term health effects of sludge management practices.

Finally, there is a class of costs and benefits in which technological impacts are felt. Disposal in the ocean, for instance, may affect ocean productivity. This impact on fisheries may be in terms of yield (possibly positive), quality of product (presumably negative), as well as food chain effects (presumably negative).

The option of reclamation of strip mined land suggests indirect costs in terms of the payments to costs of the added productive inputs employed in a productive agricultural process. These may be negligible if farm implements are currently used under capacity and employment increases accrue to unskilled workers. The indirect benefits are the increased quantities of agricultural products evaluated at a money price.

Indirect costs of sludge management may arise as a result of requirements for industrial wastewater pretreatment to control the quality of municipal wastewater sludge. These indirect costs would relate to loss of jobs due to any closure resulting from pretreatment requirements. Some indication of the magnitude of the potential impact of wastewater pretreatment requirements in the metal finishing industry is available from a study prepared for the EPA on the economic effects of effluent guidelines (A.T. Kearney, Inc. 1974). That report estimated 10 to 27 percent closures (principally small establishments) as a result of pretreatment for discharge to municipal sewerage systems by the metal finishing industry. Reemployment of these displaced resources in alternative productive activities would eliminate the economic cost, but local impacts would still occur.

An item of an indirect nature concerns tax revenues. In evaluating any sludge management option, the fact of public activity may imply some amount of tax revenues foregone. The acreage involved and taxation instrument affected are easily identified. Problems arise in speculating about the type of private activity displaced when exercising the sludge management option. At best, limits could be placed on the estimate indicating high and low ranges of taxes foregone due, for example, to the occupation of intense industrial activities and/or vacant land held strictly for speculative purposes.

Finally, when sludge is used as fertilizer, certain private market activities may be displaced. While there may be a localized effect (for instance, a fertilizer distributor may be forced out of business), society at large saves costs because those displaced resources may be put to alternative use in a productive process.

Present understanding of the economics of sludge management does not permit dollar values to be affixed to the indirect costs and benefits, but these items might be estimated if adequate information were available.

SOCIAL COSTS AND BENEFITS

To complete an accounting format for evaluating the effects of exercising sludge processing-disposal/reuse options, a group of items that are regarded as nonmarket should be recognized. These social costs and benefits relate to concepts of quality of life and are not priced. Shadow pricing will not be attempted, since these items are conceived of as extra-market items of well-being. Imputation of prices implies that market values can be approximated for a class of public well-being measures that are not exchanged and cannot be exchanged because they are frequently intangible, related to common ownership (as opposed to private property rights), and nonallocable in terms of a bounded spatial unit.

In terms of the options for processing, disposal, or reuse of sludge options, social costs surface in the form of health hazards, insults to aesthetic sensibilities, and the acquisition "costs" of the air and water media receiving sludge. Social benefits may arise from exercising an option that enhances aesthetics. A major benefit to society, only superficially developed here, is that the creation of sludges manifests a flow of treated wastewater.

Health-related social costs as well as indirect costs may be created by sludge management practices. The indirect cost was valued at the cost of corrective treatment plus any losses in productivity (measured by a constellation of wage rates). Unfortunately, corrective treatment is not applied instantaneously, and the probability of correction is not 100 percent. In these instances, a psychic cost of deficient health arises. It can be expressed as the nonmarket cost of the individual not feeling well.

The aesthetic costs arise through disruption of a natural environment, and are costs only when the disruption is perceived as a nuisance. Because of the difficulty of achieving public acceptance of sludge disposal regardless of the media involved, most options are assumed to include some sort of nuisance factor and social costs are incurred. It may be argued that aesthetic benefits arise from reclaiming strip-mined land with sludge, because the reclaimed land is more appealing to the senses than the disturbances wrought by strip mining.

A major acquisition benefit associated with sludge management is the improvement in water quality by wastewater treatment. Again, the magnitude of the benefit is a function of direct expenditures. Additional acquisition benefits could be associated with sludge management practices, such as reclamation of marginal land.

SUMMARY

Some of the benefits enjoyed and costs incurred in exercising sludge management options are presented in Table 4.3. The table illustrates the types of direct, indirect, and social costs associated with sludge management schemes, but is not exhaustive--individual projects might generate important costs and benefits not included in the tables. A quantitative summation of the costs and benefits cannot currently be made because the nonmarket items and indirect items considered are not susceptible to quantification.

Indirect costs and benefits have not been given empirical content and it is not likely that firm estimates of their relative magnitudes will soon be forthcoming. For example, the impact of sludge treatment and disposal/reuse practices on land values might be estimated by use of a controlled experiment such as carried out by Nourse (1967).

TABLE 4.3 Cost and Benefit Items for Consideration

Types of direct, indirect, and social costs and benefits associated with sludge management are illustrated, but this list is not exhaustive. In addition to the water quality benefits attained by wastewater treatment, there are several potential benefits which may accrue from the use of sludge. A review of information presented here could aid in arriving at a decision concerning sludge management.

Cost and Benefit Items for Consideration	Direct	Indirect	Social
Cost			
Capital Expense: treatment, disposal, reclamation	✓		
Operating Expense: treatment, disposal, reclamation	✓		
Land Values: proximate to treatment site		✓	
Health Hazards: proximate to treatment site		✓	✓
Aesthetic Values: proximate to treatment site			✓
Transport Costs: treatment site to disposal or reuse site	✓		
Acquisition Costs: land for disposal or reuse	✓		
air for disposal			✓
water, e.g., ocean, for disposal			✓
Land Values: proximate to disposal site		✓	
Health Hazards: proximate to disposal site		✓	✓
Aesthetic Values: proximate to disposal site			✓
Productivity Cost: labor and capital for agriculture		✓	
Governmental Cost: regulatory, research, etc.		✓	
Raising and Disbursing Tax Monies		✓	
Effects on Fisheries		✓	
Industrial Wastewater Pretreatment	✓	✓	
Benefit			
Revenues from fertilizer sales	✓		
Revenues from other reclaimed products	✓		
Proceeds from sales of land reclaimed	✓		
Land values adjacent to reclaimed site		✓	
Value of goods produced on reclaimed land		✓	
Use of treated water produced in course of generation of sludge		✓	✓
Ocean productivity		✓	
Alternate employment for fertilizer, labor, and capital		✓	

Nourse proposed a scheme based on determining the difference in selling prices of real property in two residential zones otherwise similar except for the imposition of a nuisance (in his example, air pollution). As Nourse concluded, the results of such an experiment are limited in terms of generalizations permitted. The nuisance effect is peculiar to a limited spatial area, a fact that makes intercity extrapolation highly speculative.

In contrast to indirect and social costs and benefits, quantitative data on the direct costs and benefits of alternative sludge management options are available. However, comparisons of direct and operating costs obtained from various sources revealed variations which could not be anticipated by described differences in conditions influencing cost. A better understanding of the direct costs of alternative sludge management schemes would seem desirable to aid decision making in residuals management.

The existence of governmental grants for appreciable portions of the capital expenditures for sludge management may be expected to bias judgments in favor of capital-intensive options with low recurring costs. Similarly, options with higher indirect and social costs may appear more attractive as annual direct costs are diminished by selection of a capital-intensive option.

Source control and pretreatment of some industrial wastewaters may help to reduce overall costs (including direct, indirect, and social costs of sludge management). From the limited information available on the cost of industrial wastewater source control and pretreatment, it does not seem that direct cost to industry would preclude this approach.

Comparisons of alternative sludge management schemes would ideally involve study of life cycle costs and benefits associated with various options. Figure 4.1 shows a hypothetical comparison of that sort. The figure shows the cumulative present value for various systems of sludge management. No benefits of the improvement in water quality resulting from the wastewater treatment that generated the sludge were considered.

Lowest capital costs were assumed for the ocean disposal option. For purposes of illustration, social and indirect costs were assumed to increase with time. The option labeled "agricultural land" was assumed to involve application of "fertilizer grade" sludge on land, and total direct, indirect, and social costs and benefits incurred following the initial capital outlay were assumed to be comparable. A higher front-end cost was assumed for the air

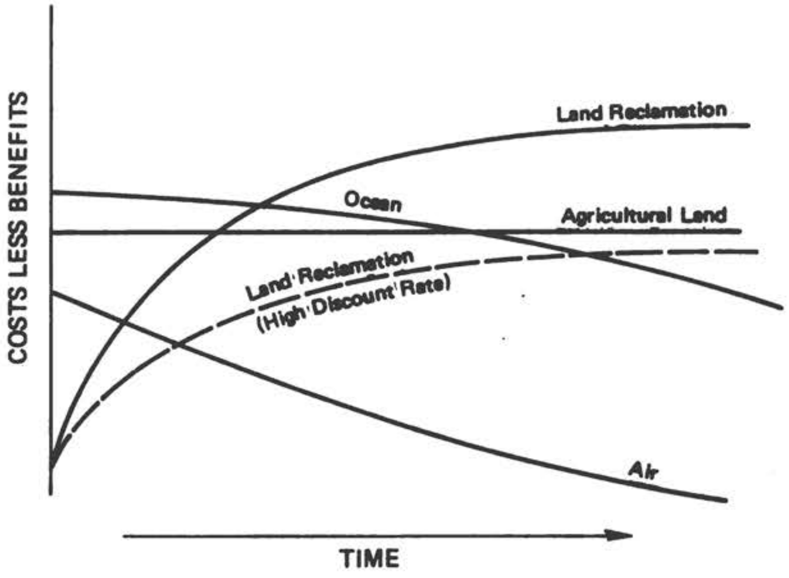

FIGURE 4.1 Hypothetical accumulative present value for various sludge management options.

This figure illustrates a hypothetical comparison of sludge management schemes by plotting associated life cycle costs and benefits (benefits resulting from improved water quality not included). By means of this type of graphic presentation, the cost comparison of alternate methods can be readily visualized.

(thermal process) option, and net annual increments could not be envisaged as being positive.

The land reclamation curve is based on the assumptions that high capital expenditures are necessary (perhaps to grade strip mined areas) but that dramatic improvement in land value and productivity occurs early in the life of the project. The dashed cumulative curve for land reclamation illustrates the effect of the discount rate chosen to depict costs and benefits in terms of present value. In the illustration, a higher discount rate has the effect of lessening the value of those benefits generated by land reclamation that persist well into future years. The same type of effect of the assumed discount rate could have been illustrated for any of the options presented in the hypothetical example.

In conclusion, it must be admitted that this analysis of costs and benefits associated with sludge treatment and disposal has answered fewer questions than it has raised. At the outset, any mention of cost-benefit analysis implies that some alternative can be pointed to as being preferred. As noted in the discussion, the elements contributing to a criterion for establishing preferences are frequently non-quantifiable or are quantifiable only with rigorous social experimentation. This does not defeat the effort; instead it defines the areas for future inquiry.

FINDINGS AND ANALYSIS

1. Effective planning for management of municipal sludges is hampered by lack of adequate data on the capital and operating costs of various alternative sludge management options. Inadequate attention to the true direct costs of sludge management, and complications resulting from segregating costs of wastewater treatment and sludge management appear to have contributed to the dearth of direct cost data.

2. Sources of quantitative estimates of the indirect costs and benefits associated with alternative sludge management schemes are not known. While it is not to be expected that firm data on indirect costs and benefits will ever be developed, attention to the magnitude of such costs and benefits could help to develop an information base useful in arriving at sludge management decisions.

3. It should not be expected that choices between sludge management options ever will be made on the basis of rational economic analyses alone. The social costs and benefits attributable to alternative sludge management schemes can and should be weighed heavily in sludge

management decisions. While these social costs and benefits require consideration, they defy quantitative assessment.

4. Industrial source control and pretreatment of heavy metal bearing wastewaters to control the quality of municipal wastewater treatment sludges is not economically prohibitive. Available data suggest that, in addition to the environmental benefits of heavy metal removal (i.e., reduction of indirect and social costs), the overall direct costs of sludge management could be reduced because of industrial source control and pretreatment. This is because lower-cost, environmentally-acceptable techniques for sludge management may be rendered unavailable if the quality of industrial wastewater discharges is not controlled.

5. The existence of government programs for grants to cover significant portions of the capital costs of sludge management may lead to selection of capital-intensive sludge management schemes that do not have the lowest overall direct, indirect, and social costs.

NOTES

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CHAPTER 5

LEGAL AND INSTITUTIONAL CONSIDERATIONS

SLUDGE REUSE OR DISPOSAL AND THE LAW

Introduction

Sludge management is subject to a number of legislative and institutional requirements: international conventions regarding dumping at sea, federal and state laws and regulations on disposal and reuse, public and private incentives for developing secondary and advanced wastewater treatment processes, and social attitudes towards waste disposal and reuse. Sludge has not usually been singled out for separate legislative treatment whether at the state or federal level. Instead, it has been included within the statutory scope of regulations concerning any substances generally considered to be pollutants discharged into water or disposed of on land. Under these regulations, therefore, disposal of raw or treated sludge into water is subject to restrictions relating, for instance, to biochemical oxygen demand (BOD), coliform organisms, suspended or settleable solids, toxic materials, and so forth. The net effect has been to inhibit the disposal of sludge directly into receiving waters (except perhaps the ocean). Disposal on land has been lawful provided that it met requirements applicable in general to solid wastes or that it did not conflict with general nuisance laws or some restriction on use of the land in question. Air quality requirements have not been phrased specifically for sludge disposal. As will be explained subsequently, legislators are becoming aware of the sludge problem, but it is still considered mainly as a subordinate element of solid or liquid waste management.

Definition poses an initial problem for identifying the legal status of sludge; because of its physical properties, sludge could be regarded as either liquid or solid waste. Because of the way many laws are written and administered, the definition of sludge will bear directly upon the type of treatment to be provided and the agency responsible for it. Determination that the substance is liquid waste could lead to the conclusion that sludge management is the responsibility of the sewage treatment agency and of the policymaking and administrative apparatus governing it. Ultimately, it would be a water quality responsibility. On the other hand, categorization as solid waste leads to the conclusion that sludge should be divorced from the water quality chain of operations at or soon after generation and should be under the garbage and trash agencies.

While recognizing that sludge can be solid, semisolid, or liquid, the newest relevant Congressional enactment continues the trend to conceive of it as solid waste (see discussion of the Solid Waste Disposal Act). Although there are not yet many statutes that specifically define sludge, their number may be growing. The purposes of this legislation appear to be to make various sludge management undertakings eligible for expanded research and demonstration grant activities authorized for EPA's solid waste program and to allow the inclusion of sludge in the newly authorized EPA permit program for hazardous solid waste substances.

It is possible for a definition to apply only to a particular statute without affecting any other laws or relationships. However, in a field where concepts are in an evolutionary and still fairly primitive stage, early definitions may have more precedential influence on later decisions than the strict necessities of the earlier instance require.

Water Quality Acts Before 1972

Neither the Federal Water Pollution Control Act (FWPCA) of 1956 (PL 84-660), nor the Water Quality Act of 1965 (PL 89-234) contained any effluent standards, although they both provided the federal government with tools for encouraging secondary treatment requirements at the state level.

The FWPCA of 1956 instituted a "conference procedure" by which the cognizant federal official could call a meeting of appropriate federal, state, and interstate agencies whenever in his or her judgment particular discharges in one state were threatening the health or welfare of persons in other states. Although not so called, these conferences were developed by the federal water quality agency into proceedings resembling hearings. The representative of that agency, who was the conference chairperson, always undertook to produce recommendations and to negotiate agreements on specific remedial action.

During the late 1960s, the federal chairperson of the conferences recommended that secondary treatment of wastewaters be required everywhere and sought agreement from the state water pollution control agencies. While federal and state participants at the conferences did not always agree unanimously, the recommendations of the federal chairperson were regarded by the federal water quality agency as governing. This did not necessarily mean that the conference recommendations became part of state law, but did contribute significantly to the framework implemented by the grant-giving parts of EPA. Accordingly, the presence of conference recommendations or findings that a minimum of secondary treatment be required provided a basis for denying construction aid to sewage treatment plants of lesser grade. Furthermore, the annual state water pollution control agency programs had to be compatible with the secondary treatment requirement to qualify for federal program grant assistance.

Although states usually did not formulate the minimum secondary treatment requirement without federal assistance or encouragement, there is little evidence of vigorous resistance to the requirement. When proposals to implement secondary treatment were advanced by the federal chairperson, state conferees generally accepted them.

The Water Quality Act of 1965 provided another means by which federal agencies (i.e., the water quality agency within the Department of the Interior before 1970, and EPA thereafter) could insist that the states adopt secondary treatment requirements. The statute prescribed state development of water quality criteria which were denominated "water quality standards," which were enforceable as federal and state law once approved by EPA. Of course, a state acting pursuant to its own statutes could independently make its own standards whether or not they conformed to federal requirements, but the threat of financial and other penalties for noncompliance was serious enough that within a relatively short time all states were participating in the federal-state process of making standards. Although more than secondary treatment was involved, it is relevant to note that parameter requirements for both effluent and receiving waters generally presumed secondary treatment of municipal wastewaters as well as treatment of industrial wastewaters.

Thus, the federal government, by administrative action pursuant to a broad and largely procedural pair of statutory provisions, succeeded in influencing state water pollution control agencies to include secondary treatment requirements in the policies and regulations made pursuant to state water quality laws. One, not specifically intended, result was to assure an increase in the quantity of sludge that would have to be disposed of by local government agencies, because upgrading primary effluents by further processes can produce more sludge, as was described in Chapter 2.

Federal Water Pollution Control Act Amendments of 1972

As indicated at a number of points in this report, the FWPCA Amendments of 1972 (PL 92-500) precipitated a further increase in the quantities of sludge generated by liquid waste treatment and thus gave more importance to sludge management than it might otherwise have had. Table 5.1 lists the provisions of the statute particularly significant to sludge. The necessity of handling large volumes not only increases the size of the operation, but can change the character of the problem as well.

The National Pollutant Discharge Elimination System (NPDES) established by Section 402 (33 USC 1342) of the Amendments, is crucially important to sludge management. Since all point source discharges to surface waters must be under permit, both public sewage treatment plants and industrial waste discharges operate under NPDES permits which contain conditions and restrictions governing the composition of their effluents. Section 405 of PL 92-500 specifically prohibits the discharge of sewage sludge into navigable waters unless directly authorized by EPA. Thus, compliance with this provision influences the choice of methods of management.

In the past, the most direct and pervasive control over municipal sludge treatment and disposal or reuse methods has been exerted by state health departments or water pollution control agencies. Generally, before a treatment plant can be built and begin discharging effluents, a permit or approval must be obtained from these state authorities. State permission can be and frequently is conditioned on the use of an acceptable method of sludge disposal or reuse. Thus, the fixing and administration of sludge treatment and disposal requirements may now be accomplished through state permit procedures, via NPDES permits, (administered by EPA or the states), or under Section 405 of the FWPCA Amendments of 1972 which, however, has not been implemented. Under 1976 legislation, regulation may soon exist for sludges denominated hazardous. Permits procedurally similar to the NPDES Program may be required.

Secondary wastewater treatment may now be said to be a minimum requirement of federal law, since the language of the Act, which prescribes "best practicable treatment" (BPT) by 1977 and "best available treatment" (BAT) by 1983, was generally understood to indicate secondary treatment as the minimum for BPT when PL 92-500 was enacted. However, the concepts of BAT and BPT and their entry into the law were built by a process of administrative interpretation which, although procedurally lawful, was certainly not made

TABLE 5.1 Major Federal Statutory Provisions Affecting Sludge Management

There are a large number of statutes and administrative regulations which directly or indirectly affect planning processes, operating programs, and requirements having a bearing on municipal sludge management. Only the few most directly relevant statutory provisions are presented in this table.

Federal Statute	Citation	Relevant Provisions	Effect on Sludge Management
Federal Water Pollution Control Act Amendments of 1972	33 USC 1251 et seq.	*Sec. 1252* Goal to protect fish and other wildlife and to provide for recreation so that nation's waters are fishable and swimmable by 1983.	Provides for reduction or elimination of discharges of pollutants into water bodies, resulting in increased production of sludge and limiting options for disposal.
		Sec. 1282 Administrator to assist states with wastewater treatment plant construction by making federal grants of 75% costs of construction.	Favors treatment of sludge by capital intensive means.
		Sec. 1284 Administrator to make federal grants only when satisfied that applicant for assistance will receive proportionate shares of maintenance and operation costs from waste treatment plan and users and proportionate share of construction costs of industrial waste treatment for industrial dischargers to public sewerage systems.	Can affect distribution of costs for treating sewage and sludges containing both sanitary and industrial waste.
		Sec. 1288 Regional and state agencies to develop areawide and statewide waste treatment management plans, which require approval of Governor or Governors and EPA to qualify state and local agencies for federal grant assistance.	Regulatory to extent approved plan prescribes methods and programs for sludge treatment and disposal or reuse.
		Sec. 1311 (b) (1) (State) To develop effluent limitations for Best Practical Technology by 1977 and Best Available Technology by 1983, approved by EPA.	Result in requirements for removal of sewage constituents before effluent discharge, influencing amount and characteristics of sludge produced.
Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter	Treaties and Other International Acts, (TIAS) 8165	*Annex III (c) (4)* To consider land-based alternatives to ocean disposal, or treatment of discharge to render it less harmful for dumping, in establishing criteria restricting issuance of permits for such ocean dumping.	Sludge specifically mentioned in Convention as prohibited for ocean discharge without permit from signatory nation.
Safe Drinking Water Act	42 USCA 1959 to 1959h	EPA to establish and enforce mandatory water supply standards for surface and ground waters used for public supplies.	Presence of sludge and sludge residues can affect sources of public water supply.
Clean Air Amendments of 1970	42 USC 1857 et seq.	To establish air quality standards for emissions into atmosphere.	Air pollution resulting from combustion methods for sludge treatment, and to some extent from other methods, must be kept within prescribed limits.
Housing Act of 1954	40 USC 461	*Sec. 701* Land use elements of plans prepared with HUD funds must be taken into account since all other governmental actions are to be consistent with them.	Land uses in sludge disposal or reuse.
National Environmental Policy Act of 1969	42 USC 4321 et seq.	*Sec. 4332 (c)* To prescribe certain procedures and types of environmental evaluations and reports for federal and federally assisted programs with environmental effects.	

TABLE 5.1 (Continued)

Federal Statute	Citation	Relevant Provisions	Effect on Sludge Management
		Sec. 1313 (c) Governor or State water pollution control agency to periodically review applicable water quality standards. Any standard prepared must be approved by EPA.	Standards designed to maintain quality of receiving waters for protection of beneficial uses. Standards are achieved by prescribing effluent quality, pretreatment, and other allowance or prohibition of materials dumping such as sludge; indirectly influences amounts and characteristics of sludge produced.
		Sec. 1317 (b) (EPA) To establish pretreatment requirements for pollutants interfering with, or not filtered out by, publicly owned treatment works.	Pretreatment can improve sludge quality by reducing toxicity, but results in pretreatment residuals which also must be disposed in environmentally sound manner.
		Sec. 1342 To require NPDES permits containing conditions restricting composition of effluents prior to making any point source discharge.	Administrative device for regulating effluent content, thus influencing amount and characteristics of sludge produced by sewage treatment.
		Sec. 1345 To prohibit any sewage sludge disposal from operation of sewage treatment works which discharges sludge pollutants into navigable waters, unless under EPA permit.	Direct regulation of disposal into waters.
Marine Protection, Research and Sanctuaries Act of 1972	33 USC 1401 et seq.	*Sec. 1412* EPA to issue permits for ocean dumping where such dumping will not have an unreasonably deleterious effect.	Limits ocean disposal.
		Sec. 1412 (a) (G) EPA to establish criteria for evaluating permit applications for ocean dumping, considering the viability of land-based alternatives.	Tends to emphasize land disposal or reuse.
		Sec. 1443 Secretary of Commerce to assist financially and in other ways research or investigations to end or minimize ocean dumping by 1977.	Same as above.
Solid Waste Disposal Act, as amended	42 USC 3251 et seq.	Administrator to protect health and environment by developing guidelines for solid waste management, by determining what substances comprise category of hazardous waste, and by authorizing federal grants to states to promote improved solid waste management plans; permit program established for hazardous solid waste; office of Solid Waste within EPA to administer Act.	May supplement or duplicate other regulations under FWPCA affecting sludge management.
Toxic Substances Control Act	15 USC 2601 et seq.	Administrator to protect health and environment from substances which may present unreasonable risk of injury by conducting test, research, and investigations and by establishing regulations for chemical manufacturers, processors, and distributors.	Could strengthen pretreatment program, and affect disposal of toxic-containing sludges.
Administrative Procedure Act	5 USC 551 et seq. 701 et seq. 1305 3105 3344 6363 7562	Agency regulations fall within the definition of a "rule."	EPA Technical Bulletin on sludge disposal may have the force of law.

inevitable by requirements of the statutes existing at the time.

In general, the water quality and related requirements contained in or promulgated pursuant to federal statutes govern. These may be in force directly as federal law or as state law made within the framework of the cooperative federal-state programs of environmental management such as those contemplated by PL 92-500 and the Clean Air Amendments of 1970 (PL 91-604). However, Section 510 of PL 92-500 specifically negates federal preemption of the making and enforcement of water quality standards and requirements by allowing state and interstate agencies to make and enforce regulations equivalent to or more stringent than those otherwise in effect pursuant to the federal law. Consequently, it is possible that state laws and administrative actions could precipitate further increases in the amounts of sludge produced or could add restrictions on treatment and disposal to those resulting from EPA policies.

Section 307 of PL 92-500 mandates that EPA require pretreatment as a means of water quality management and authorizes EPA to require it. EPA has left this provision largely unimplemented. A citizen suit (National Resources Defense Council [NRDC] v. Train 1976) was brought to require EPA to proceed with regulations and program implementation; a court decision directed EPA to establish pretreatment and source control requirements for a long list of specific substances, many of which concern sludge quality. In response, EPA published a proposal looking toward pretreatment regulations in the Federal Register for February 2, 1977 (U.S. EPA 1977). However, at the present writing, the regulations have not been issued. While at least part of the intent behind Section 307 appears to be to prevent discharge to treatment plants of wastes that would damage or destroy the treatment process and/or equipment or pass through into the effluents, the statute could also be used to keep harmful ingredients from reaching sludges and so to make disposal or reuse options more flexible.

Section 208 of PL 92-500 requires development of state and areawide waste treatment management plans. Once a plan is adopted, certified by the appropriate governor or governors and approved by EPA, the law provides that compliance with the plan is a necessary condition of federal grant assistance.

Marine Protection, Research and Sanctuaries Act of 1972 and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter

A body of federal law, including the Marine Protection, Research and Sanctuaries Act of 1972, (PL 92-532), concerns the disposal of any substances, including sludge and sludge residues, into territorial waters or at sea. Before the FWPCA Amendments of 1972 and the Marine Protection, Research and Sanctuaries Act of 1972 were enacted, the U.S. Corps of Engineers, authorized to protect navigation, exercised permit authority over marine dumping from a limited number of harbors. The 1972 legislation has the direct consequence of placing the fate of ocean disposal of sludge in the hands of the federal government and specifically of EPA. Moreover, PL 92-532 notes that EPA permits are intended as regulation in the interest of the entire gamut of environmental concerns. These permits are required for all disposal (excepting dredge spoil which is disposed under permits issued by the Corps of Engineers) into the ocean and the territorial sea. Although neither PL 92-532 nor the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter (1972), to which the United States is a party, prohibits ocean dumping of sewage sludge or its residues, EPA's present policy is that such dumping be ended by 1981 (U.S. EPA 1976b). Furthermore, the expectation at the time the FWPCA Amendments of 1972 and the Marine Protection, Research and Sanctuaries Act were passed was that water disposal of liquid wastes and residues resulting from waste treatment would, as a result of the zero discharge goal and permit restrictions, be phased out.

Examination of PL 92-532 and of the Convention makes it clear that the extent to which ocean disposal of sludge is actually curtailed or abandoned is within the reasonable discretion of EPA. According to criteria contained in the international convention, the Agency is to apply it on behalf of a signatory to compare ocean dumping and the available land-based alternatives. The relevant provision (Annex III C4) requires consideration of "the practical availability of alternative land-based methods of treatment, disposal, or elimination, or of treatment to render the matter less harmful for dumping at sea." Section 1412(a)(G) of PL 92-532 provides for a similar comparative judgment: "appropriate locations and methods of disposal or recycling, including land-based alternatives and the probable impact of requiring use of such alternate locations or methods upon consideration affecting the public interest."

In addition, a provision of the Act directs the Secretary of Commerce to

> "conduct and encourage, cooperate with, and render financial and other assistance to appropriate public (whether federal, state, interstate, or local) authorities, agencies, and institutions, private agencies and institutions, and individuals in the conduct of, and to promote the coordination of, research, investigations, experiments, training, demonstrations, surveys, and studies for the purpose of determining means of minimizing or ending all dumping of materials within five years of the effective date of this Act" (33 USC 1443).

This stipulation clearly indicates that Congress has been anxious to do what it could to reduce dependence on the ocean as a receptacle for wastes, including sludge. However, the use of the terms "minimizing" and "ending" as alternatives to be achieved by 1977 shows that the lawmakers were not ready to declare that reliance on the sea could be completely abandoned, all relevant circumstances considered. An examination of the legislative history has yielded no reason for changing this interpretation.[1]

1975 Safe Drinking Water Act

For many years, state laws and administrative processes have concerned themselves with the integrity of public water supply sources. Further, water pollution control laws typically define effluent discharges to include substances so placed as to flow, or run off into, receiving waters. Recently, the Safe Drinking Water Act (PL 93-523) has authorized and directed EPA to secure enforcement of mandatory standards governing water supplies. Both directly and indirectly, the Act requires consideration of the quality of surface and ground waters used for public supplies--defined very broadly to include all but individual wells or other systems serving a very few users. In picking and implementing sludge management methods, the need to keep sludge or sludge residues from entering water supply sources must be specifically recognized.

Clean Air Amendments of 1970

None of the technological processes results in complete discharge of the transformed sludge into the air. However, as with innumerable manufacturing processes, reduction of sludge by combustion produces emissions that must be held within air quality requirements such as those specified under the Clean Air Amendments of 1970 (PL 91-604) and other related legislation if the method is to be lawfully used. Since most highly urbanized areas have already exceeded these limits, with respect to particulates and--in some cases--other parameters, permits for new emissions, even with pyrolysis as the combustion method, would be issued only where the new emission source would be more than offset by emission reductions from existing sources in the area, according to the new EPA "Emission Offset" policy (U.S. EPA 1976d). Accordingly, the only available approaches that would accommodate new incineration or pyrolysis of sludge would be to relax existing standards, to make an exception for combustion disposal of sludge, or to oblige other sources to reduce emissions.

Housing Act of 1954

Some statutes concerned mainly with planning contain not only projections and recommendations, but regulatory aspects that bear on sludge management. For example, Section 701 (40 USC 461) of the Housing Act of 1954 (PL 83-590) declares that all government actions are to be consistent with the land use elements of comprehensive plans aided by the U.S. Department of Housing and Urban Development pursuant to Section 701 Programs. Indeed, some local master plans, once adopted, acquire an official status and can bind governmental agencies.

National Environmental Policy Act (NEPA) of 1969

The National Environmental Policy Act of 1969 (PL 91-190) mandates certain procedures and types of analysis (e.g., the Environmental Impact Statement) to cover interrelated aspects of federal and federally-assisted projects and programs having environmental effects. Section 4332 (c) sets forth five requirements for environmental analyses: (1) the environmental impact of the proposed action, (2) any adverse environmental effects which cannot be avoided should the proposal be implemented, (3) alternatives to the proposed action, (4) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and (5) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented. Nevertheless, NEPA is not a statute directing the conduct of development and operating activities in any specific substantive sense.

Similarly, the Council on Environmental Quality authorized by NEPA is a fact-finding and recommendatory body rather than a regulatory agency. Its normal functions are to advise the President and make annual reports.

New Solid Waste and Toxic Substances Acts

Until recently, the federal solid waste statute was not regulatory in character. It provided only for planning and demonstrations, for which it offered some grants and technical assistance. However, in the latter part of 1976 Congress enacted two statutes that are the precursors of a greater regulatory role for EPA.

The strictly regulatory provisions of the Solid Waste Disposal Act (PL 94-580) and the Toxic Substances Control Act (PL 94-469) emphasize especially dangerous substances rather than those that are obnoxious, unaesthetic, or generally undesirable and in need of disposal.

Both statutes expressly recognize that their provisions overlap somewhat with laws already in effect, such as the FWPCA Amendments of 1972 and the Clean Air Amendments of 1970. Accordingly, they direct the EPA Administrator to coordinate their administration with the other laws for which he is responsible and to avoid duplication (Solid Waste Disposal Act, Sec. 1006 [b]; Toxic Substances Control Act, Sec. 9 [b]).

Since most sludges contain varying amounts of harmful substances, they might be found by the Administrator to qualify for places on the list of wastes that require disposal permits. However, the provisions of the Toxic Substances Control Act seem to pertain to certain kinds of manufacturing wastes and chemical products. In coordinating the several statutes, EPA will probably find laws most applicable to sludge management in either the FWPCA Amendments of 1972 (particularly Section 405) and/or the Solid Waste Disposal Act provisions relating to hazardous wastes. The federal permit program established by the Solid Waste Disposal Act for disposal of hazardous solid wastes can be administered either by EPA or by states whose programs are approved by EPA (Section 3005).

The Solid Waste Disposal Act contains a broad definition of "sludge" and a definition of "solid waste" which expressly includes sludge. Section 1004 (26A) reads: "The term 'sludge' means any solid, semisolid, or liquid waste generated from a municipal, commercial, or industrial wastewater treatment plant, water supply treatment plant, or air pollution control facility or any other such waste having similar characteristics and effects."

Section 1004 (27) reads:

> "The term 'solid waste' means any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility

> and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but does not include solid or dissolved material in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges which are point sources subject to permits under section 402 of the Federal Water Pollution Control Act, as amended (86 Stat. 880), or source, special nuclear, or by-product material as defined by the Atomic Energy Act of 1954, as amended (68 Stat. 923)."

Sludges from municipal wastewater treatment are included in this definition of solid waste because the solid material is no longer in the sewage but is part of the residue remaining after the effluent has been separated. If the Solid Waste Disposal Act is regarded as not intended to operate for substances that can be dealt with under previous enactments, it would seem that sludge from sewage treatment processes is more appropriately subject to permit and regulation pursuant to the FWPCA Amendments of 1972 and the Marine Protection, Research and Sanctuaries Act. On the other hand, the existence of these overlapping statutory permit programs and regulatory authorizations is an invitation to duplication.

FEDERAL AGENCY INVOLVEMENT IN SLUDGE MANAGEMENT

U.S. Department of Agriculture and U.S. Food and Drug Administration

There are no specific federal statutory controls for the disposal of sludge or sludge residues on land, although regulation in some instances might occur by virtue of the powers of the U.S. Department of Agriculture (USDA), U.S. Food and Drug Administration (FDA), and EPA to protect the safety and healthfulness of crops and other foodstuffs. The three agencies appear to be working their way toward such regulation.

Both USDA and FDA have been researching the effects of spreading sludge on agricultural land. However, USDA has no regulatory authority to prescribe enforceable requirements of limitations on landspreading. FDA has no direct authority either, because--except in the area of pesticides--its powers attach only once food processing, transportation, and sales commence.[2] Accordingly, FDA officials have expressed concern that applying sludge on lands used for crop production or grazing might increase the toxic content of commodities entering the human food chain so much that foods grown on these lands might have to be banned from interstate commerce (Braude et al. 1975, Jelinek et al. 1976). However, the FDA would seize only contaminated commodities at the processing plants, in the canneries, or on the supermarket shelves.

The protective measures would work only to the extent that the products actually contaminated were discovered, tested, and found to violate statutes under which unsanitary or adulterated food can be kept off the market. Widespread seizures of this kind would probably force contaminated acreages out of production, but would entail great confusion and recrimination. Moreover, efforts to catch unsafe shipments are not likely to prove satisfactory as a means of public protection. Even with the predicted increases in amounts of sludge, it is probable that only a small part of the nation's productive acreage will ever be treated with sludge or produce enough foodstuffs to be frequently subjected to FDA's random checks on shipment.

The views of the researchers in these federal agencies can find their way into "guidelines" or informational bulletins published to assist municipalities, farmers, and others considering sludge treatment and disposal options. However, they can be mandatory only if embodied in regulations having the force of law. This stage can be reached only if the agency in question has regulatory authority pursuant to statute.

U.S. Environmental Protection Agency

A recent Technical Bulletin, published by EPA (1976a) for comment, reviews methods of sludge disposal. In dealing with landspreading, it offers no numerical values for sludge content and no maximum level which, if exceeded, would cause the land to be unsafe for productive use. The Bulletin offers the following advice for those who spread sludge on land:

> "Protection of Food Products and Agricultural Lands.
>
> Regulations exist to control the level of mercury and persistent organic chemicals, such as pesticides and polychlorinated biphenyls (PCBs), in certain components of the food chain. However, similar guidelines have not been established for all trace elements in foods. When standards are implemented, those sludge applications involving crops in the human food chain will have to be adjusted to conform. Cadmium and lead are of

> particular concern in municipal sludge and in some crops grown in sludge-treated soil, as well as mercury, arsenic, selenium, and persistent organics such as pesticides and PCBs.
>
> "Because of the wide variety of conditions that can affect the level of heavy metals that may be toxic to plants or taken up by the crop and eventually consumed by humans as part of their diet, absolute numerical limitations are not appropriate. It is recommended that the project conform to any limitations established by FDA or USDA. Where a sludge relatively high in heavy metals content is used, the following measures are prudent:
>
> - reduce heavy metals contamination in the sludge by pretreatment of wastewaters from industrial users;
>
> - maintain a high pH (above 6.5) in the combined sludge and soil;
>
> - concentrate on growing grain crops as opposed to leafy vegetables;
>
> - intensify monitoring of heavy metals in the sludge, soil, and plant tissues.
>
> "Even though stabilization methods are used, additional precautions should be taken when sludge is used for agricultural purposes (paragraph 2-3.2). Under certain conditions, specific organisms may survive in the soil for extended periods. Consequently, sludge-treated land should not be used for growing human food crops to be eaten raw until three years after sludge application. For orchard crops eaten raw, heat-dried sludge can be used provided the project is approved by the Food and Drug Administration" (U.S. EPA 1976a).

A fundamental difficulty facing attempts to apply these recommendations is that USDA and FDA, the agencies suggested for guidance on limitations, have no requirements directly applicable to growing crops or feeding livestock on agricultural or grazing lands, nor do they have the authority to make any. If EPA proposes to make existing or future guidelines or other recommendations emanating from USDA and FDA binding, publication of a Technical Bulletin is not the best method to achieve the result. A regulation would be more appropriate.

The Administrative Procedure Act defines "rule" as follows: "the whole or a part of an agency statement of general or particular applicability and future effect designed to implement, interpret, or prescribe law or policy describing the organization, procedure, or practice requirements of an agency ..." Agency regulations fall within this definition and may be validly made only by following the requirements of the Administrative Procedure Act.[3] The form in which an agency issues a requirement (such as technical bulletin, guideline, or policy statement) does not necessarily determine whether or not it is a rule.[4] The test is whether it has the force of law.[5]

For regulation of land application, PL 92-500 offers a direct means. Section 405 provides for a permit program. Subsections (a) and (b) read:

"(a) Notwithstanding any other provision of this Act or of any other law, in any case where the disposal of sewage sludge resulting from the operation of a treatment works as defined in Section 212 of this Act (including the removal of in-place sewage sludge from one location and its deposit at another location) would result in any pollutant from such sewage sludge entering the navigable waters, such disposal is prohibited except in accordance with a permit issued by the Administrator under this section.

"(b) The Administrator shall issue regulations governing the issuance of permits for the disposal of sewage sludge subject to this section. Such regulations shall require the application to such disposal of each criterion, factor, procedure, and requirements applicable to a permit issued under Section 402 of this title, as the Administrator determines necessary to carry out the objective of this Act" (PL 92-500).

Subsection (c) makes it possible for states to take over the administration of this permit program in a fashion similar to that provided for NPDES Permits under Section 402 of the Act.

To date, this section of the statute has been a dead letter. There is no permit program for sludge applied to land. In the absence of an administrative structure and the regulations called for by the section, it is by no means clear what the program would be like. This is especially true in view of the fact that the statutory language makes the controlling circumstance that the sludge or pollutants therefrom would reach navigable waters. More than the unaided words of PL 92-500 are necessary to visualize the intended regulatory scheme and precisely what it would cover.

Presumably not all landfilling or spreading of sludge would require a permit under this section. A key question concerning the scope of the program is how it is to be determined that particular sludge applications do result in pollutants reaching streams or other water bodies. For land immediately adjacent to such waters, it might be presumed or easily demonstrated that runoff occurs and that it would contain sludge particles. In structuring a practicable program, it would be essential to decide whether activities on other lands would require permits, what the dividing lines would be between locations requiring permits and those that are exempt, and how the actual or prospective presence of the permit-triggering runoff or seepage would be ascertained in all but the obvious cases.

A possible alternative approach is to leave regulation of landspreading to the states. The policy behind the EPA Technical Bulletin clearly invites this approach. The states do have constitutional authority to act in the interest of protecting health. However, they would have to enact statutes regulating land disposal of sludge in terms specific enough to make satisfactory control possible. Laws concerning public dumps and landfills are not sufficient, because the practice here contemplated is not ordinary waste disposal but application of substances for agricultural or silvicultural purposes, or to assist in the maintenance and improvement of public park and recreational acreages. This study has not been broad enough in scope to determine which, if any, states at present have waste management laws with language that would clearly support satisfactory regulation of landspreading. However, it can be said that few states now have programs, funds, or personnel committed to such regulation.

STATE AND LOCAL GOVERNMENT INVOLVEMENT IN SLUDGE MANAGEMENT

Introduction

The federal laws discussed above have two major implications for state and local governments. First, those provisions requiring quality control of effluents or authorizing grants for up to 75 percent of the cost of new treatment facilities are conducive to increases in sludge production and its subsequent burden on state and local resources. Second, federal restrictions on the use of water and air media force state and local consideration of land as the final repository for sludge.

Furthermore, as state and local governments confront limited disposal alternatives and reuse options that are not yet operative, they are likely increasingly to favor quality control of effluents at the source, particularly with regard to industrial wastes. State and local governments may also find it advantageous to resolve questions about the definition of sludge as a solid or liquid waste, since the statutes, regulations, and agencies governing solids are generally different from those governing liquids.

The ambiguity in the legal status of sludge, its inherent relationship with wastewater, and the intermedium impacts of any disposal option are incentives for state and local governments to develop a comprehensive, multimedium approach to management. The major deterrent to such development is the present lack of its counterpart within EPA, which coordinates its federal activities with those of state and local governments.

In addition to the future direction within EPA itself, there are a number of imponderables in the prospects for changes in the federal-state-local relationship. If the federal and state (as opposed to local) governments were directly responsible for sludge treatment and disposal, statutes could conceivably prescribe the method or methods to be used. Statutorial prescription would occur either by outright identification of certain methods in the legislation or by measures authorizing bond issues or appropriations for particular facilities.

Regardless of desirability, statutes requiring communities to use specific processes would be within the legislative province of state governments whose agencies administer wastewater treatment. Consequently, no questions of arbitrariness or other due process concerns in a regulatory program would arise.

Presumably, a state law could also prescribe the permissible methods for treating and disposing of sludge. Local governments might be less able than private entities to complain on grounds of arbitrariness that there were other reasonable options. A county, municipality, or special district, which is legally a creature of and subordinate to the state, may be limited in its ability to complain on grounds of due process or equal protection violations.[6] However, since our present knowledge of disposal technologies is limited, it is not likely that a legislature would want to prohibit all but one or two specific means of treatment and disposal; to do this, it might be necessary to prove that any and all other treatment and disposal methods were dangerous and destructive to some recognized and legitimate public interest. Nevertheless, the present body of applicable law and its administrative implementation do materially and substantially influence the available mechanisms for sludge management.

State and Local Laws

Regulatory laws relating to liquid waste management are those made by state and federal governments. For over 20 years, and in many instances for much longer, the states have had comprehensive water pollution control statutes. Local governments sometimes have ordinances dealing with certain aspects of water pollution but they do not specifically provide for the regulation of sludge treatment or disposal. Public treatment plants are operated almost entirely by counties, municipalities, or special districts, and their methods of sludge production are subject to regulation by other levels of government.

To the extent that laws dealing with solid waste affect sludge handling, the area of concern has been and will largely continue to be state and local. However, when the new federal solid waste legislation enacted at the close of the 94th Congress is implemented, EPA will have an increasingly significant role. A substantial and growing number of state statutes provide for solid waste management planning (often on an areawide basis), deal with regulation in the interest of public health, and require permits for dump or landfill sites. Local laws may deal with the same matter but are most likely to concern use of public dumps and the disposal of refuse by private persons. Where the county, municipality, or waste management district is itself the disposer, regulation comes from the state.

No program at either the federal or state level exists that is based on a complete analysis of the nature and ramifications of either the sludge management problem or the entire waste management problem. However, it is probable that governments will ultimately find it advantageous to combine all types of waste treatment, disposal, and resource recovery into a single multimedium governmental waste management function, with a unified administrative structure and an integrated set of underlying laws.

Whether sludge management is to be part of liquid or solid waste management or *sui generis*, should depend on analysis of the technical and governmental rationales for categorizing it.

Coordination between Levels of Government

Federal-state-local coordination is also problematic. Reorganizations in most of the states have consolidated departments of the environment that deal with EPA, and these agencies are organized in ways at least partially similar to those of the federal counterpart. Thus, the most frequent and effective communications are between federal and state water quality agencies, federal and state air quality agencies, and so on. If sludge management impinges on more than one environmental medium, the compartmentalization and multiplication of agencies involved is likely to increase. If these trends are extended to the local level of government, the identification of responsibilities will be greatly complicated.

Customarily, state liquid and solid waste agencies are separate. The movement for consolidated environmental departments has made some headway at the local governmental level and more in state governments. But even where consolidation has occurred, sewage treatment and solid waste management are in distinct units that may have relatively little overlap in the areas of policymaking or operations. Thus, treatment and disposal of sludge, be it by incineration, pyrolysis, or landspreading, may require the forging of new administrative relationships within and among local governmental agencies. Only thus will it be possible to administer disposal programs that combine garbage, trash, and sludge in the same incinerators or on the same sites. In some communities, coordination has already occurred but in most it will still require new arrangements. The alternative course, authorization and funding of separate sludge incinerators or disposal sites under the jurisdiction of the sewage treatment agencies, will be justified only where the volume of sludge is sufficient to make separate operations efficient.

In dealing with a specific project, a municipality must integrate and coordinate all of these disparate policies and actors. If its construction grant for a sludge treatment facility is involved, as almost certainly it will be, the local government will have to conform to or negotiate over the EPA requirements to receive federal aid. Presumably, its plan will have to accommodate federal and state air requirements as well as those of the state water quality program.

But these processes do not necessarily produce sludge management policies that take into account the full range of environmental, social, and economic considerations. They are more likely to produce choices selected from among the diminishing number of alternatives that can survive the combined constraints of the several unipurpose environmental programs and the federal and state policymaking levels.

Problems may also be created by the processes that, at least on the local level, are channeling responsibility for sludge programs toward the solid waste agencies. It is doubtful that many local governments are yet facing consciously the question of whether sludge should be treated and disposed of by the sewage agencies which generate it or by the solid waste agencies. Usually, the former have carried through until the sludge has reached its ultimate disposition. But if consignment of responsibility to the Office of Solid Waste within EPA authorized by Section 2001 of the Solid Waste Disposal Act centers major federal responsibility for sludge programs there, the results may be administrative dislocations in necessary federal-state-local communication systems and disruption of reorganization patterns at the state and local levels. However, it is to be hoped that awareness of the potential problem and the development of preventive administrative and intergovernmental arrangements will reduce confusion.

ORGANIZATIONAL STRUCTURES AND IMPLEMENTATION METHODS

Introduction

Can the present institutional structure accomplish the objectives attainable by application of existing and anticipated scientific knowledge and technology? Which organizational patterns are suitable for making and executing informed and sensible decisions about the treatment and disposal or reuse of sludge?

Organization of environmental management into categories such as "solid waste," "liquid waste," "air resources," "water quality," and "integrity of soils" may serve to define bases for legislating and administering major public programs. If so, will sludge management, which is growing in importance, merit a category of its own with distinct legislative substructures and/or administrative subagencies? What would be the institutional nature of these sludge-centered policy and administrative units?

Institutional Structures

The present environmental institutional structure has been devised--or perhaps, more accurately, has grown--to address what is thought to be the main environmental objectives: to promote clean water and clean air. Until now, land quality has been conceived more in terms of uses than of purity. Each of these environmental media interacts with the others in many ways, but public administration has found it practical to organize them as distinct areas of government activity with generally separate implementing mechanisms. Sludge management cuts across these established boundary lines in almost all its key aspects.

Furthermore, methods of treatment and disposal inevitably impinge on one or more of the established environmental objectives and may be approached differently, depending on which of the organizational sectors has primary responsibility for sludge. Ocean disposal or methods that reach either surface water or groundwater affect those resources. All of the oxidation processes must be examined to assess their effect on air quality. Spray irrigation, composting, landspreading, and landfill obviously have impacts on the land and on water resources. Who now evaluates these effects and decides on the tradeoffs involved in choosing sludge treatment and disposal methods? Which agencies monitor and enforce? Which legislative subcommittees have jurisdiction in the making of new laws and in performance of the oversight function?

There seem to be two general approaches to the problem. Almost any of the existing administrative subagencies could claim sludge as its domain. A case also could be made for a separate pattern of organization for sludge management, established at a level of authority equal to that of others and predominant in matters relating to sludge. The latter approach could significantly affect the jurisdiction of each of the well established environmental subagencies and would doubtless raise a host of political and administrative issues. Consequently, it is likely that major reorganization to accommodate sludge management will be undertaken reluctantly; such a course will be pursued only if it can be demonstrated that it is necessary.

The customary alternative to single agency responsibility for and performance of a function is coordination of those agencies having portions of the developmental, operational, and regulatory processes. Such an approach is evolving at EPA and will probably also appear at the state level. If this option is preferred, coordination must be carefully planned to assure knowledgeable consideration of both the sludge problems and their interrelationships with other phases of environmental management.

State environmental agencies participate in policy formulation to varying degrees. Most state governments have umbrella agencies whose subunits administer the water, air, solid waste, and natural resources or environmental programs. The policymaking authority of these organizations is subject to the constitutionally and practically dominant role of the federal government where Congress and the administering federal agency have chosen to assert themselves.

The state role becomes even more important in the vital domain of operating activities, partly because EPA has been geared to rely on the states for substantial parts of the implementing field activities. This expectation rests partially upon the basis of our political traditions and federal form of government, which favor local and state independence. Thus, the actual results of any program of sludge management will depend on how and to what extent the policies embodied in federal law and high levels of administration are carried out in practice by the states. A program inscribed on the statute book or in the paragraphs of federal regulations may be poorly or only sporadically applied to activities in the field. In some ways, it may be worse than no program if it causes people to mistakenly rely on the development of mandated activities.

Local governments play an essential role as waste management operators. They nearly always run the sewage treatment plants and produce the sludge. At present, they dump it at sea, spread it on the land, and consider whether they should invest in one of the combustion methods. The local role is not so much policy determination or regulation as the performance of a function within the mandates and alternatives prescribed by the federal and state governments. However, the degree to which local governments are willing and able to perform in accordance with federal- and state-determined objectives and requirements is important. It affects not only the achievement of results but the speed with which they are attained by new programs or shifts in approach.

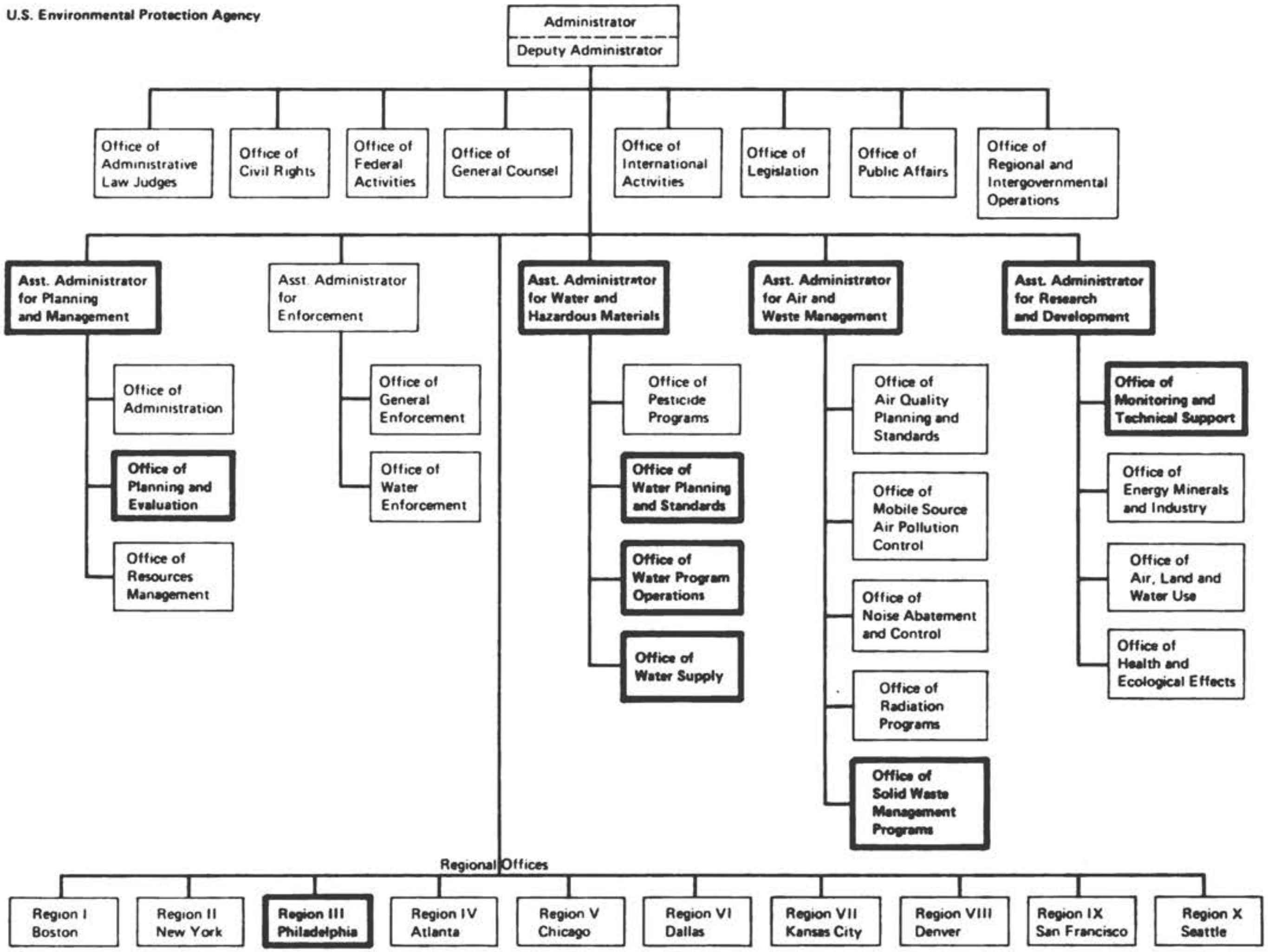
Thus, the problem of organization for sludge management is both an interagency and intergovernmental one. Without extremely far-reaching changes in both administrative structures and well-entrenched political and philosophical attitudes, it is unlikely that the existing patterns of water-air-land and federal-state-local program classifications will be easily pushed aside, even though some important alterations in detail could occur.

Whatever the obstacles, change is most likely to be extensive if it begins at the federal level. If EPA were structured to achieve maximum effectiveness in sludge policy, unnecessary competition between EPA subagencies having overlapping interests in sludge would be eliminated, and sludge would be defined as a solid, liquid, or "special case" waste management concern. State and local governments would then be encouraged to follow suit, and ultimately a matrix of similarly patterned but site-responsive multimedium programs would be forged.

To date, there have been two coordinating mechanisms within EPA. One involved a structure of subunits having elements of jurisdiction over sludge, at times in the form of a task force, at other times an assistant administrator's coordinating committee. The other mechanism is an interdepartmental working group composed of representatives from agencies whose clients are or could be either users of sludge or regulators of its use. These coordinative bodies have been further subdivided and interspersed with units that may overlap (Figure 5.1). Moreover, a second set of subunits is built on procedural or functional service lines rather than on substantive subject matter. For example, the enforcement, planning, and research and development organizations within EPA are or should be significantly involved in virtually every facet of EPA's mission and so are or should be inevitably relevant for sludge management.

Interagency work at the federal level has also proceeded by the committee or task force method. As indicated earlier in this chapter, the administrative bodies mainly involved have been EPA, USDA, and FDA. However, the results that can be expected from such an organizational approach appear to vary depending on whether the product is to be knowledge and guidance or regulation having a mandatory effect. Research and development activities such as investigation of landspreading techniques and efforts to determine the actual or probable effects of various ingredient concentrations in sludge certainly benefit from the kinds of interchange to which the committee process is suited. However, interagency committees are not empowered to formulate, enforce, or otherwise administer sludge requirements. Below the level of the President and the Office of Management and Budget, there are no Executive Branch mechanisms for requiring the coordination of sludge policies and programs lodged in different departments.[7]

Moreover, the establishment of compulsory coordination at the Presidential, OMB, or Cabinet Secretary levels is not inevitable. Unless sludge management gains high priority as a federal concern, topmost officials of all agencies involved cannot be expected to devote to it enough continuous time so that coordination by force of their actions will ensue. The prospects for intervention by Congress (particularly the Committees on Public Works of the Senate and House) are similarly limited. Through its oversight functions, Congress can influence the performance of the individual agencies. However, sludge management is not at present a highly visible political issue. Furthermore, aside from legislative authorization of programs and appropriations, direct Congressional impact on coordination of activities within another branch of government is minimal.



SOURCE U.S. EPA 1976c

FIGURE 5.1 Units of U.S. Environmental Protection Agency involved in municipal sludge management.

EPA offices that are assigned tasks by the Action Plan for Residual Sludge Management, dated September 1976, are highlighted on the chart. These different offices may not be coordinated in a way that permits development of a comprehensive sludge management policy.

Incentives

A frequently-considered mechanism for exertion of regulatory influence is provision of incentives. These generally take the form of grants, tax reduction or forgiveness, or some other form of economic advantage conferred to induce the desired conduct. EPA has already used the construction grant to some extent to make particular sludge management practices more attractive. The cost of digesters, for example, can be covered by such grants to the extent of the 75 percent federal share. Moreover, the willingness of some communities to try a given method of treatment may depend on the availability of a research and demonstration grant which, if the project thus financed succeeds, actually pays for part of the facilities and equipment cost of the municipality's sludge management process. In this connection, it should be noted that the Solid Waste Disposal Act, which recently became law, authorizes funds for research and demonstration projects which, because the Act's definition of solid waste includes sludge, could be available for sludge treatment and disposal facilities. Of course, tax incentives do not offer anything of direct benefit to municipalities or other public bodies because they are already tax exempt.

Other economic incentives have figured in public sludge management methods and perhaps will do so increasingly. In such instances, the municipality is likely itself to be the prime mover, motivated by desire to minimize the costs connected with disposal of the sludge or sludge residues. For example, if fertilizer or some other useful product resulting or made from the sludge can be sold, the method which produces the marketable commodity acquires improved chances of employment. If sales were actually to make the treatment and disposal process in question profitable, a perfect incentive would exist. More realistically, a community could decide to sell sludge treatment by-products at prices that would make them attractive to users, even if the effects were only to reduce the net cost of a particular management method. The incentive would be to the purchasers rather than to the municipality but might be a factor in the decision to employ one treatment method rather than another.

Grants

As already noted, legislative enactments contain scant references to sludge and rarely if ever seek to treat it as a subject in its own right. It is doubtful that either Congress or the state legislatures were aware that their enactment of those statutes that were used as a basis for upgrading treatment also laid the groundwork for the making of sludge policy. However, a major administrative movement was discernible at least as early as 1968 or 1969.

A New York City episode provides an illustration of how the construction grant program can be used as a policymaking and regulatory instrument, even in the absence of any readily identifiable legislative directive. Several years before the 1972 enactment, FWPCA Amendments and the Marine Protection Act, New York City, like most of the other major processors of sewage in its region, was well established in the use of ocean dumping as its preferred means of sludge disposal. Accordingly, the city sought to include in an application for federal construction grant aid the cost of barges to carry sludge from the projected treatment works. Since as yet there was no policy against marine dumping, the ensuing controversy was not over the legitimacy of the particular disposal method. However, the Federal Water Pollution Control Administration apparently believed that offshore dumping of sewage sludge was a health hazard and was perhaps otherwise environmentally undesirable. Consequently, the agency held up a construction grant until it was persuaded that contributing to the cost of barges would not necessarily promote indefinite continuance of ocean disposal.

The two federal statutes enacted in 1972 created more of a basis for administrative control over sludge treatment and disposal, at least in terms of restricting or blocking off water disposal options. However, it should be emphasized that the essence of sludge management programs at the federal and state levels is still primarily administratively rather than legislatively determined. Statutes have provided tools that the water quality management agencies can use but that do not necessarily compel any particular approach or result. For example, the NPDES, functioning pursuant to Title 4 of the FWPCA Amendments of 1972 and other federal and state permits, can regulate sludge disposal but need not do so to any specific degree.

Since they are point source dischargers, municipal waste water treatment plants must have NPDES permits, issued directly by EPA or by a state that has assumed responsibility for an EPA approved NPDES program. These permits may contain conditions relating to in-plant processes, and so could be issued or withheld on the basis of the arrangements made for sludge management as well as of other aspects of the wastewater treatment and effluent discharges. If not directly discharged as effluents, residuals (including sludge) will require further permits for their ultimate disposal, depending on the method used.

Constriction of the alternatives available to local units of government actually emanates from both the federal and state levels. The following sections offer illustrations that indicate the fact and nature of this dual level control.

Comprehensive Approaches

In recent years, both Congress and the Executive Branch have shown signs of recognizing the need to view the environment as a whole. If this can be done in the actual program development and implementation, rather than merely in academic or descriptive terms, interactions of sludge management activities with the broad spectrum of environmental concerns, and even other governmental responsibilities, could be achieved. However, our experience with the holistic approach is tentative and often lacking in sophistication.

In substantive fields, Congress and EPA have adhered closely to patterns that handle one environmental medium at a time. The Clean Air Amendments of 1970 and FWPCA Amendments of 1972 deal with their respective subdivisions of the environment. They refer to the need to consider other environmental, economic, and social concerns. But these Acts actually merge the various environmental concerns only in those provisions establishing procedures whereby individuals and business firms may seek exemptions from requirements, on grounds of economic or social considerations.

Within EPA the water, air, and solid waste programs have been separately administered, even though the last two have appeared together on an organization chart (Figure 5.1) as a combined unit. The 1976 Solid Waste Disposal Act identifies an "Office of Solid Waste." It is difficult to see how it could be otherwise. To legislate and administer "environmental laws" on some other basis than with specific and categorical reference to the water, air, and other components would require entirely different conceptualizations than have been developed to date.

MANAGEMENT MECHANISMS FOR SLUDGE ON LAND

Introduction

The issue of management mechanisms for land disposal or reuse of sludge cuts across laws, regulations, and agencies. Present federal statutory and administrative policies are clearly designed to force sludge and sludge residues onto the land. Where land is plentiful, competing uses few, and costs low, it is possible at any governmental level to set acreages aside in public ownership solely for waste disposal purposes. It may even be possible to look with equanimity on the prospect of indefinite maintenance of these parcels solely as repositories for the wastes of bygone generations.

For instance, filled dump sites can be converted into recreational lands, but this usually presumes their continuance in public ownership. Taxes, fees, or private revenues from such lands will be lost for very long periods, or perhaps forever. Moreover, there are limits upon the use for such purposes of land subjected to disposal of sludge or other waste. If land disposal of sludge and its residues is to be relied on primarily or exclusively, the areas that are to receive the material will often be large acreages from which it would be desirable to obtain income, that is, land that should be devoted to some constructive use other than waste disposal, and that must therefore be managed or regulated so as to coordinate the disposal use with concurrent or sequential economically productive activities. Furthermore, at least in those instances where reception of sludge from large urban places is concerned, many and perhaps most of the parcels will be outside municipal limits.

Private crop, range, and forest lands constitute the nonpublic acreages to which sludge could be applied. Regular and large scale application would have to be accompanied by a regulatory program that would assure observation of application rates and practices that do not adversely affect other media, lower plant quality, destroy the land resource, or ultimately endanger public health.

As part of an examination of private-land disposal or reuse methods, it would be necessary to construct acceptable subsidization programs. Among the questions to be considered are whether each community interested in using its sludge as a resource should undertake its own subsidy and marketing program or whether this is best done by intermunicipal waste authorities, states, or the federal government.

We must also determine the basis on which private agricultural and forestry interests might be induced to accept significantly large quantities of sludge or sludge derivatives. Wherever fertilizers or other storable products can be made from the sludge, the prospects for acceptance will be much improved. Private landowners can be expected to apply sludge to their lands only if they can see the economic benefits. An alternative to genuine sale is subsidizing landowners to apply usable sludge or sludge derivatives that are not useful enough to make their own way in the marketplace. If some part of the costs associated with treatment and disposal can be recouped in this way, the approach might be practicable.

Another problem is the continuity of the market which would thus be established. Ordinarily, raw or processed sludge is dispatched to landfills, the ocean, or incinerators daily or at least every few days. Agricultural applications may require large acreages and site rotation, and are likely to be limited to particular seasons or to several times a year. The use of landspreading methods will probably be dependent on the creation of alternative means of disposal when a particular community's sludge is not being applied to crop, grazing, or forest land.

Vastly increased acquisition of land by municipalities, states, or perhaps the federal government may be necessary to assure the availability of sufficient acreages properly located to receive raw or processed sludge, to control its quality properly, to apply it as it arrives, and to take whatever measures are required to assure that harmful substances do not escape to contaminate groundwater or surface waters.

Local Control through Laws

State and local laws regulate land use. Consequently, methods of sludge management that depend on disposal by landfill or other spreading or burial are affected by the zoning and subdivision of particular lands. State and local permit requirements for dumps or other disposal areas and processes must also be considered in making decisions on sludge management. Of course, the state legislature or local governing board, as the case may be, can alter any restrictions imposed by or resulting from its enactments. Frequently, an administrative agency has enough leeway to affect the situation through its own decision-making processes. Nevertheless, it is generally more desirable and easier to comply with than to deviate from, especially with so large and publicly sensitive a matter as waste treatment and disposal.

Aside from regulation of air quality and land use, the scope of the present chapter does not identify all the kinds of laws and areas of governmental activity to which sludge treatment and disposal must accommodate and which in turn must accommodate to waste management activities.

The zero discharge goal set forth in the 1972 FWPCA Amendments will have a profound effect, if it is literally achieved or even substantially promoted by administrative action and future legislation. It would effectively force municipalities to use only those methods that resulted in land disposal of raw sludge or treated products and residues; these methods include incineration and pyrolysis since their combustion residues can be disposed of on land.

However, any method of treatment and disposal which avoids discharges into water must also survive statutory and implementing administrative restrictions on land and air disposal.

Local Control Through Zoning

Zoning controls can either diminish or entirely preclude land disposal or reuse as a practicable alternative for some municipalities, unless the resulting materials are suitable for use on recreational lands, or as construction materials or acceptable soil conditioners and fertilizers. Frequently, such land use regulations in heavily urbanized areas may simply deny use for dumps or landfills. Indeed, even where not actually prohibited, dumping may be precluded because local government authorities cannot acquire and maintain enough cheap or vacant land suitable for waste disposal.

Until recently, virtually anything that was not obnoxiously malodorous could be spread on open land. However, increasing knowledge of the biological and chemical properties of wastes and of their potential direct or indirect effects on the environment or on human health is promoting statutory and administrative limitations on treatment and disposal options. For example, incinerators must meet emission limitations and should also be located so as not to interfere with the attainment and maintenance of ambient air standards. Unless they can be operated effectively, dumps and landfills may also be precluded or restricted by the need to keep odors and other nuisances within permissible limits.

Finally, in the interest of crop safety and integrity of water supplies, there is increasing regulation of soil and groundwater pollution at both federal and state levels.

SOCIAL ATTITUDES

Introduction

Two basic types of social values have come to play a part in waste management decisions. One concerns "quality of life." The other involves relationships between groups and the equitable distribution of the burdens and benefits of waste treatment and disposal practices among sectors of the population.

Many attempts have been made to define quality of life so that potential effects on this intangible can be accorded appropriate weight in decision making. Not surprisingly, no objective definition has been reached; far less has any attempt at quantification been successful. Nevertheless, definitions and even measurements of quality of life are implicit in the choices made in reaching almost any political decision.

Effects on quality of life are even more difficult to define for sludge than for most other environmental impacts, since the effects seem to be largely a matter of differing individual perceptions.

Sociological and psychological researchers have not provided any significant data to prove or disprove the existence of popular distaste for sludge. Some recent studies of public acceptance of renovated wastewater, however, provide some indications of the kind of public reaction that might be expected. Several papers, (Baumann and Kasperson 1974; Sims and Baumann 1974, 1976) suggest that lack of acceptance of sewage converted into water supply may reflect prejudices among the engineering and health professions more than public attitudes. Sims and coworkers argue that these groups prefer to continue their customary project and program patterns, which emphasize the development of predominantly natural supplies. They also believe that real or fancied adverse public reactions may be attributable to the conviction of these professional groups that the general public will be antagonistic.

This relatively optimistic view derives from study of three regions where renovated wastewater was used. The researchers noted public acceptance in Santee, California and Windhoek, South West Africa, but considerably less success in Chanute, Kansas. In the last case, the public was aware that there were other feasible options and the use of the renovated wastewater was intended only as a temporary measure. In Santee, reclaimed water was not directly used for municipal supply. At Windhoek, reclaimed water is used directly only after being mixed with twice its volume in fresh water. All three of these cases involve water-short areas where the alternatives were limited. In Santee, a public education campaign was carefully executed over a period of several years.

The researchers drew their conclusions partly from polls in which they asked representative samples of the population in several other communities whether they would be willing to drink or otherwise use renovated water. They reported mixed results, with a positive correlation between acceptance and education. However, as the researchers themselves point out, their questions were hypothetical because none of the places involved were actually using reclaimed sewage for municipal supply.

For sludge, any lesson that may be drawn from these studies would probably apply most directly to landspreading. By analogy, the chances of public acceptance might depend heavily on (a) the choices actually available (as illustrated in Chanute, Kansas), (b) a well-conceived public education program, and (c) how altered from the raw sludge the materials ultimately used or disposed of may be. Thus, bagged sludge fertilizers that look much like commercial varieties or composted materials that resemble topsoil or ordinary fill may be accepted most easily, especially if the origins of the material are not pointedly and steadily advertised. Moreover, efforts at public education should avoid defensiveness arising from the expectation of public rejection.

The analogy with public attitudes towards water may be carried further. Water has positive recreational and monetary worth; sludge has been treated as an adversary of these values. Nevertheless, once the potential social and economic benefits of controlled and safe use of sludge on golf courses, parkland, public forests, grazing lands, and as an aid to reclamation on strip-mined areas are recognized, sludge should qualify as a social amenity and an economic commodity.

Intergroup Relations

A second element in the consideration of social values related to sludge management is the set of attitudes that various neighborhoods and socio-economic groups have developed toward waste disposal. Few people have ever thought it an advantage to have the public dump or sewage treatment plant in their vicinity. While much can be done with landscaping to camouflage waste treatment and disposal sites, many remain detractors from the immediate environment. Indeed, regardless of the physical appearance of such facilities and their actual impact on the senses, the mere idea of sewage or sludge is unattractive enough to make most people want to oppose their location close at hand.

The tendency has been to locate landfills, dumps, incinerators, and treatment plants in low-income parts of town, partly because land is cheaper and partly because high quality of life and good environment were not so much expected by lower income groups. Moreover, in the past they were seldom organized to protest. Today it is not so easy to handle the problem of siting. Political organization for neighborhood preservation or improvement has become more common in all sectors of the community.

In some instances, the subject of waste facilities has taken on racial or ethnic overtones. A specific example of this sort of racial contention in the late 1960s concerned the building of a sewage treatment plant along the North River in West Harlem. The local residents objected to the transportation of waste from upper-income white neighborhoods into their area for treatment. In response to the resultant outcry, the city developed a plan to landscape the plant with a recreational park and other facilities, successfully camouflaging the plant and furnishing badly-needed services. However, the plan to build the plant still generated racial disputes and dissatisfaction. Edward Taylor, who identified himself as a representative of the Architects Renewal Committee in Harlem, Inc., announced that "the sewage plant was completely against the interests of the community and was contrary to the recommendations of the President's National Advisory Commission on Civil Disorders, which urged respect for the concerns of the people." The citizens viewed the location of the treatment plant as "the latest in a series of crimes against nonwhites by whites." According to President Sutton of the Borough of Manhattan, "Now you build a sewage treatment plant in West Harlem . . . These are the indignities that make people feel they are not equal . . ." Although much racial discord resulted from the decision to build the plant at that particular location, the New York Times suggested that the racial aspect was not the reason the West Harlem site was chosen, since many other sewage treatment plants in the city are located in white neighborhoods.

Rural-urban conflict also exists. Major metropolitan communities find it difficult to contain all their wastes, effluents, and residues within their own confines. Because of the greater volumes involved, extraterritorial disposal disputes have most often concerned garbage and trash, but the social conflict is much the same for sludge.

Events in the Washington Metropolitan Area are illustrative. The initiation by the District of Columbia of a landfill in nearby suburban Virginia was hotly contested by the local population; feeling generated by a proposal to haul metropolitan area wastes to rural Caroline County, Virginia was even more intense, exacerbated by animus reported on the part of white residents against accommodating refuse generated by an area largely populated by blacks. A few years later, more affluent, white Montgomery County, Maryland (part of the Washington Metropolitan Area) was equally rebuffed in a short-lived consideration of disposal in Ohio (Fry 1974; Bonner 1974a, 1974b, 1974c, 1975).

Much of the regional sewage is treated at the Blue Plains facility of the District of Columbia. Of the several jurisdictions of the region, none was willing to accept all of the sludge produced. An arrangement among the jurisdictions feeding into Blue Plains[8] provides for each to dispose of the percentage of sludge representing its contribution to the Blue Plains wastes. The only exception is the District of Columbia which has exhausted available landfill sites within its territory. Consequently, each of the participating suburban jurisdictions agrees to take District sludge in the same proportions as it takes sludge attributable to its own wastewater entering Blue Plains for treatment. The wastewater treatment plant is in the District, whose government has the responsibility for its operation, but it would be misleading to infer that the distribution of burdens was thought out in advance, with the District assuming the responsibility of sewage treatment and the other jurisdictions doing their part by accepting sludge.

The Blue Plains Sewage Treatment Plant Agreement[8] was a stipulated arrangement in a court proceeding. The fact that these are contentious issues charged with emotion as well as economic and other considerations makes it difficult to settle them unless there are pressures militating toward regional solution. Although the present balance appears to be feasible, the agreement states that it is only an interim arrangement and that it must be replaced by a more permanent solution.

For the most part, initial reliance has been on disposal of all municipal wastes either into adjacent streams or onto lands within the boundaries of the jurisdiction whose people generated them. The minimization of costs through avoidance of transportation has been a major determinant. However, the antipathy toward taking someone else's wastes has also played a significant part in shaping decisions.

FINDINGS AND ANALYSIS

1. Since authority given to EPA to handle various aspects of water quality management has been based on broadly-phrased legislation, the Agency's development of sludge policies and programs has evolved mainly through administration and implementation. The sludge problem is little recognized in Congressional enactments or state laws. Until recently the development of sludge policy has been a peripheral result of the administration of some other responsibility, for example, the construction grant program.

2. Federal statutes have precipitated the increase in production of sludge and either directly or indirectly control its distribution in the environment. This is

accomplished with little specific mention of the material but rather comes about through protection of water and air.

3. Section 307 of PL 92-500 mandates pretreatment of wastewater and authorizes EPA to require it. The lack of thoroughgoing implementation of this provision for certain toxic materials such as metals greatly limits the available options for disposal or reuse. The agency actions should immediately establish pretreatment guidelines and requirements as ordered in the decision of NRDC v. Train (1976). These could be implemented through conditions in NPDES permits and by enforcement of state and/or local laws requiring discharges into public sewers to be substantially free of the objectionable substances.

4. Historically, the legal impetus to greater sludge production resides in two largely procedural statutes (FWPCA of 1956, Water Quality Act of 1965). As a result of their influence through grant and other provisions, state water pollution control agencies included secondary treatment requirements in policies and regulations pursuant to state water quality laws.

5. EPA's authority to make implementing regulations in its administration of a number of existing statutory provisions could be used to require a multimedium approach to decisions concerning treatment and disposal of sludge. Among the provisions appropriate for this purpose are Section 208 (construction grant procedure), Section 402 (NPDES permits), and Section 405 (permits for application of sludge to land) of PL 92-500, the permit requirements of the Marine Protection, Research, and Sanctuaries Act, and the applicable sections of the Solid Waste Disposal Act.

6. Neither the International Convention nor the Marine Protection, Research and Sanctuaries Act requires cessation of municipal sludge disposal at sea. However, EPA regulations have made it clear that ocean dumping in certain areas will end by 1981. There are two fundamental objections to absolute prohibition of this one medium. First, both the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972) and the Marine Protection, Research and Sanctuaries Act as quoted in this chapter require a comparative assessment of alternative solutions, including land. Indeed, one might interpret the requirements of a comparative assessment to imply that absolute prohibitions of any one medium is not consistent with the legislation. Second, an absolute prohibition of the use of the marine environment implies that in all instances other options will always be less harmful to the environment. The discussion presented in Chapter 3 does not allow such a conclusion.

7. Piecemeal and often confusing regulation has likewise resulted from the attempts of EPA and others to control land application. The mechanism of the Technical Bulletin (U.S. EPA 1976c) is being developed as guidance to the Regional Administrators. It purports to be regulatory, but may be technically deficient as regulation because it does not follow the procedures for rule making required by The Administrative Procedure Act. Moreover, the USDA and FDA, upon whose powers the Technical Bulletin appears to rely, do not have authority to regulate land application of sludge.

First, while both the USDA and FDA have contributed and indeed the introductory language to the bulletin emphasizes their roles, the USDA has no regulatory authority and the FDA has regulatory authority only after the foodstuffs leave the farm. Accordingly, guidance that appears to direct sludge applicators to conform to USDA and FDA requirements is misleading. Such "requirements" may be nonexistent or no more than recommendations. If EPA proposes to give any recommendations of these agencies the status of requirements, they would in effect become regulations and so improperly developed unless issued in the same manner as other EPA regulations having the force of law.

8. The federal legislative and regulatory framework places a series of constraints on state and local government that on the one hand require the production of sludge and on the other strictly limit its disposition in the environment. The number of alternatives is diminishing, and a choice among them will be further constrained by several unipurpose environmental programs. Such a choice may not incorporate the full range of environmental, social, and economic considerations. For example, one possible institutional approach is to dispose of the sludge in the jurisdiction that generated it. However, it is possible that major quantities of sludge from urban areas cannot be disposed of by any of the generally recognized methods. Such a solution may minimize governmental problems but can be either costly or environmentally harmful or both.

9. The existing patterns of governmental organization are water-air-land and federal-state-local program classifications. Their application to sludge management is largely by default: enactment of the statutes and their administration by the various levels of government is designed to protect water through wastewater treatment. That aim in turn mandates the production of sludge. Current sludge policy is afflicted by the fact that sludge production is mandated, but its disposition in the environment is not adequately considered. A legislative and administrative policy vacuum results. It has built into it not only the management problems for the issue as a whole,

but also inevitable organizational problems for whatever unit of government attempts to administer such a regulatory program. There is some evidence of administrative efforts within EPA to fill this vacuum, but so far it has been limited to increased financing for sludge studies and the in-house activities of intra-agency and interdepartmental committees and task forces.

10. The absence of a consistent policy exacerbates the administrative and organizational intricacies. Most simply stated, the organizational question revolves around whether separation by the medium affected (air, land, or water) or by specific material (sludge in this case) is most appropriate. In either case coordination beween units via task forces, coordinating committees, or interdepartmental working groups becomes necessary. The common failure of such groups to deal adequately with sludge matters may largely be due to the lack of a consistent policy. It should be emphasized that under such conditions the essence of sludge management programs at the federal and state levels is still primarily determined by administrative rather than legislative considerations.

11. In the absence of consistent and comprehensive management policy, federal grants are likely to shape the options a given municipality may institute.

12. To the extent that federal policy has been articulated, it tends at present to force sludge on to the land. Those who may prefer a system under which a single governmental level, or perhaps a single agency such as EPA, has effective control of the entire sludge management process may be led to advocate that the federal government assume control over aspects of land management and land use policy now exercised by state and local authorities. Alternatively, states may face the need to develop and implement sludge management programs which specifically deal with the several methods of land application. A third possibility, which may well be comprehended by the solid waste legislation enacted in 1976, is that the federal-state technique of the NPDES Permit Program may be applied to sludge disposal.

13. Social attitudes among segments of the population toward each other and toward their quality of life also influence sludge management decisions. Since sludge management planners may share some preconceptions about the social value of sludge, their attitudes should also be addressed.

NOTES

1 Pertinent documents include House Report (Merchant Marine and Fisheries Committee), No. 92-361, July 17, 1971 (to accompany H.R. 9727); Senate Report (Commerce Committee), No. 92-451, Nov. 12, 1971 (to accompany H.R. 9727); House Conference Report, No. 92-1546, Oct. 9, 1972 (to accompany H.R. 9727); Congressional Record, Vol. 117 (1971), pp. 24792, 25288, 26533, 30850, 31129, 31750, 40844, 43052, 43078, 43141, and 43468; Congressional Record, Vol. 188 (1972), pp. 34378, 36041, 35841, 36213, 36522, 37026, and 37201.

2 Food, Drug, and Cosmetic Act, 21 USC 344, 346a (1970). (Includes regulations on adulterated and deleterious foods containing poisonous substances, color additives, confectionary and alcoholic substances, or missing valuable ingredients).

3 Detroit Edison Co. v. EPA, 496 F.2d 244 (6th Cir. 1974); Buckeye Power Inc. v. EPA, 481 F.2d 162 (6th Cir. 1973); Nader v. Butterfield, 373 F.Supp. 1175 (D.C.D.C. 1974); City of New York v. Diamond, 379 F.Supp. 503 (S.D.N.Y. 1974); Percy v. Brennan, 384 F.Supp. 800 (S.D.N.Y. 1974).

4 Lewis-Mota v. Sec. of Labor, 469 F.2d 478 (2nd Cir. 1972); Natural Resources Defense Council, Inc. v. SEC, 389 F.Supp. 689 (D.C.D.C. 1974); Pharmaceutical Mfs. Association v. Finch, 307 F.Supp. 858 (D.C. Del. 1970); See City of New York v. Diamond, 379 F.Supp. 503, 517 (S.D.N.Y. 1974); Cf. Housing Authority of City of Omaha, Neb. v. U.S. Housing Authority, 468 F.2d 1, certiorari denied 410 US 927, 93 SCt 1360, 35 L.Ed.2d 588 (8th Cir. 1972); Cf. NLRB v. Wyman-Gordon Co., 394 US 759, 89 SCt 1426, 22 L.Ed.2d 709.

5 National Nutritional Foods Association v. Weinberger, 512 F.2d 688 (2nd Cir. 1975); See Rodway v. USDA, 514 F.2d 809, 813-814 (D.C. Cir. 1975); See Matczak v. Sec. HEW, 299 F.Supp. 409, 412 (note 4) (S.D.N.Y. 1969).

6 Soliah v. Heskin (1912) 222 US 522; City of Trenton v. New Jersey (1923) 262 US 182; Chicago v. Sturges (1911) 222 US 313; Louisiana ex. rel. Folsom v. Mayor of New Orleans (1883) 109 US 285.

7 42 USC (1962) (1970) The Water Resources Planning Act, PL 89-80 establishes the Water Resources Council whose statutory responsibility is the coordination of the policies and procedures of the federal water resources agencies. However, the Council is not given any

enforcement powers and is directed by a collegiate body consisting of the heads of the affected agencies.

8 Blue Plains Sewage Treatment Plant Agreement (June 1974). Signed by U.S. Environmental Protection Agency, Virginia State Water Control Board, Fairfax County, Maryland Environmental Services, Prince George's County, Montgomery County, Washington Suburban Sanitary Commission, Washington, D.C. Unpublished legal document for on-site inspection only.

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Bonner, A. (1974b) Montgomery trash plan hits a snag. Washington Post 12:13:C1:7.

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Public Law 89-80 (1965) Water Resources Planning Act. 79 Stat. 244; 42 USC 1962 (1970).

Public Law 91-190 (1969) National Environmental Policy Act of 1969. 83 Stat. 852; 42 USC 4321 (1970).

Public Law 91-512 (1970) Resource Recovery Act of 1970. 84 Stat. 1227; 42 USC 3251 (1970).

Public Law 91-604 (1970) Clean Air Amendments of 1970. 84 Stat. 1676 42 USC 1857 et seq. (1970).

Public Law 92-500 (1972) Federal Water Pollution Control Act Amendments of 1972. 86 Stat. 816; 33 USC 1251 et seq. (1973).

Public Law 92-532 (1972) Marine Protection, Research and Sanctuaries Act of 1972. 86 Stat. 1052; 33 USC 1401 et seq. Supp. III (1973).

Public Law 93-523 (1974) Safe Drinking Water Act. 88 Stat. 1660; 42 USC 201 (1975).

Public Law 93-611 (1975) Solid Waste Disposal Act Amendments. 88 Stat. 42 USC 3259 (1975).

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U.S. Environmental Protection Agency (1976c) Action Plan for Residual Sludge Management. 23 September 1976. EPA Internal Document.

U.S. Environmental Protection Agency (1977) Pretreatment standards for existing sources and new sources of pollution. Proposed regulations 42 FR 6476; 40 CFR 128, 403.

CHAPTER 6

INTEGRATED MANAGEMENT OF SLUDGE

INTRODUCTION

Findings in this report make clear that the growing problem of sludge management cannot be solved by concentrating exclusively on means of using or disposing of sludge. Sludge management provides a prime example of the need to tie together the entire process of waste management and regulatory activities designed to achieve the nation's environmental goals for clean air and water. The studies and research from which this report is drawn not only point to a need for broader consideration of protecting the water resource but also to a need for protection of land and air. Until recently federal statutes have been designed primarily to protect the water and air environment separately and have apparently paid little attention to intermedium transfer effects, or to the long-term effects on the land itself of land disposal or use.

Because of the urgency of the problem, decisions on sludge management have to be made without sufficient knowledge about all relevant factors. The volumes of sludge produced are growing, primarily as a result of increasingly high standards of wastewater treatment. The sludge must go somewhere. Municipal utility managers must find a way of disposing of the residuals that is physically attainable, economical, environmentally sound, and acceptable to the public and the relevant regulatory agencies.

Risks are inherent in any option selected for the disposal or use of sludge; worse, the level of risk is frequently not determinable. Thus, in making a regulatory decision, EPA must attempt to comply with complex federal statutes when the appropriate weight to be assigned to the several decision criteria is still uncertain.

No clear institutional guide is found in federal law. Uncertainty as to the level of risk has constrained the flexibility of regulatory decisions under federal law, influencing them in favor of land as a disposal or use medium for sludge. The crux of the matter is that, as more and more sludge is produced, a rational approach to regulatory decision making becomes increasingly urgent.

Sludge management, to be realistic and effective, must be viewed in the context of the total environment including consideration of economic, environmental, and social costs and benefits associated with various options. The regulatory process must recognize municipal sewage sludge as a potential resource, and resource recovery as a feasible and desirable option in specific situations.

Decision making in this framework must recognize and give appropriate weight to site-specific problems and opportunities. It may, however, be possible to define certain generic categories. As a guide to the regions and states in individual sludge management decisions, the EPA Administrator, through the Agency offices involved, may be able to develop guidelines for disposal or use of sludge for cities or districts with significant air quality problems, for those with suitable land areas, and for those with the option of disposal in the ocean where suitable land areas are limited or unavailable. Consideration of available options should not be initially constrained by apparent prohibitions or limitations in present laws. Decisions must be based on an assessment of trade-offs among risks, costs, and benefits as these are identified in individual instances.

In selecting options, risks of irreversible impacts should be minimized by making management choices adaptable to future conditions. Therefore, the option that necessitates the minimum initial commitment of capital, energy, or other resources should be given first consideration. For example, more uncertainties may appear to be associated with ocean disposal of sludge than with land disposal or use. On the other hand, the capital investment involved in ocean disposal for a coastal metropolitan area may be less than that for a pipeline or other fixed facility required for moving sludge to distant land disposal sites. Where this is the case, the decision should take into account comparative capital costs, the possibility of reducing risk by careful monitoring, and that both land and ocean disposal have risks. If ocean disposal is found to be unsuitable after extensive monitoring, a substantially lower capital investment would have been made than if land disposal had been tried first and found unacceptable.

The purpose of this chapter is to review the current practices in sludge management, and set forth a decision model that includes consideration of the entire wastewater and sludge management system.

CURRENT PRACTICE IN SLUDGE MANAGEMENT

As a part of the study made for this report, 23 engineering reports on municipal and regional sludge management were evaluated. Detailed analyses of the studies are given in the Appendix. The purpose of evaluating these reports was to suggest the state of current practices of sludge management, the multimedium options available to a municipality or region, and the extent to which regulatory or social constraints affect comprehensive multimedium evaluation. The reports are also valuable in pointing out the randomness with which study objectives were identified and constraints on the study accepted. The analysis found no consistency among the studies in choice and weighting of criteria for evaluating options for sludge disposal or use. The EPA Administrator or the regional offices of the Agency can provide guidance to regions or municipalities in resolving such inconsistency.

The municipal and regional engineering studies were prepared between 1961 and 1976 and thus were governed by different federal regulatory legislation. Of the 23 reports examined, 12 considered both economic and environmental criteria, and evaluated all reasonably proximate, geographically available media (i.e., air, land, and ocean for coastal localities, and air and land for inland activities).

Of the 23 engineering reports, 17 listed land application or sale of dried or composted sludge among the final sludge management choices for consideration. Of those 17, only 4 designated an available site for sludge application. Two findings cited elsewhere in this report are relevant here. One is that proper site selection for land application of sludge should not be equated only with the availability of a site. The majority of studies listed land application among the final options to be considered, and several listed it as the final choice. These rankings also highlight the second finding, that the tendency of current policy for protection of ocean and air is to compel decisions to place sludge on the land.

DECISION-MAKING PROCESS

Policy to guide individual sludge management decisions by EPA regions or the states must be formulated by the Administrator through Agency offices.

Sludge management decisions must be related to goals for clean air and water quality, and proper disposal of hazardous or other solid wastes. Figure 6.1 outlines a theoretical process for sludge management decision making.

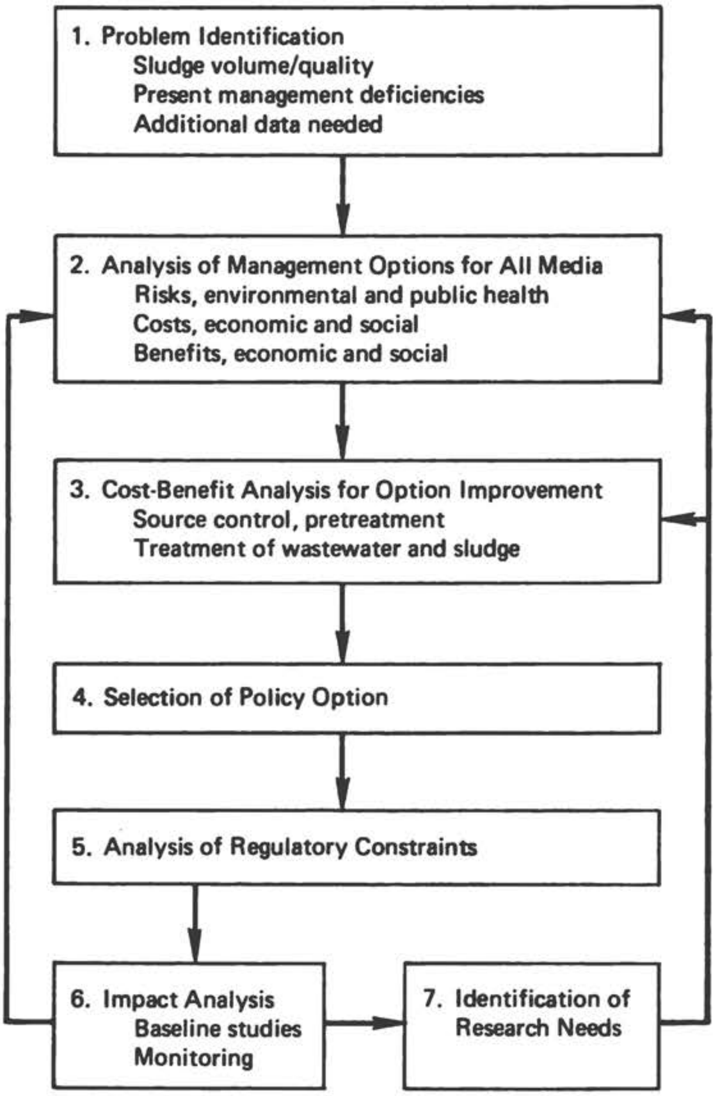

FIGURE 6.1 Diagram of a theoretical decision process for implementation of municipal sludge management policy.

The diagram outlines the steps of a process by which EPA, regions, states, municipalities, and acceptors or users of sludge could arrive at a comprehensive municipal sludge management policy. A basis for the model is that EPA develop a consistent internal policy, which would be followed by implementation by states and municipalities.

Such a process could lead responsible jurisdictions to a comprehensive municipal sludge management policy in collaboration with EPA, other federal agencies, regions, states, municipalities, and acceptors or users of sludge such as landowners. The policy should thus be implemented through the states and municipalities. Many units of EPA headquarters are now involved in determination of municipal sludge management policy (Figure 5.1) for the states or regions that must implement it, but there is at present no assurance that these units are coordinated for a consistent policy. Implementing a consistent policy requires internal coordination within the Agency and systematic policy application on a nationwide basis.

Step 1 - Problem identification. Either through its own resources or with the assistance of outside experts, the Agency should assess the volume and quality of municipal sewage sludge by metropolitan area and region, and require inventories from currently operated facilities for sludge treatment where this information has not already been gathered. This problem identification inventory, updated annually through continuing surveillance, should for a base year (1978) provide as a minimum the following information:

- number and location of individual systems;
- data about the quantity and quality of input and output for individual systems;
- sludge use or disposal operations by site and by quantity and quality of sludge received; and
- descriptions of problems encountered identified by site, specifying those that necessitate consideration of a change in current practice.

The inventory should be continuously analyzed to provide, as a minimum:

- the scope and nature of the sludge management problem;
- availability and reliability of data from current sources; and
- the need for additional data or data sources, or both.

The base study should include an evaluation of data acquisition, handling, and retrieval activities; interagency and intergovernmental access to available data; and the kind of information and data needed from ongoing or additional research.

This inventory would provide the Administrator, the regions, and the states with an overview of available information and the kind of data needed to improve decision making in sludge management.

The initial phase of problem identification should put the sludge management problem into the perspective of the total waste generation and management system. With the information provided by the inventory, the identity of the sludge segment of the system could be more sharply defined, and the public and Congress could be informed about the scope and nature of the problems.

Steps 2 and 3 - Analysis of options for disposal or use. The next stage in the process of policy formulation is a careful analysis of the comparative merits of ocean, land, and air as media for disposal or use of municipal sludge. Costs, benefits, and environmental impacts of operational systems vary from region to region and from city to city. The analytical process should provide the Agency with an evaluation of multimedium effects; economic, social, and environmental costs and benefits; and relative risks to public health and the environment of the various options.

There is a difficult problem in identifying and measuring risks associated with disposal or use of sludge in the several media. The analytic process of Step 2 thus provides insights crucial to Step 3, so that Steps 2 and 3 are inextricably related.

As costs and risks are identified, the potential for reducing them to acceptable levels through source control, pretreatment, or upgraded treatment of wastewaters in the wastewater management stream can begin to be assessed. The costs that each method of control adds incrementally to the total process must be weighed against the resulting overall benefits, including minimization of risks. The comparative cost effectiveness of each potential change in present practice as a more cost-effective part of the overall waste treatment system needs exhaustive analysis. Obviously, this part of the decision process should be carried out in greater or less detail according to the situation, and the formulation of policy by EPA should include guidelines that help the regional decision maker to select the soundest practices for each.

Step 4 - Selection of policy options. The information and analyses of Steps 1, 2, and 3 provide the Administrator with a methodology through which (a) the options for sludge disposal or use can be displayed with their associated costs, benefits, and risks; (b) the availability and reliability of present information and the additional data and research needed can be ascertained; (c) possibilities for improving each media option through system changes can be identified; and (d) the level of risks associated with a combination of these upgrading options and the media options can be assessed.

Step 5 - Needed regulatory practices evaluated. Federal environmental law needs to be reviewed to make certain that the policies formulated by the Agency do not set up constraints more prohibiting than Congress intended. This is particularly true for the ocean and the air as disposal media. Guidance to the states and the regions should be general so that decisions recognizing local variations can be made in the context of EPA's broad policy formulation.

Municipal utility managers must take the initiative for proposing solutions and for increasing the number of options available through source control, pretreatment, and pricing incentives. The EPA regions and states in them must accept the responsibility for consistent and timely reactions to innovative proposals by municipal utilities so that regulatory decisions can be made before rather than after costly capital investments. System changes require public acceptance, and the municipal utility has to earn the confidence of the public it serves. However, the utility is inhibited when its proposed solutions to the problems of increased sludge volumes or other crises receive negative responses from state or EPA regulatory entities without constructive assessments of alternatives.

When an option has been selected by a municipal utility and is proposed to the state and EPA region for consideration, the regulatory entity should carefully consider any constraints on or opportunities for approval of that option in existing laws. The regulatory entity should work with the municipal utility in the planning stages so that the option submitted for approval will already have gone through a preliminary screening in the regulatory process, thus assuring at least a favorable climate for its consideration.

The Agency's policy formulation should be sufficiently clear and broad for the regional offices to make timely decisions, and the proposals of the municipal utility should receive coordinated consideration from both the regional and state regulatory utilities.

Step 6 - Impact analysis. A carefully designed and continuing system should be initiated by the Administrator to monitor experience with sludge use or disposal policies and practices. These monitoring data on economic, social, and environmental costs and benefits and on public health effects will be essential as the Administrator formulates or revises policy.

Monitoring systems should be designed to provide baseline information as well as data for impact analysis after policy implementation, so that existing policies can be modified in the light of experience.

Continuing political pressure and pressures from special interest groups will be applied to the Administrator as policy matters are considered. Carefully structured impact analysis can help build the information base required to resist undue pressures on the one hand and, on the other, to distinguish pressures that are relevant and useful from those that are not. Except where crises are encountered, or where confrontation politics has made decision making at the state or regional level impossible, the Agency should not become involved in decisions on sludge management options for individual municipal systems.

Step 7 - Research needs identified. As a follow-on to continuing impact monitoring analysis, research needs for individual problems and issues should be identified by the Agency. Research to develop more precise information on the possible hazards of sludge disposal to the several environmental media as well as other research needs identified in the problem identification phase should be initiated and funded by EPA headquarters. However, structuring of research needs, scope of research activities, and the objectives to be achieved by funded research require substantial input from municipal utilities confronting real problems. This input should be sought by EPA and processes should be devised to feed research results continually and systematically to the regions, states, and individual system managers.

The assistance of federal and state agencies concerned with the whole spectrum of sludge management decisions should be consistently sought and relied on throughout the process of formulating national policy. The complexity of the sludge management problem merits the combined judgment of all those agencies and entities that will affect or be affected by final decisions.

Of equal importance is the Administrator's responsibility to disseminate information on the sludge question to the public and to Congress. Congressional action on funding and public acceptance of the trade-offs between benefits and costs will be key elements in resolving the problem of achieving national objectives of clean air and clean water while simultaneously using or disposing of the residuals from the processes required to meet those objectives with proper protection of the land resource. There is no indication that Congress or the public either understands the costs or appreciates the problems involved. It is the responsibility of the Administrator throughout the process of policy formulation to keep Congress and the public informed so that decisions are understood and, as one result, easier to implement.

FINDINGS AND ANALYSIS

1. Past practice in analyses and evaluations of options leading to sludge management decisions has varied widely. Investigations of potential sites for final disposal or use of sludge residuals have been inadequate in many cases; the possibilities of intermedium impacts have--with a few notable exceptions--been largely ignored. Selection of the options to be implemented has generally been based exclusively on comparisons of direct costs. Source control and pretreatment of industrial wastes have received little consideration for their effect on sludge quality and latitude in choices for sludge management.

2. Comparatively little attention has been given to impacts on the land resource where land disposal or use of sludge residuals has been considered.

3. National policy concerning sludge management has not been clearly articulated at the Administrator's level. Such policy is needed to guide regulatory decision making by EPA regional offices, and to aid the state regulatory agencies in coordinating their regulatory programs with the requirements of nationally mandated programs.

4. National policy guidelines regarding sludge management should be formulated in the context of total environmental management for the entire wastewater system from collection of wastewaters in a municipal system to final disposal or use of sludge residuals.

In formulating national policy, EPA should carefully consider programs of other agencies that affect sludge management decisions.

Policy at the national level should provide clear assignments of responsibility to EPA regional offices and to the states so that municipal utility managers will know where to turn for guidance.

5. Since environmental and social impacts of disposal into the several media have not been clearly established, systems for both pre- and post-decision analysis must be established. Baseline studies are needed on the three principal media to provide information for assessment of post-project impacts.

6. Both policy guidance and decisions on individual situations should remain as flexible as possible so that irreversible impacts can be held to a minimum and changes in system design effected by the municipal utility manager as changing conditions or monitoring information warrant.

APPENDIX

MUNICIPAL/REGIONAL STUDIES

INTRODUCTION

Various sludge management options have been evaluated for wastewater treatment plants in a number of municipalities and regions. Twenty-three studies (Table A.1) have been identified as formal systematic attempts at such evaluation for particular political or geographic units. The unit studied may be a municipality, a supramunicipal political jurisdiction, or a supramunicipal geographic region. Whereas municipalities and other political jurisdictions generally perform or commission their own studies, surveys of geographic regions are usually commissioned by outside parties, e.g., EPA.

The scope of the 23 studies ranges from regions inhabited by millions of people to localities with populations of less than 40,000; their length varies from fewer than 20 pages to many volumes. Some of the studies propose short-term interim solutions and others advocate options for an indefinite time scale. The differences in format and substance are great and, as a result, the difficulties in drawing general conclusions from them are substantial.

In general, each study consists of six major parts: (1) goals, (2) a data base, (3) a set of sludge management options, (4) the criteria employed in evaluating the study's options, (5) the option evaluations, and (6) the sludge management recommendations and their rationale. Individual examination of each of these aspects will yield the best systematic analysis. In addition, important insight into the comprehensive multimedium approach to municipal sludge management will be gained if the information obtained from the study of these six subjects is applied to two vital questions: (1) What does each study imply about the characteristics and value of comprehensive multimedium evaluative procedures? (2) What do comparisons of option evaluations among studies imply about sludge management?

TABLE A.1 The Regional Municipal Studies

The studies listed were identified as formal systematic attempts at an evaluation of various sludge management options. The studies vary in size of geographic region and population, in time scale, and in depth.

A Plan for Sludge Management prepared by Havens and Emerson, Ltd. for Commonwealth of Massachusetts Metropolitan District Commission, June 1973. (Boston–1973)

A Sludge Management Study (Preliminary) prepared by Engineering-Science, Inc. for Washington Suburban Sanitary Commission, June 1970. (Washington, D.C.–1970)

A Study of Alternative Methods of Sludge Disposal for the Deer Island and Nut Island Sewage Treatment Plants prepared by the Boston Harbor Pollution Task Force for the Commonwealth of Massachusetts Metropolitan District Commission, April 1972. (Boston–1972)

Alternative Sludge Disposal Systems for the District of Columbia Water Pollution Control Plant at Blue Plains prepared by Camp, Dresser and McKee, Inc. for District of Columbia Department of Environmental Services, December 1975. (Washington, D.C.–1975)

Alternatives for Sludge Disposal: Metropolitan Sewerage System prepared by Harvey M. Cole, Jr. for City of San Diego Utilities Department, November 1968. (San Diego–1968)

An Analysis of the Sewage Sludge Disposal Problem in Southern California prepared by Engineering-Science, Inc. and J. B. Gilbert and Associates for U.S. EPA, October 1974. (Southern California–1974)

Corpus Christi, Texas Study of Solids Processing: Oso Wastewater Treatment Plant prepared by Black and Veatch for City of Corpus Christi, 1971. (Corpus Christi–1971)

Demonstration of a Planning Perspective for Waste Water Sludge Disposition: Knoxville/Knox County prepared by Engineering-Science, Inc. for U.S. EPA, November 1975. (Knoxville/Knox County–1975)

Demonstration of a Planning Perspective for Waste Water Sludge Disposition: Ohio/Kentucky/Indiana prepared by PED Co–Environmental Specialists, Inc. for U.S. EPA, January 1976. (Ohio/Kentucky/Indiana–1976)

Metro Denver District Sludge Management, Volume II: Alternative Systems prepared by CH2M Hill for Metropolitan Denver Sewage Disposal District No. 1, May 1975. (Denver–1975)

Montgomery County, Ohio Wastewater Treatment Plant Solids Ultimate Disposal, Phase I: Engineering Study and Report prepared by Moulenbelt and Seifert for Montgomery County Sanitary District, December 1971. (Montgomery County–1971)

Phase I Report of Technical Alternatives to Ocean Disposal of Sludge In The New York City-New Jersey Metropolitan Area prepared by Camp, Dresser and McKee and Alexander Potter Associates for Interstate Sanitation Commission, June 1975. (New York City-New Jersey–1975)

Project Report for the East Bay Municipal Utility District Sewage Sludge Management Project prepared by East Bay Municipal Utility District Special District No. 1 for East Bay Municipal Utility District, March 1975. (East Bay–1975)

Report on Disposal of Solids and Control of Odors at the Dallas-White Rock Wastewater Treatment Plant prepared by Black and Veatch for Dallas Department of Water Utilities, March 1969. (Dallas–1969)

TABLE A.1 (Continued)

Report on Management and Disposition of By-Product Solids prepared by Greeley and Hansen for City of Tampa Department of Sanitary Sewers, June 1975. (Tampa–1975)

Report on Sludge Handling, Treatment and Disposal Patapsco Wastewater Treatment Plant prepared by Alexander Potter Associates for City of Baltimore Department of Public Works, March 1972. (Baltimore–1972)

Report on the Management of By-Product Solids From Water Pollution Control Plants prepared by Greeley and Hansen for City of Philadelphia Water Department, Water Pollution Control Division, June 1973. (Philadelphia–1973)

as summarized in "By-Product Solids Management Alternatives Considered for Philadelphia" by E. F. Bullotti and T. E. Wilson in *Municipal Sludge Management 1975*, and

"Land and Sea Solids Management Alternatives in Philadelphia" by C. F. Guarino et al. in J.W.P.C.F. 47(11):2551

Report to the City of Baltimore Bureau of Sewers on Future Disposal of Digested Sludge from the Back River Sewage Works prepared by Whitman, Requardt and Associates for the City of Baltimore Bureau of Sewers, December 1965. (Baltimore–1965)

San Francisco Bay Area Municipal Wastewater Solids Management Study prepared by Brown and Caldwell for Bay Area Sewage Services Agency, May 1975. (San Francisco Bay–1975)

Sludge Handling and Disposal, Phase II: Evaluation of Alternative Systems prepared by Stanley Consultants for Metropolitan Sewer Board of the Twin Cities Area, 1973. (Twin Cities–1973)

Solids Disposal: Idaho Falls Water Pollution Control Facility prepared by CH2M Hill for City of Idaho Falls. (Idaho Falls–1973)

Study of Pollution Abatement: The Metropolitan St. Louis Sewer District, Part IV: Sludge Processing and Disposal prepared by Horner and Shifrin and Havers and Emerson for the Metropolitan Saint Louis Sewer District, 1961. (Saint Louis–1961)

Study of Wastewater Solids Processing and Disposal prepared by Sacramento Area Consultants for Sacramento Regional County Sanitation District, June 1975. (Sacramento–1975)

THE COMPREHENSIVE MULTIMEDIUM MATRIX

A study is defined as "multimedium" if it contains a reasonably thorough evaluation of the merits and demerits of options involving all reasonably proximate, geographically available media (i.e., air, land, and ocean for coastal localities and air and land for inland localities). It is "comprehensive" if both economic and environmental criteria are applied explicitly in the evaluation of options. Thus, four types of studies are possible: (1) comprehensive multimedium, (2) noncomprehensive multimedium, (3) comprehensive nonmultimedium, and (4) noncomprehensive nonmultimedium. The studies are presented within a matrix in Table A.2, which also indicates the political or geographic unit for which each study was performed.

In assessing a comprehensive multimedium approach to municipal sludge management, the most relevant aspects of the studies are the options considered and the evaluative criteria employed. These aspects can be used to organize the studies on the bases of the media represented by the sludge disposal options and the comprehensiveness of the evaluative criteria.

It must be emphasized that the regional/municipal studies categorized in Table A.1 were prepared under a variety of circumstances for a variety of purposes. The reports are classified with regard to their comprehensiveness and their consideration of alternative media for purposes of the present analysis; the classification does not relate to the adequacy of the reports for the purpose for which they were prepared.

Moreover, the classifications are often a matter of subjective judgment rather than objective differences, and portray only the relationship of each study to a rather specific set of criteria. In addition, numerous other criteria that are not represented in this matrix are applied in varying degrees to many of these studies. Of particular interest are engineering criteria (feasibility, reliability, etc.); materials balances (resource consumption and generation); and legal, social, and institutional criteria (public reaction, regulatory restrictions, etc.).

Of the 23 studies examined, 12 may be termed comprehensive multimedium or Group I studies. Seven of these involve all three disposal media and thus may be termed comprehensive all-media or Group Ia studies. Five concern inland localities to which the ocean medium is unavailable. One of the noncomprehensive multimedium or Group II studies involves all three disposal media and two involve inland localities that consider only air and land options. These three studies are termed noncomprehensive

TABLE A.2 The Comprehensive Multimedium Matrix

Twenty-three engineering studies of municipal and regional sludge management analyzed for this report are classified in this matrix. Studies considering environmental and economic factors are classified as comprehensive; those considering all disposal options are multimedium. The purpose of the analysis was to indicate the state of current practice of sludge management.

	Criteria	
Media	Comprehensive (Economic and Environmental Criteria)	Noncomprehensive
Multimedium (all available media)	COASTAL Boston–1972 (pj) East Bay–1975 (m) Philadelphia–1973 (m) San Diego–1968 (m) San Francisco Bay–1975 (pj) Southern California–1974 (gr) Washington, D.C.–1975 (m) Group Ia	COASTAL Baltimore–1965 (m) Group IIa
	INLAND Denver–1975 (m) Knoxville/Knox County–1975 (gr) Ohio/Kentucky/Indiana–1976 (gr) Saint Louis–1961 (m) Twin Cities–1973 (m) Group Ib	INLAND Dallas–1969 (m) Montgomery County–1971 (pj) Group IIb
Nonmultimedium	Boston 1973 (pj) New York City-New Jersey–1975 (pj) Sacramento–1975 (pj) Tampa–1975 (m) Group III	Baltimore–1972 (m) Corpus Christi–1971 (m) Idaho Falls–1973 (m) Washington, D.C.–1970 (pj) Group IV

m = municipality. pj = political jurisdiction. gr = geographic region.

because they deal almost exclusively with cost as the important evaluative criterion. Four studies are termed comprehensive nonmultimedium because they fail to consider the available ocean disposal option. In one of these cases, the evaluation was postponed to later study phases; in another, a previous, preliminary study eliminated consideration of the ocean disposal option. In the other two cases, four studies are assigned to Group IV, being neither comprehensive nor multimedium. All are based primarily on cost and fail to evaluate available disposal options.

The organization of studies into this matrix demonstrates the kinds of studies available and information the various studies may yield. For our purposes, the comprehensive all-media studies are of most value, since they provide the most wide-ranging evaluation of sludge management options and thus aid us in answering the questions raised in the first section of this chapter. The comprehensive multimedium and the comprehensive nonmultimedium studies will provide substantial insight into evaluation of a narrower set of sludge management options. The noncomprehensive studies, both multimedium and nonmultimedium, may provide some data of interest.

DESCRIPTION OF THE STUDIES

The Goals of the Study

All of these studies have as a basic goal an evaluation of sludge management options. However, the ultimate purpose of such an evaluation varies substantially from study to study. Most studies are aimed at direct implementation of a sludge management plan based on the recommended option(s). A few studies are more general efforts, designed to separate the reasonable and unreasonable options and to delineate an evaluative procedure or the important evaluative factors. In some cases, studies may simply be part of an ongoing attempt to keep information about sludge management options on hand. There is a good correlation between the final purpose and the type of jurisdiction for which the study was performed: the degree of orientation towards implementation parallels the jurisdiction's responsibility for implementation and its power to implement. Almost all the studies for municipalities are oriented toward implementation. Studies for geographic regions consider whether an option is reasonable or unreasonable. Studies for supramunicipal political jurisdictions may be of either type, depending upon the amount of authority vested in the jurisdiction concerned. Interestingly, the ultimate purpose also correlates with the comprehensive multimedium matrix. Reasonable-unreasonable studies are concerned with a wide variety of options and evaluative criteria and can thus be classified as comprehensive multimedium. Implementation studies are distributed throughout the matrix, and are often restricted to fewer media and/or less comprehensive criteria. Apparently, the comprehensive multimedium approach is seen as less than a necessity when direct implementation is the ultimate goal.

The Data Base Used

Three types of data are found in these studies. The most basic and important data in sludge management are the facility and input/output parameters: e.g., the population served, wastewater flow, wastewater treatment and sludge management processes, and sludge production quantities. Data on the physical, chemical, and biological characteristics of the sludge, while not as relevant as the basic facility and input/output data, are often equally significant, since such matters as environmental impacts and process costs depend directly on them. Finally, data on numerous peripheral items not specifically related to sludge, such as demographics and climate, are also important. Documentation in these three areas exhibits variability that is well correlated with the comprehensive multimedium matrix.

All studies include thorough description of the facilities and the average quantities of sludge produced; most include additional data on population served and wastewater flow. Information about input/output variability whether short- or long-term, is occasionally lacking. Moreover, the assumptions upon which projections are made and their degree of uncertainty are rarely emphasized, since these are not considered major factors. The amount of attention given to the "basic" data does not correlate well with the comprehensive multimedium matrix. Authors may have placed special emphasis on certain parameters because they believed them to be particularly significant to the criteria considered relevant or the specific options being evaluated.

The attention given in each study to data on sludge characteristics is well correlated with its position in the comprehensive multimedium matrix. Noncomprehensive studies have no data beyond the most basic physical parameters, such as percentage of solids and type of sludge. While comprehensive studies usually provide basic physical and chemical data, they only occasionally provide thorough assessment of the physical, chemical, and biological characteristics of the sludge. Even when the data are presented, they are not always applied in the evaluations of options.

The Sludge Management Options Considered

The distribution of disposal options by media reveals that 12 of the studies--including seven that examine all three media--comprehensively examine disposal options involving all available media. Within each medium, however, there are numerous disposal techniques and numerous degrees of specificity in describing these options. In addition, each study has its own way of developing the initial disposal options and selecting those most worthy of ultimate evaluation. Thus, a strict comparison between studies is impossible. Furthermore, the fact that certain options involving a particular medium have been considered does not necessarily imply that all or most of the disposal choices involving that medium have been reasonably evaluated.

The most general procedure is the consideration and ultimate evaluation of disposal via the three basic media: air, land, and ocean. The most specific approach involves the consideration of myriad "process sequences" and the evaluation of a select few. The Twin Cities study discusses such a process sequence: "thickening to consist of either mixing the two sludges and gravity thickening or keeping them separate and thickening only the secondary using flotation; anaerobic digestion of the mixed sludge; pumping through a pipeline to storage lagoons; landspreading in a wet condition." A complex option such as this one may encompass five or ten of the options in another study. The 23 reports run the gamut between very general and very specific considerations. In addition, there is some variation in the extent to which "considered" or "mentioned" options receive ultimate systematic evaluation. Particularly in "process sequence" evaluations, there may be several levels of analysis, each with its own criteria. This enables the authors to reduce as many as several hundred options to a much smaller number that will be evaluated systematically.

Further complications result from the use of options dependent upon site-specific facilities or geographic location. The San Francisco Bay study includes "Bay Delta Levee Reinforcement" as a specific option. San Diego includes "ocean disposal through the present sludge outfall." These options are available only to the specific locality involved, in the first case because of geography and in the latter because of in-place facilities.

An additional complication is the use of options in which parts of the sludge produced are disposed of through different means. Options must then be evaluated continuously rather than discretely, because choices are no longer among a finite number of options but among an infinite number of combinations. One study's single option may thus be comparable only to parts of several options in another study.

The wide range of schemes for organizing the options considered in each study provides much information for the first question on the nature of evaluative approaches to municipal sludge management but makes the second question, concerned with comparisons among studies, exceedingly difficult to answer.

Evaluation Criteria

The division of studies into comprehensive and noncomprehensive on the basis of the evaluation criteria of economics and environment has already been discussed. Variations in substance and format exist for each of these criteria, and for the supplemental criteria that may or may not be found in a particular study.

Substance

As the only criterion for which a national scale exists, economics is the most clear-cut of the three general areas. Economic considerations are usually expressed as capital cost, operating and maintenance cost, and equivalent annual cost. The last is the yardstick by which most evaluations are made. Despite the existence of the common dollar scale, uncertainty enters cost evaluations within and among comparison studies as a result of several complicating factors: the inclusion or exclusion of federal and/or state matching funds; the inclusion or exclusion of related costs, such as land, demonstration projects, monitoring requirements, public relations, etc. and "cost credits" for nutrients, energy, and crops produced at some market value; and the variability in accounting procedures and cost curves. Matters are made more difficult when the exact means of the cost determinations and the assumptions underlying them are not explicitly stated.

The evaluation of environmental impact centers on the definition of both "environmental" and "impact." Many studies consider the environment to be subdivided. For example, one separates the environment into eight sectors: water, air, land, flora and fauna, aesthetics, public health, community impact, and resource conservation. Others deal with more specific aspects of the environment, concentrating on public health or the most directly affected medium, e.g., the air for incineration options. Still others deal with the environment as a whole and attempt to assess the overall impact of a disposal option without explicitly dividing the environment into components.

Additional variations become evident when the "impact" concept is addressed. It is often unclear whether the evaluative criteria are based on actual, theoretically measurable effects (impact) or on the chance that damage will occur (risk). This ambiguity is most disturbing in studies that deal with options whose impacts the authors consider manageable, thereby implying that they are really reducible risks. Thus it is unclear whether the environmental damage or the risk of damage is being measured in these studies. Furthermore, the boundaries of specific sectors become hazy when impacts are examined. What is an impact on the water quality sector if not an impact on the public health sector and the aesthetics sector via the water medium? All in all, a wide range of definitions of environmental impact is employed, most of which seem to be plagued by severe problems of imprecision and ambiguity.

Other evaluation criteria include engineering, materials balances, and legal, social, and institutional aspects. Engineering and materials balances are often explicitly related to economic and environmental impacts. Materials consumption, for example, can be seen as a discrete concept or as increased cost and negative environmental impact. The legal, social, and institutional aspects include variable human factors and are usually distinguished from the scientific and quasi-scientific criteria. Some studies do avoid this division by including public acceptance as an aspect of "feasibility" (an engineering criterion) or making legal restrictions a guide for environmental impact. The attention devoted in a specific study to legal, social, and institutional factors can indicate the extent to which the study is aimed at a solely scientific determination or a scientific-social one. This orientation manifests the degree to which the study's authors feel that social questions must be considered in achieving their particular goals.

The specific sectors of the environment are inseparable. On the other hand, the various issues represented by these sectors are important and cannot be ignored. It should be made clear that air, land, and water are media through which effects may be transmitted. The environment is composed of these three media and the impact is that which they transmit to the rest of the biosphere and, ultimately, to humans. The focus of evaluation should be the propensity of the media to transmit and, thus, to cause impacts.

Format

The format for economic criteria is arranged as an economic ranking, with the major variation the extent to which the study's authors believe their figures actually permit differentiation of similarly expensive options. For environmental and other criteria, the format ranges from very quantitative to very qualitative, and usually parallels the degree to which the criteria have been broken down into identifiable, scorable sectors.

The most extensively developed quantitative system is a sophisticated weighting rating scoring system. Each subcriterion (sector) is weighted for its importance on a 1-10 scale. Each option is rated technically on a 1-10 scale for its status (favorable or unfavorable) in relation to the subcriterion. The weighted ratings are grouped into larger criteria for a general score. For example, incineration may rank a 3 (unfavorable) in resource conservation, which is considered to rank 5 in importance. This score of 15 combines with other environmental factors to produce a total, which is compared to a theoretical no-change level. Another system, while less elaborate in that qualities are not weighted, employs several factors on which each option is rated. These are combined into subcriteria and then into criteria. The numerical criteria ratings are then compared. In a less quantitative system, each option is ranked as poor, fair, good, or unknown on its ability to satisfy a particular criterion and each option's impacts are rated as significant, insignificant, or unknown. Another system simply estimates qualitatively the extent of impact on the basis of a general knowledge of the option involved.

The variations in format raise several questions. The most basic seeks to determine the level of analysis that is justified by the state of scientific information on these subjects. The assignment of specific numerical values to environmental impacts has no meaning unless those numbers clearly reflect well-defined measurable effects. The existence of unsupportable assumptions of comparability and equality among highly diverse and poorly defined factors when using a numerical scheme is sufficient to require the rejection of such a system. On the other hand, highly generalized, diffuse discussion of environmental impact is of little real value. Attempts at precision must be scaled to the level justified by the available data. Unfortunately, in many cases, the only attempt that can be validated is a quasi-quantitative evaluation, in which the crucial factors upon which the judgment is based are pointed out.

The Option Evaluations

The nature of the evaluations of options in each study is determined by the types of options considered and the nature of the evaluative criteria. If the options are specific process sequences and the criteria are expressed in quantitative terms (dollars, numerical scores, etc.), then the options are usually ranked explicitly. For generalized options evaluated according to qualitatively expressed criteria, a discussion of each option is usually presented from which the relationship among options can be assessed. Again, the option evaluations in a specific study may be found anywhere between these poles, depending upon the study's particular attributes. The evaluative process is, at this point, criterion-specific; tradeoffs between criteria (economics and environment, for example) remain to be addressed in later stages.

Ideally, the variability or lack of it in the option evaluations among the studies would express itself in discernable patterns. From these patterns, one could reach conclusions concerning the status of individual options or sets of options with respect to various criteria and the correlation with properties of the unit under study. For example, a pattern might lead to the conclusion that landspreading is inexpensive for small municipalities in rural areas. The lack of discernable patterns could, on the other hand, permit the conclusion that sludge management options do not correlate with these properties. The major flaw in this scheme is that the extreme differences between studies presents a virtually insurmountable obstacle to drawing general conclusions about sludge management options and their relative merit with respect to certain criteria. The aim of the studies, the data bases used, the sludge management options considered, and the evaluative criteria all vary to such an extent and in such a manner that neither patterns nor the lack of them can be determined to be real (correlated with the properties examined in the study) rather than artificial (correlated with the properties of the study). In numerous individual cases, though, it is possible to see how the specific properties of the study and/or unit influence the evaluation of particular options. These latter insights may be the most valuable aspect of this examination.

The Recommendations and Their Rationale

The recommendations made in each study are a function of the option evaluations and the final purpose behind those evaluations. The studies concerned with implementation normally fulfill their mandate by recommending a single option that is felt to be the most sound on scientific, social, legal, and institutional grounds. "Reasonable-unreasonable" studies recommend those options that seem to be able to satisfy the scientific criteria. The degree to which recommendations are flexible, that is, they are made pending further study or possible regulatory changes, depends upon the particulars of the situation studied.

Whether a single option or several options are recommended and whether for an interim or indefinite period of time, the recommendations are the first point at which assessment is made on the basis of more than one criterion. In most cases, the relative importance of economic and environmental impact criteria is paramount. A relatively simple method is to set an environmental impact level that is considered acceptable and to choose the least expensive criteria that satisfy it. This acceptable level may be determined by the study's authors or by legal or regulatory guidelines. The alternative method selects and recommends one or more of the relatively well-ranked options on the basis of the information available and the convictions of the authors. Obviously, these two methods may be combined in that a choice may be made among a number of options that satisfy a specific level of environmental impact.

Table A.3 shows each comprehensive study's recommended options and indicates how these options fared on the basis of the criteria specifically employed in the evaluations. Certain specific types of information may be extractable from this array, but the arguments that apply to the analysis of option evaluation patterns apply here with equal force. The recommendations emphasize unique aspects of each study and the variability among them.

IMPLICATIONS FROM THE REGIONAL/MUNICIPAL STUDIES

This analysis began with two questions whose answers should provide insight into the comprehensive multimedium approach to sludge management. The six-point descriptions highlighted those aspects of the studies that are most relevant to these questions. Some preliminary answers can now be suggested.

Each regional/municipal study is a real-world application of a theoretical evaluative procedure. The most important information gained from examination of these studies does not concern the relatively straightforward evaluative theory but rather the obstacles to its concrete application. These obstacles are found primarily in the areas of data handling, evaluative terminology, and assessment of the scientific basis of the evaluative process.

Data Handling

The importance of data in evaluating sludge management options (and science as a whole) is uniformly accepted, as are the additional requirements for data associated with increasingly comprehensive or multimedium analyses.

TABLE A.3 Evaluation of Recommended Options

The recommended options of the studies are listed, and each option is rated against the criteria used for the specific evaluation.

Group Ia

Boston–1972

Recommended Options: Further study of incineration, wet oxidation, pyrolysis, sludge reformation, land disposal, and others. Clarification of legal status of ocean disposal.

Evaluations: too complex

East Bay–1975

Recommended Options: Dewatering and landfill. Further study of other options

Evaluations: Capital Cost: ranks 2 of 6, Annual Operating Cost: ranks 6 of 6; Average Annual Cost: ranks 3 of 6; Environmental Impact: not significant; Reliability: good; Flexibility: good; Public Acceptance: unknown (long term); Ability to Implement: good; Energy Utilization: produces energy; Resource Utilization: poor (short term), unknown (long term); Meeting Regulatory Requirements: fair.

Philadelphia–1973

Recommended Options: Sea dispersal (present practice or modified)

Evaluations: Total Annual Cost: ranks 1, 2, or 4 of 15; Total Annual Cost with Credit for Energy and Nutrients; ranks 1, 2, or 5 of 15; Environmental Impact: nondetrimental; Engineering: simple and easily controlled.

San Diego–1968

Recommended Options: Land application (present practice) or conversion to ocean disposal

Evaluations: Capital Cost: ranks 2 (land) or 1, 3, or 9 (ocean) of 10; Annual Cost: ranks 2 (land) or 1, 4, or 5 (ocean) of 10; Environmental Impact: beneficial (land) or nondetrimental (ocean).

San Francisco Bay - 1975

Recommended Options: too complex

Evaluations: too complex

Southern California–1974

Recommended Options: Processing for sale or landfill. Further study of ocean disposal and incineration.

Evaluations: Combined Cost: ranks 2 (processing) or 3 (landfill) of 7; Environmental Impact: ranks 1 (processing) or 2 (landfill) of 7; Feasibility: ranks 1 (processing) or 2 (landfill) of 7; Performance: ranks 6 (processing) or 5 (landfill) of 7

Washington D.C. - 1975

Recommended Options: Composting or incineration.

Evaluations: Cost Range: ranks 13 (composting) or 3 (incineration) of 58; Fuel: ranks 21 (composting) or 47 (incineration) of 58; Electricity: ranks 3 (incineration) or 20 (composting) of 58; Environmental Impact: controllable so as to be nondetrimental (both); Public Acceptance: low (incineration).

Group Ib

Denver–1975

Recommended Options: Anaerobic digestion with beneficial reuse

Evaluations: Total annual cost without grant funding: ranks 2 of 8; Total Annual

TABLE A.3 (Continued)

Cost with Grant Funding: ranks 1 of 8; Environmental Impact: beneficial, Engineering: sinple and flexible.

Knoxville/Knox County–1975

Recommended Options: too complex

Evaluations: too complex

Ohio/Kentucky/Indiana–1976

Recommended Options: too complex

Evaluations: too complex

Saint Louis–1961

Recommended Options: Incineration of raw sludge.

Evaluations: Total Equivalent Annual Cost: ranks 3 of 8; Environmental Impact: nondetrimental; Engineering: reliable, flexible.

Twin Cities–1973

Recommended Options: too complex

Evaluations: too complex

Group III

Boston–1973

Recommended Options: Incineration.

Evaluations: Capital Cost: ranks 1 of 3; Total Annual Cost: ranks 1 of 3; Resource Recovery: ranks 2 of 3; Final Residual Solids: ranks 1 of 3; Process Impact: ranks 1 of 3; Land Impact: ranks 1 of 3; Air Impact: ranks 1 of 3; Water Impact: ranks 1 of 3; Energy Impact: ranks 1 of 3; Public Health Impact: ranks 1 of 3; Noise Impact: ranks 2 of 3.

New York City-New Jersey–1975

Recommended Options: Pyrolysis.

Evaluations: Total Cost: ranks 1 or 2 of 9; Net Cost Including Energy Credits: ranks 1 or 2 of 9; Power Consumption: ranks 1 or 2 of 9; Environmental Impact: controllable so as to be nondetrimental.

Sacramento–1975

Recommended Options: Agricultural utilization.

Evaluations: Economic: ranks 1 of 4; Energy: ranks 1 of 4; Direct Impact: ranks 4 of 4; Secondary Effects: ranks 1 of 4; Functional Stability: ranks 1 of 4.

Tampa–1975

Recommended Options: Air drying for public use as soil conditioner.

Evaluations: Capital Cost: ranks 1 of 10; Average Annual Cost: ranks 1 of 10; Environmental Impact: controllable so as to be nondetrimental; Energy: low consumption: Engineering: reliable.

Nevertheless, the disparity between the data handling desirable and the data actually identified, acquired, and/or adequately used is disquieting and inhibits the application of comprehensive multimedium evaluative procedures.

The most basic omission in data handling involves a primary failure to identify the important parameters about which information would be desirable and state their significance. Without this introduction to the evaluative process, neither the author nor the reader can reasonably determine the degree to which the process can be successfully completed. Furthermore, only when data requirements are specifically noted can the acquisition of that data be actively pursued.

A more mundane omission is simply the failure to acquire data. If the unacquired data are important in a certain identified area, this failure is limited in effect to that area of importance. If, on the other hand, the relevant area is not precisely defined, this failure undermines the entire evaluative process.

The final data handling omission involves the failure to apply the data adequately, and to note the uncertainty involved. This failure may stem from obstacles such as those noted below.

Evaluative Terminology

Options cannot be properly evaluated or applied unless the terminology used in the evaluations is precisely defined. The ability to evaluate the impact of a sludge management option on any environmental entity requires a precise definition of this entity and the nature of the impact. Even something as simple as the cost of an option can be evaluated only if cost is specifically defined. This is a significant problem when general concepts and educated impressions are being dealt with and is of paramount significance when specific and objective evaluations are attempted. A related requirement of the evaluation of options is that the evaluative criteria be delineated; that is, that the relationships of the criteria to each other be noted. Failure to define and delineate the evaluative terminology invalidates the entire processes of evaluation, because its basis is a set of terms whose meanings and interrelationships are unknown.

Assessment of the Scientific Basis of the Evaluative Process

The final obstacle to the application of comprehensive multimedium procedures is the failure to assess specifically what level of analysis the scientific information will allow in each aspect of the evaluative process. The consequent inability to apply the knowledge gained in that assessment will prohibit scientifically justifiable analysis.

The relevance of this obstacle is clear throughout the various studies. Only such an assessment will indicate if the options to be considered can actually be differentiated, or if the evaluative criteria, such as numerical weighting/rating systems of environmental sectors, are justifiable. Only such an assessment will indicate whether the pollutant levels set by regulations are adequate protectors of the environment. The end result of any such assessment will almost certainly be that very little quantitative accuracy is possible in the evaluation of sludge management options, particularly with regard to their environmental impact. Nevertheless, this operation is an absolutely necessary precondition to the realistic application of any comprehensive multimedium evaluative procedure to the real world.

Comparisons of the evaluations of options would ideally indicate the relative value of sludge management options. Unfortunately, because of the variability among studies, value judgments cannot be made except perhaps in a few, very limited, cases.

The fact that inferences with specific regard to the value of sludge management options can only rarely be drawn implies certain things about sludge management. The state of the art at present embodied in the regional/municipal studies is not advanced enough to permit rational assessment of the nationwide desirability of any particular sludge management program. This state of the art, while the primary responsibility of the performing agencies, is also a secondary responsibility of the federal agencies responsible for their guidance and for the administration of the very program that generates sludge.