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Sewage Disposal and the Ocean: The Sea Grant Role

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by

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RELATED SEA GRANT REPORTS

Kildow, Judith T. BOSTON HARBOR MANAGEMENT STUDY. MITSG 81-15. 268pp. Photocopy only available. $10.50. 13 pages of colored maps, included in the text in black and white, are available at $1.00 each.

MIT Marine Industry Collegium. WASTEWATER MANAGEMENT: TECHNICAL ALTERNATIVES AND REGULATORY OUTLOOK: OPPORTUNITY BRIEF #32. MITSG 83-9. 21pp. $3.50.

Myers, Edward P., ed. OCEAN DISPOSAL OF MUNICIPAL WASTEWATER: IMPACTS ON THE COASTAL ENVIRONMENT. MITSG 83-33. 2 vols. 1115pp. $35.00.

Trump, John G., Kenneth A. Wright, Edward W. Merrill, Anthony J. Sinskey, Dineshchandra Shah, and Steven Sommer. PROSPECTS FOR HIGH-ENERGY ELECTRON IRRADIATION OF WASTEWATER LIQUID RESIDUALS. MITSG 75-19. 20 pp. No charge.

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Introduction

The impetus for this study was the general and growing awareness of serious pollution in Boston Harbor; this was recently emphasized by the City of Quincy lawsuit against the Metropolitan District Commission (MDC) and other public agencies. In the Quincy suit, it was shown that the causes of specific concerns, such as shellfish bed closing and bacterial contamination of beaches, are multiple and complex; storm water drainage, combined sewer overflow, and lack of maintenance of the sewage treatment system seem to be more at fault than the inability of the Boston Harbor-Massachusetts Bay system to assimilate the regional primary treatment wastes (Commonwealth of Massachusetts, Superior Court, 1983). Still, the basic question of ecosystem health remains. Current EPA regulation requires that all communities meet standards through minimum secondary waste treatment. Boston has developed extensive waste management plans but action has been held in abeyance because of two unresolved questions, viz, the outstanding MDC request for a waiver of the secondary treatment requirement and the identification of how best to manage or dispose of the solids residuals (sludge) (Commonwealth of Massachusetts, MDC, 1983; USEPA, 1979; NSF, 1978). The MIT Sea Grant College Program undertook this study to examine the best ways to draw upon its various resources to help address this important regional issue which is also of national concern.

Five laws directly address the management of society's waste material. These are the Federal Water Pollution Control Act (known as the Clean Water Act); the Marine Protection, Research, and Sanctuaries Act (the Ocean Dumping Act); the Safe Drinking Water Act; the Resources Conservation and Recovery Act (RCRA); and the Clean Air Act. Each law is designed to protect a specific medium (air, land, freshwater, ocean). Because of the overlap among the regulations, it has become difficult, if not impossible in some cases to find an acceptable disposal site for municipal wastes. Concerned scholars are increasingly pointing toward the need for a central and overriding set of regulations which will allow an analysis of the probable health and environmental consequences of each disposal option, and a rational selection of the best alternative on a case by case basis (Knauss, 1982; NACOA, 1981). This desired new procedure is called multi-medium management.

The Sea Grant contribution should relate mainly to the ocean disposal option. The oceans, of course, have long been utilized for the disposal of human wastes by coastal communities. Even after people became aware of pollution problems in rivers and streams and the development of modern sewage treatment facilities this practice continued. The reason was not necessarily callous disregard of the environment or simple cost advantage, but more likely stemmed from a belief that ocean processes can substitute for sewage treatment facilities by naturally degrading organic materials (O'Leary, 1959; Pearson, 1974; Calvert, 1974).

Three Waste Disposal Case Studies

New York Bight

In this country, sewage disposal in the New York Bight has received the most national attention. It is generally regarded as one of the most seriously degraded coastal environments in the world. Two incidents in 1976 attracted news media special attention. Long Island bathing beaches were closed because of extensive floatable debris "pollution", and hypoxic or anoxic bottom waters in the New York - New Jersey area caused a large scale and costly fish kill. Studies have shown that unusual natural events were the real cause of the anoxia problem and the floatable crisis. Although there are in the New York Bight, as there are in Boston, multiple sources of pollution (Squires, 1983; Swanson, 1978), public attention is often focused on one specific contributor to the overall pollution. This is true of the present sewage sludge dumping by barges, and the USEPA is moving to halt this dumping in the Bight at the present nearshore (12 mile) site. Instead, they favor a site at the edge of the continental shelf (106-mile), but some scientists predict that without other significant improvements in waste disposal practices, there will be little environmental improvement. Beaches, a common concern, will be unaffected (Gunnerson, 1982). Other sources of pollution include dredge spoil dumping, raw sewage discharge into the Hudson River, combined sewer overflow, stormwater drainage, and sewage treatment plant effluents.

Among the environmental effects of domestic waste discharge in the New York Bight, excessive nutrient levels from raw and treated sewage discharges in the estuary are major factors in stimulating summer algal blooms. Decomposition of the dead algae contributes to lowered average oxygen concentrations in the region. Other effects attributed to these human wastes include diseased fish, stimulation of red tide blooms, accumulations of organics, metals, and toxic chemicals in the sea floor sediments, and associated changes in the species of organisms living in these sediments. A large area of shellfish beds has been closed because of bacterial contamination, but other economic effects on the fisheries have not been shown. Fin rot disease in winter flounder is seen as an indicator of environmental stress and does not appear to have a major effect on the population dynamics or marketability of the species (Murchelano, 1982). Catch statistics for commercially valuable species in the New York Bight reveal few changes in abundance that are directly attributable to pollution (Sinderman, 1982).

Careful analyses of the contributions from the various sources to the overall contaminant loading in the Bight have been made (NOAA, 1976; Gunnerson, 1982) but these studies have not yet led to an implementation plan showing priority corrective measures in relationship to expected cleanup objectives. No one seems to question that a cleaner estuary would be more pleasant and less dangerous to the health of the people using it for food or recreation. Considering the many demands on the financial resources of a large metropolitan area, however, it should be recognized that some measures, although expensive, will yield only a small or negligible beneficial impact. In this case, it appears that attention should be directed toward the inadequacies of the combined sewer network, and the incomplete sewage treatment system before sludge dumping practices.

Southern California Bight

Another area which has received large volumes of sewage and sewage sludge for many years is the Southern California Bight. In this case, both the sewage treatment plant effluent and sewage sludge have been discharged into the ocean through pipeline outfalls. The prevailing winds are towards the shoreline, and contaminated and closed beaches were prevalent prior to the 1950's. However, on this coast deeper water is found within a few miles of the shore; the beach pollution problem was solved by lengthening the outfall pipes and fitting them with diffusers to dilute the sewage. Because the discharge point is in all cases below the pycnocline, which acts as a barrier to the effluent plume, surface pollution is minimized, and the beaches are thereby protected. (Mearns, 1981; Bracewell, 1980).

In the New York case, most of the waste effluents are released inside the harbor entrance. This system is relatively enclosed, and even at the 12-mile site outside the harbor where sewage sludge and dredge spoils are dumped by barge, the environment is relatively non-dispersive (Norton, 1983). In contrast, in Southern California the effluents are released in open areas exposed to the longshore coastal ocean circulation. There is no excessive nutrient buildup except in the near vicinity of the outfalls. Extensive testing has confirmed that water chemistry in the Southern California Bight is not adversely affected by waste discharges (Mearns, 1981). Trace metals are elevated above natural levels near and downstream of the outfalls, but these elevations are well below concentrations known to produce subtle effects in organisms.

Undesirable waste discharge effects in the Southern California coastal area are seen mostly in contamination of sediments and "degraded" benthic communities in the vicinity of the largest outfalls. Concentrations of carbon, nitrogen, trace metals and synthetic organic chemicals in the sediments are within a factor of two to three above background at three sites. There is one site, Palos Verdes, where some materials are elevated by more than a factor of 100. In a restricted zone near each of the outfalls benthic infaunal communities are changed and pollutant concentrations in infaunal invertebrates and some larger epibenthic invertebrates, such as crabs, are increased above normal. However, bottom fish do not accumulate excess trace metals, and levels of DDT and PCBs are not a serious concern (Mearns, 1981; Bascom, 1983). Fin fisheries appear to be enhanced rather than reduced.

Continued concern about environmental effects has led to industrial pre-treatment, source control, and increased solids removal from the sewage. Sewage sludge is still discharged at a site near Santa Monica, but that practice will also cease soon. These actions have resulted in noticeable improvement to the impacted bottom areas. Because deep water is so close to shore, and adverse effects as well as increased cost are associated with land disposal of composted sewage sludge and incineration, a proposal for an experimental pipeline discharge of sludge at 300 meters depth near the edge of a submarine canyon is now being considered (Brooks, 1982; Jackson, 1979). This amounts to a strategy of containment as contrasted to a strategy of dispersion as generally used in sewage disposal practice.

United Kingdom

Outside the United States, the most useful information on the effects of sewage discharge on the marine environment comes from the experience of the United Kingdom. For nearly 100 years the United Kingdom has discharged effluent from treatment plants into estuaries, and in a number of communities has granted permits for barge dumping of sewage sludge. Permitting today is done more carefully than in the past and follows a careful review of probable impact. The British law differs from U.S. law in this regard. U.S. law is concerned with "unreasonable" degradation of the environment, while Britian's is concerned with the pathways of pollutants to humans. U.S. law is difficult -- or impossible -- to satisfy without cessation of all sludge dumping, because ecological insult has not been defined (O'Connor, 1982; Rowe, 1982).

In the United Kingdom the largest volumes of sludge have been dumped in the Thames estuary (London wastes), where the tidal currents provide good dispersive conditions. There is some accumulation of organic materials and metals in the vicinity of the dumpsite but there have not been adverse effects on fisheries and even the effects on the benthic organisms have been minor. Accumulation of mercury in fish was detected by routine monitoring in the early 1970's but after the source was located and source controls instituted, this dropped to a safe level (Norton, 1983). Some of the United Kingdom dumpsites which receive the wastes from smaller communities exhibit no obvious signs of deterioration (Jenkinson, 1972). Several others show slight changes in the benthic communities and some accumulation of organics and other pollutants in the nearby sediments. The most highly impacted area is the Firth of Clyde, which has the characteristics already noted for New York, i.e. multiple sources of contaminants and relatively non-dispersive oceanographic conditions (McKay, 1972; Norton, 1983).

Conclusions from Case Studies

The result of worldwide accumulated experience and the related research and monitoring programs is a commonly held scientific opinion that well managed programs of sewage sludge dumping in the ocean are possible (UNESCO, 1982; NACOA, 1981). This seems to be reflected well in British policy where the objective has been to gain the maximum environmental benefit from the commitment of financial resources. The general behavior and effects of sludge dumping can be predicted from a knowledge of the characteristics of the receiving area (Norton, 1983). The British require high levels of sewage treatment in the upstream parts of estuaries, but accept lower treatment levels seaward where the dilution and dispersion are greater. The environmental effects of the sludge dumping itself can be restricted to chemical contamination in the immediate vicinity of the disposal area and minor ecological changes (USEPA, 1977; Boesch, 1983). In comparison to the problems associated with other alternatives such as composting and incineration, disposal at sea may represent in many cases the best option for environmental as well as economic reasons. It also appears that with proper source control of hazardous substances the risk is minimal in a long term sense, since the California studies of abandoned outfalls show the reversibility of the effects of contamination of the sediments by excessive nutrients (Brooks, 1983).

In the past few years many excellent articles have reviewed the practice and regulatory status of ocean disposal of sewage wastes in the United States (Farrington, 1982; Feliciano, 1981; Knauss; 1982; Lahey, 1982; Swanson, 1982; Walsh, 1981). From different perspectives (scientific, legal, legislative) each points out that a striking feature of our existing pollution control laws is an implicit assumption that ocean disposal is the least preferable alternative compared to land disposal and incineration. Most, however, see the tide of opinion changing as the sensitivity to other pollution problems (air and ground water contamination) grows. There is an emerging consensus that ocean disposal is not necessarily the least desirable alternative, and that a flexible policy would be preferable, coupling case by case decision making (Multi-medium Management) with careful monitoring, continued research, and a continual re-evaluation as more is learned.

Contrary opinions are still expressed, of course (Kamlet, 1981). Some key concerns seem to be: 1) the oceans are "out of sight-out of mind" and therefore not protected by the market place and political forces; 2) although the oceans can handle readily degraded materials in moderate amounts, we do not yet appreciate the possible effects of chronic low level toxicity; 3) synergistic effects of toxicants are not understood; and 4) we cannot rely on scientific research and monitoring to detect problems before catastrophes occur.

Although the scientific literature reflects a changing climate of opinion concerning the safety of ocean disposal for municipal wastes, as already noted, this change is not noticeable in the general population. Policy change might be expected to take place slowly therefore, since without this change in attitude in the general population, managers in a democratic society can find the status quo to be the least threatening position to take.

The Social Context

The question of disposal of human wastes in the ocean has achieved the status of meriting regular forums such as the International Ocean Disposal Symposiums; and the number of scholars contributing to related studies has grown to the point that it is easy to generate bibliographies listing thousands of recent citations (Champ, 1982). While it is perhaps to be expected that physical and biological scientists predominate in this group, with the focus being ecological impacts, it is disappointing that the number of social scientists who have become actively involved so far is quite low. Any large scale operation such as sewage treatment and disposal affects the lives of people, and different groups will perceive the affects in various ways. Since large amounts of material are involved (for Boston approximately 500 million gallons per day of wastewater and at least 2000 tons per day of sludge depending on the level of treatment), the construction of treatment facilities, and the logistical systems for handling sludge are significant. Not only are the people living in the vicinity of treatment facilities generally aware and concerned, but other groups who use nearby coastal lands or water for business or recreation, or who are in the path of regular servicing truck traffic, etc. Also, we presently have multiple and overlapping regulations, and the review process is long, including many independent opportunities for challenge. The opportunity for confrontation is not limited to the permit process either, since the courts have become a regular mechanism for citizen appeal. Delays can be costly, and although some will always regard a delayed or cancelled project as a victory, any change at all can be difficult to accomplish. When the present facilities and methods are obviously inadequate, this is indeed unfortunate.

The literature on environmental problem solving makes clear the inevitability of conflict where it is difficult/impossible to separate values from the decision process (Bacow, 1982; Susskind, 1982). In this country, we have relied heavily on regulation to control "pollution" of the environment, an approach which insists upon a uniform solution to multiple and dissimilar problems. That this approach has not been efficient is well recognized (Knauss, 1982; NACOA, 1981; NAS, 1978). Multi-medium assessment, as presently proposed, may not improve the situation if all it provides is an expansion of the boundaries for the technological assessment, i.e. inclusion of more options. If we continue to avoid the essentially judgmental nature of the decision process, the problem may only be exacerbated. Value judgments must be included in the decision making because the complex pattern of multiple effects of any action, when superimposed on the diverse interests represented by a pluralistic society precludes reaching a completely fair and efficient solution by rational methods alone.

Some writers, while recognizing the social nature of the problem and the complexity of the issues, focus on a form of resolution which supposes a rational decision at some level of government. For example, from the legal perspective, it can be seen that the rights of the public are not protected legally in the same way as private property rights. It has been suggested (Sax, 1971) that the courts are the proper place for individual citizen appeal. The courts are seen as having the advantage of being an "outsider" not subject to the same pressures as the executive branch; they can therefore check that reasonable planning has been done and raise important policy issues helpful to the legislative branch of government. To the contrary, of course, others recognize that the adversarial nature of our legal system necessarily produces winners and losers, and strongly discourages consensus (Susskind, 1982).

Similarly, the Congress is described as balancing and resolving complex issues (Kitsos, 1983). Decisions are reached in direct response to the understandings of the problems by various constituency groups as the technical understandings of the issues mature. It is equally possible to believe in regulation and enforcement -- an outgrowth of representative government -- and litigation through the courts. So far, however, no suggestions have been made which outline procedures which will lead smoothly toward a fair and efficient solution of specific problems.

Conflict Resolution - What Can Sea Grant Do?

The uniqueness of the Sea Grant Program lies not only in the fact that it assembles scholars from all disciplines to examine an issue, but it also combines research, education, and advisory services to find better ways to solve problems. Thus far, the many forums on ocean disposal have involved scholars talking to each other, generally about the scientific aspects of the problem, but more "reasonable" regulation from the perspective of present scientific knowledge has also been discussed.

A characteristic of public disputes on environmental problems is intractablility. This is largely because there are multiple parties and interests involved. Although the inadequacies of our present "command and control" system of regulation are apparent (Drayton, 1979), progress toward alternatives is slow. In recent years out-of-court conflict resolution methods have been used often to handle corporate disputes. Some of the lessons learned have been analyzed with regard to environmental problems (Quinn, 1983; Susskind, 1982). While the courts can be seen as a means to equalize power in conflict resolution, the mediative process offers greater participation, flexibility, and choice. It is not clear which options minimize costs and delays and which maximize fairness. Sea Grant, with its focus on public education and advisory services, should be able to contribute significantly to understand better the environmental problems and to improving mechanisms for resolution.

Economics

Although economics, or the costs of various alternatives are regularly discussed in relation to various sludge management alternatives, no economist has carefully studied the question. This appears to be a fate suffered by the social sciences in general, i.e., basic resource economics theory is developed, but not enough attention is devoted to problems of implementation. It seems it will be some time before anyone can write on the economics of sludge management options with much confidence (Dales, 1968).

It is commonly acknowledged that the market system has failed to deal with common property resources, (Anderson, 1977; Kneese, 1968), but from the economists' point of view, the regulatory-enforcement approach cannot produce an "efficient" solution (Kneese, 1975). Attempting to correct for the market failure or diseconomies by calculating the external costs and charging a compensating fee for pollutant discharge is suggested as theoretically possible, but appears to be impractical because the calculation is enormously complex. In defense of the present system of planning, it has been suggested that it is easier to determine how high external costs need to be (i.e. the severity of social impacts) to reverse a decision based solely on internal costs, than to determine the external costs themselves; therefore the subjective judgement of decision makers can be thought of as defining the bounds of external costs (Huetteman, 1983). This solution, however, has not yet been carefully defended as fair and efficient, and, the history of public acceptance of proposed pollution control projects does not seem in agreement with the hypothesis.

A system of charges or fees for pollutant discharge has been shown to produce a least cost solution in combination with a defined water quality goal, -- for example, a minimum dissolved oxygen level for a stream (Kneese, 1968). Charge systems are strongly advocated by some (Lahey, 1983); Huetteman, 1983), but the goals specified by these advocates appear mixed, and the serious implementaton problems have not been addressed carefully (Rose-Ackerman, 1973).

In other fields of pollution control there have been serious attempts to develop new approaches. Air pollution control seems to have received the most attention (Foster, 1983; Krupnik, 1983). In fact, regulatory reform initiatives are seen as required by the severity and complexity of pollution problems (Drayton, 1979). One of these initiatives, marketable pollution rights, has been suggested as an efficient solution to the river pollution problem (Montgomery, 1972), and has been utilized in at least one specific case (Eheart, 1983). This scheme, after an initial distribution of pollutant discharge licenses, allows dischargers to trade these licenses among themselves if the water quality goals are not thereby violated. Some features of this system seem superior to effluent charges, but there appears to have been no serious attempt to consider how the lessons might apply to the case of ocean dumping.

Some have suggested (Lahey, 1983) the use of charges to increase the costs of ocean disposal until they equal the costs of other alternatives; this would purposely penalize the ocean option and hamper the attempt to find the most efficient solution. A possible approach is to see whether it is desirable to adapt the air pollution concept of an ambient-based permit system, APS, (Kruprik, 1983). This provides "pollution licences" which limit emissions by allowable pollutant concentrations. This could mean specifying water quality goals and/or sediment quality goals, by reference to a low extreme of assimilative capacity. For example, this might mean specifying a low limit of dissolved oxygen for near bottom conditions during summer months in Massachusetts Bay. Such specifications for several areas, excluding the use of shell fishing areas, etc., might tend toward an efficient multi-medium solution, but the help of economists seems needed to address the cross comparisons among the options (which presently seem to be composting, incineration, and ocean disposal).

Environmental Considerations

The reduction of the biochemical oxygen demand (BOD) is one of the serious considerations in designing sewage treatment facilities for inland situations where the effluent is discharged into a river. For ocean discharge, this assimilative capacity consideration is not the same, since with reasonable mixing conditions the dissolved oxygen content (DO) of the water column will not be significantly reduced, and the biota will not be endangered from this particular direct cause. However, if excessive phytoplankton growth is stimulated by added nutrients, the near bottom DO conditions can become dangerous because the bacteria use up the oxygen when they act on the dead cells which settle to the bottom. This condition is most likely to be serious during summer months when the waters are stratified and there is little vertical mixing (Redfield, 1958; Ryther, 1971).

The choice of treatment level affects oxygen consumption in several ways. Primary treatment facilities remove a portion of the suspended solids in the sewage by simple sedimentation processes; approximately 60 percent of the suspended solids are removed thereby reducing the BOD by 30 percent. Secondary treatment adds a biological reduction step which significantly increases the solids removal, and has an even larger effect on the BOD. However, the biological treatment results in a higher level of inorganic nutrients in the effluents; in this form the nutrients are more available for phytoplankton growth with the possible undersirable effects of decreasing the summer near bottom DO conditions (Officer, 1977; Nixon, 1975). The additional solids removal has two additional but desirable effects. A large percentage of many of the contaminants present in the sewage adsorb to particles and are thereby removed. Also, the smaller solids content in the effluent will cause reduced settling and accumulation of these solids in the vicinity of the outfall pipe, and the zone of sediments and benthos impacted by the discharge should be reduced. These contrasting effects provide a tradeoff, and if limiting conditions for the granting of licenses were specified, as already suggested, it would be possible to direct research toward rational design methods. At present, the conditions for granting a waiver of secondary treatment are loosely stated.

Regarding the possible disposal of the sludge resulting from the sewage treatment, little attention is presently being given to pipeline discharge except for the Southern California containment proposal (Brooks, 1982). While the oceans are seen as a good dispersal medium (Kamlet, 1981), better initial dilution and thereby better spreading can be achieved by barge discharge. Initial dilution factors for pipeline diffusers can be somewhat more than 100, but dilution factors for barge dispersal are commonly near 1000 (NOAA, 1981). Also, consideration of barge discharge is not tied economically to the near coastal zone as tightly as pipeline discharge.

Particulates

To aid in the design of minimum impact disposal systems, more research attention should be given to predicting the effect of sewage associated particulates. While, in a general way, the kinds of sediment changes associated with accumulation of sewage associated solids are known, the settling characteristics of these particles in seawater are poorly understood. For example, near the Southern California outfalls, the accumulations appear to account for only a small percentage of the discharged solids (Herring, 1980; Mearns, 1981). Some laboratory studies on the nature and characteristics of sludge have been done (Gibbs, 1982; Faisst, 1980). The limitations of these studies are recognized, however, since coagulation of small particles is an important mechanism controlling the settling rate, and the turbulence present in seawater would produce very different conditions from the laboratory (Morel, 1980). It is reasonable to expect existing waste discharge sites to become the focus of the work of the field experimentalist in explaining and predicting the fate of organic compounds in the ocean.

Another interest in particulates stems from the fact that for the most part, the contaminants are not present in the dissolved state, but rather they attach themselves by various mechanisms to the particulates (Olsen, 1982). More fundamental research is needed on the geochemical processes of attachment and release as well as those processes which affect particle dynamics. This knowledge is needed also for the careful assessment of methods for handling contaminated sediments without releasing the contaminants in a dangerous way.

Benthic Effects

Although methods are being refined for studying pollution induced changes in the benthic community, (Hargrove, 1983) at present this does not seem to be a high priority area from the decision making viewpoint. Increased knowledge of benthic ecosystem development and change is certainly important for other reasons, but these effects apparently can be kept localized, and unless shellfisheries are located in the dumping area (not likely) adverse effects on commercial fish species have not been shown.

Experimental Methods - Controlled Ecosystems

Bioassay or standard toxicity testing may continue to be utilized by regulatory agencies, but additional research should not be encouraged since there is no correspondence to natural field (oceanic) conditions (White, 1983). Controlled ecosystems or marine microcosms are not suggested as a direct substitute for pollutant effect studies, but careful laboratory studies of specific questions can provide useful insights (Hunt, 1983). When attempting to advance our knowledge concerning particulate dynamics, storm mixing effects, the link between the water column and the sediments, bacterial decomposition of sewage, changes in phytoplankton species assemblages due to low level pollutant effects, etc., microcosm studies should prove useful. Although care is needed in formulating the experiments and interpreting the results, because there is not scientific agreement that it is in principle possible to track the natural system well this way, more effort to advance the state-of-the-art of these methods is warranted (Davis, 1979; Oviatt, 1981; Pilson, 1980; Steele, 1979; Zeitzschel, 1978).

Trace Metals

Evidence to date suggests that the disposal of trace metals in sewage does not pose an environmental threat. Except for organic forms such as methyl mercury, metals do not increase with trophic level in the fisheries and there is no rise in the body burden of metals for the larger invertebrates near discharge areas as compared to control areas (Bascom, 1983; Brown, 1983; Morel, 1980). The concern over trace metals at this point seems to be that they may play a role in controlling planktonic species assemblages, and small enrichments resulting from waste discharges may have a subtle but important impact on the nature of the local flora and fauna (Morel, 1980). This is a difficult long term research problem, and the effects, if real, are perhaps more pertinent to areas in which the metal enrichment is maintained, (near a pipeline discharge point) than in areas only periodically enriched by dumping.

Human Pathogens

Discharge of the effluent from sewage treatment plants into ocean or estuarine waters will undoubtedly continue to be the most common way for disposing of wastes for coastal cities. Raw sewage also reaches these waters in some locations through overflows from combined sewer systems in some of the older cities and incomplete sewage treatment networks. The possibility of human disease outbreaks associated with water recreation or contamination of food, especially shellfish, therefore exits; and guidelines for the microbiological quality of effluents, as well as the quality of waters near bathing beaches and shellfish beds, are needed (Bonde, 1974; Mosley, 1974). The most commonly used indicator of contamination is fecal coliform density, and judging by the low incidence of disease outbreaks in this country this index has served us well in recent years. However, the present guidelines are imperfect, as illustrated by recent studies in the New York area which show an increased rate of swimming-associated gastroenteritis at beaches with "barely acceptable" water quality. The search for better indicators and guidelines continues, with many of the current studies sponsored by the USEPA (Cabelli, 1979, 1982).

Although the connection of disease with sewage effluent discharge via nearshore pipelines can be made, beach contamination from pathogens associated with sewage sludge dumping via barge, even at the nearshore, 12-mile, site in New York has not been shown. As in the case of trace metals and chemical contaminants such as halogenated hydrocarbons, enteric bacteria and viruses associated with sewage effluent and sludge are mostly associated with particulates. Bacteria, for example, included in grease balls and other particles are apparently protected from chlorination in the sewage treatment facilities, and survive some time in the ocean (Bracewell, 1980). Most of the particulates settle slowly, and sewage-associated bacteria as well as viruses are found in the sediments near sewage outfalls and sludge dumping sites. Chemical and biological activity in seawater tend to deactivate viruses quickly (Mitchell, 1969), although some can retain their infectivity while attached to organic particulates (Schaub, 1975). Careful studies made at the time of the 1976 "floatable crisis" showed that the bacteria count for the debris on the beach was not high, and only a small percentage of that debris could have arrived from the sludge dumping location (Swanson, 1978).

Sewage outfalls, also, can be designed to minimize the possibility of beach contamination, as shown by the fact that beach closure has rarely been necessary in the Los Angeles area since the new multiple-port diffuser systems have been used. The main concern for human health stemming from enteric bacteria, viruses, and other human pathogens is contaminated shellfish (Squires, 1983; Dufour, 1983). From the standpoint of sewage sludge dumping, since this will undoubtedly never be allowed close to shore or in a commerical shellfishing area, human pathogens do not seem to be a critical concern.

Strategies, Predictions, and Monitoring

There have been a few attempts to begin to formulate strategies which might guide site selection and permit requirement conditions for ocean disposal. This kind of effort has probably been subdued by the official policy to stop all dumping activites. One of these attempts is philosophical/ecological in nature, and is based on the concept of diversity, as well as the continual limitations of human knowledge (Bella, 1972; Odum, 1969). Another of its tenets, i.e. a need to insure future flexibility of action relates well to more recent thoughts which suggest advantages to multiple site operations (Swanson, 1983). There may, for example, be seasonal disadvantages to a relatively nearshore site (summer stratification and/or beach use), and shifting sites might compensate for a present inability to calculate what constitutes nutrient overloading related to sediment conditions.

Assuming that at some future time regulations may be eased to allow equal consideration of the ocean option for disposal, it will be necessary to develop various models to predict the environmental effects for each site. At present, this capability is very limited. Gross simplications are generally used, such as assuming all pollutants remain in the dissolved state (Paul, 1983; O'Connor, 1983); the finfish reside permanently within the upper mixed layer of the "polluted" zone; none of the organics which reach the bottom will have been oxidized, etc. This seems to be to an effort to state a "worst case", but when the assumptions are so much at variance with present knowledge they can be misinterpreted or misused unless the related knowledge and present confidence limits are clearly stated. Modelling capability related to the fate of the organic particulates needs considerable attention, as already noted. Will the degradation rates relate to nutrient regeneration conditions for phytoplankton? For example, whereas a high percentage of the primary production reaches the bottom in shallow waters, only a very small percentage reaches the bottom in deep ocean waters (Zeitzshel, 1979). There are bits of evidence to substantiate a similar speculation for sewage particulates, e.g. the fact that after years of dumping industrial wastes at the 106 mile dumpsite, there is no evidence that any of it has reached the bottom, (NOAA, 1981), although, of course, other conditions such as the long settling times and resultant spreading complicate monitoring (Dollar, 1982).

Accepting the limitations of knowledge and other uncertainties, it is clear that monitoring programs will always be required. Compliance monitoring should be minimized (NOAA, 1981) and the intensity of monitoring should be reduced when a more or less steady state condition is reached (Segar, 1982). The best reason for scientific studies related to ongoing disposal activities, outside of providing data for reassuring the various interested publics, is to improve future decision making by validating the models and assumptions which were used (Rago, 1983; Norton, 1983). Careful development of models leads to specification of testable hypotheses directly linked to the objective of impact assessment. Research programs such as Sea Grant should concentrate solely on this type of activity.

Summary and Recommended Sea Grant Activity

All areas of active research and environmental concerns have not been reviewed above, of course. A broad brush approach has been used with an effort to note important niches that the uniqueness of the Sea Grant College Program might try to fill. For example, the persistent toxic chemical problem (e.g. PCBs) has been largely passed over, as has the subject of the response of organisms to stress (Capuzzo, 1981). It seems that it will be impossible in the near future to prevent all entry of persistent pollutants into the global environment. The reduction of the ocean inputs can probably best be accomplished through source control. At the present time, for example, the greatest input of PCBs to the ocean in the Los Angeles area is atmospheric and not from the large ocean sewage outfalls (Mearns, 1981). Research on the effects of low levels of pollutants on organisms will continue, since important ecological knowledge would be expected. However, this is basically long term work.

Increased Sea Grant attention in the following areas should prove most useful to decision makers.

1. In the near future, it is likely that sewage treatment and disposal issues will be analyzed on a case-by-case, multi-medium management basis, on the assumption that the best solution on both environmental and economic grounds will vary from one region to another. The socio-political factors, however, are also region dependent, and produce as many constraints on the ultimate solution as do the economic and scientific factors. Workshops and symposia can serve the purpose of focussing the attention of social scientists on these issues, and outlining the most fruitful directions for research. The goals for the research program should be the formulation of useful conflict avoidance and conflict resolution methods.
2. Likewise, workshops or symposia might attract resource economists to the careful study of multi-medium management.
3. Research should be directed toward the development of models for predicting the fate and effects of sewage particulates in the ocean environment. This includes degradation, ingestion by marine organisms, and also the geochemistry of pollutant attachment and release.
4. Models should be tested carefully in the laboratory, and whenever possible, verified by experiments conducted in actual sewage particulate fields in the ocean. Experimental work should be limited to the testing of hypotheses and the validation of models already developed.

REFERENCES

Akin, E.A. et. al. 1971. "Enteric Viruses in Ground and Surface Waters: A Review of their Occurrence and Survival." Proc. 13th Water Quality Conference. U. of Ill., Urbana.

Akin, E.A. et. al. 1974. "Mortality of Enteric Viruses in Marine and Other Waters." Inter. Symposium Discharge of Sewage from Sea Outfalls. London, England.

Anderson, F.R. et al. 1977. Environmental Improvement through Economic Incentives. Johns Hopkins University Press, Baltimore.

Bacow, L.S. 1982. "Exploring Environmental Impacts: Beyond Quantity to Quality." Technology Review. Vol. 85, No. 1.

Bascom, W. 1983. "The Disposal of Sewage Sludge in Coastal Waters via Outfalls." Intern. Ocean Disposal Symposium. Ocean Waste Management: Policy and Strategies. University of Rhode Island.

Bascom, W. 1983. "The Non-Toxicity of Metals in the Sea." Marine Technology Society Journal. Vol. 17, No. 1.

Bella, D.A. and W.S. Overton. 1972. "Environmental Planning and Ecological Possibilities." J. Sanitary Engineering Division, ASCE. Paper No. 8994. SA3.

Berg, G. 1971. "Integrated Approach to Problems of Viruses in Water." J. Sanitary Engineering Division, ASCE. SA6.

Boesch, D.F. and M. H. Roberts. 1983. "Biological Effects." Ocean Disposal of Municipal Wastewater: Impacts on the Coastal Environment. E. P. Myers and E. T. Harding (eds.), MIT Sea Grant College Program, Cambridge, MA.

Bonde, G.J. 1974. "Bacterial Indicators of Sewage Pollution." Intern. Symposium Discharge of Sewage from Sea Outfalls. London, England.

Bracewell, L.W. et al. 1980. "Contribution of Wastewater Discharges to Ocean Surface Particulates." Water Pollution Control Federation. 52: 2230-2245.

Brooks, N.H. et. al 1982. Deep Ocean Disposal of Sewage Sludge off Orange Country, California: A Research Plan. EQL Report No. 21. California Institute of Technology. Pasadena.

Brooks, N.H. 1982. "Evaluation of Key Issues and Alternative Strategies." Ocean Disposal of Municipal Wasterwater: Impacts on the Coastal Environment, Vol. 2. E. P. Myers and E. T. Harding (eds.) MIT Sea Grant College Program, Cambridge, MA.

Brown, D.A. et. al. 1983. "Bioaccumulation and Detoxification of Contaminants in Marine Organisms from Southern California Coastal Waters." Waste Disposal in the Oceans: Minimizing Impact, Maximizing Benefits. D.F. Soule and D.Walsh (eds.) Westview Press, Boulder, Colo.

Cabelli, V.J. 1978. "Swimming Associated Disease Outbreaks." J. Water Pollution Control Federation. June.

Cabelli, V.J. et al. 1979. "Relationship of Microbial Indicators to Health Effects at Marine Bathing Beaches." Am. Journal of Public Health, Vol. 69, No. 7.

Cabelli, V.J. 1982. Predicted Swimming Associated Gastroenteritis at New York Bight Bathing Beaches. "Oceans '82 Conference Proceedings. Washington, D.C.

Calvert, J.T. 1974. "The Case Against Treatment". Intern. Symposium Discharge of Sewage from Sea Outfalls. London, England.

Capuzzo, J.M. 1981. "Predicting Pollution Effects in the Marine Environment" Oceanus Vol. 24, No. 1.

Champ, M.A. and P.K. Park, 1981. "Ocean Dumping of Sewage Sludge -A Global Review." Sea Technology. Vol. 22, No.2

Champ, M.A. and P.K. Park, 1982. Global Marine Pollution Bibliography: Ocean Dumping of Municipal and Industrial Wastes. IFI Plenum. New York.

Commonwealth of Massachusetts. Metropolitan District Commission. 1983 Application for Modification of Secondary Treatment Requirements for its Deer Island and Nut Island Effluent Discharge into Marine Waters

Commonwealth of Massachusetts. Superior Court Civil Action No.138477. 1983 Report of the Special Master Regarding Findings of Fact and Proposed Remedies.

Council on Environmental Quality. 1970. Ocean Dumping: A National Policy. U.S. Government Printing Office. Washington, D.C.

Dales, J.H. 1968 Pollution, Property, and Prices. University of Toronto Press

Davies, J.M. and J. C. Gamble. 1979. "Experiments with Large Enclosed Ecosystems." Phil. Trans. R. Soc. Lond. B.286, 523-544.

Devine, M. 1983 "Analysis of Mixing and Dispersion of Dumped Industrial Waste at U.S. Deep Ocean Disposal Sites: Review and Recommendations" 4th Intern. Ocean Disposal Symposium Plymouth, England

Dollar, S.J. 1982. "Sand Island, Oahu: Assimilation Capacity at a Tropical Ocean Outfall." Oceans '82 Conference Proceedings Washington, D.C.

Drayton, W. Jr. 1979. "A Tougher Job Requires Smarter Regulation." Regulatory Reform Initiatives: Progress Report - October 1979. USEPA Office of Planning and Management. Washington, D.C.

Dufour, A. and V. Cabelli. 1983. "The Risk of Infectious Disease Associated with the Marine Environment." Symposium on the Effects of Waste Disposal on Kelp Communities. La Jolla, California.

Eheart, J.W. et al. 1983. "Transferable Discharge Permits for Control of BOD: An Overview." Buying a Better Environment Joeres, E.F. and M.H. David (eds.) University of Wisconsin Sea Grant College Program Technical Report No. 239.

Faisst, W.K. 1980. "Characterization of Particles in Digested Sewage Sludge." Particles in Water: Characterization, Fate, Effects and Removal. Am. Chemical Society. Washington, D.C.

Farrington, J.W. et al. 1982. "Ocean Dumping" Oceanus. Vol. 25, No.4

Feliciano, D.V. 1981. "Sludge: Back into the Ocean?" J. Water Pollution Control Federation Vol. 53., No. 10

Foster, D. 1983. "Planning for the Development of Economic Incentives Under Institutional Constraints: The Role for Guided Incrementalism." Buying a Better Environment Joeres, E.F. and M.H. David (eds) University of Wisconsin Sea Grant College Program Technical Report No. 239

Gentile, J.H. et al. 1983. "A Hazard Assessment Research Strategy for Ocean Disposal: Concepts and Case Studies." Intern Symposium Ocean Waste Management: Policy and Strategies Univ. of Rhode Island

Gibbs, R.J. 1982. "Particle Dynamics of Sewage Sludge Dumping in the Ocean." Oceans '82 Conference Proceedings. Washington, D.C.

Goldberg, E.D. 1981. "The Oceans as Waste Space: The Argument." Oceanus. Vol. 24, No.1

Gunnerson, C.G. et al. 1982. "Management of Domestic Wastes". Ecological Stress and the New York Bight: Science and Management. Mayer, G.F. (ed.) Estuarine Research Federation. Columbia, S.C.

Hargrave, B.T. and H. Thiel. 1983. "Assessment of Pollution Induced Changes in Benthic Community Structure." Marine Pollution Bulletin Vol. 14, No.2

Haydock, I. and J. Stull. 1982. "Southern California POTW Strategies Under EPA's 301(h) Waiver Program." Oceans '82 Conference Proceedings Washington, D.C.

Herring, J.R. 1980. "Wastewater Particle Dispersion in the Southern California Offshore Region." Particles in Water: Characterization, Fate, Effects, and Removal. Am. Chemical Society. Washington, D.C.

High Voltage Engineering Corporation. 1979. A Proposal for Ocean Feeding of Electron Disinfected Sewage Sludge for its Nutritive Benefit. Prepared for Office of Water and Hazardous Materials. EPA. Washington, D.C.

Huetteman, T.J. et al. 1983. "Comparing the Costs and Risks of Ocean Versus Land-Based Sludge Management Alternatives for Nassau County." Intern. Ocean Disposal Symposium. Ocean Waste Management: Policy and Strategies. University of Rhode Island.

Hunt, C.D. 1983. "Ocean Dumping: Can Controlled Marine Ecosystems Aid in the Development of Site Selection Criteria?" Intern. Ocean Disposal Symposium Ocean Waste Management: Policy and Strategies. University of Rhode Island.

Jackson, G.A. et al. 1979. Assessment of Alternative Strategies for Sludge Disposal into Deep Ocean Basins Off Southern California. EQL Report No.14 California Institute of Technology.

Jenkinson, I.R. 1972. "Sludge Dumping and Benthic Communities." Marine Pollution Bulletin. 3:102-105.

Kamlet, K.S. 1981. "The Oceans as Waste Space: The Rebuttal." Oceanus. Vol. 24, No.1.

Kamlet, K.S. 1983. "Ocean Dumping Regulation: Issues and Approaches." Intern. Ocean Disposal Symposium. Ocean Waste Management: Policy and Strategies. University of Rhode Island.

Kitsos, T.R. et al. 1983. "The Structure of Congress: Toward an Explanation of the Struggle for an Ocean Dumping Policy." Intern. Ocean Disposal Symposium. Ocean Waste Management: Policy and Strategies. University of Rhode Island.

Knauss, J.A. 1982. "Can We Safely Dispose of Our Wastes in the Ocean?" University of Rhode Island, Maritimes. Vol. 26, No. 3.

Kneese, A.V. and B.T. Bower. 1968. Managing Water Qualtiy: Economics, Technology, Institutions. Johns Hopkins University Press. Baltimore.

Kneese, A.V. and C.L. Schultze. 1975. Pollution, Prices, and Public Policy. Brookings Institution. Washington, D.C.

Krupnik, A.J. et al. 1983. "On Marketable Air Pollution Permits: The Case for a System of Pollution Offsets." Buying a Better Environment. Joeres, E.F. and M.H. David, (eds.) University of Wisconsin Sea Grant College Program Technical Report No. 239.

Lahey, W. L. 1982. "Ocean Dumping of Sewage Sludge: The Tide Turns from Protection to Management." Harvard Environmental Law Review. Vol. 6, No.2.

Lahey, W.L. and M. Connor. 1983. "The Case for Ocean Waste Disposal." Technology Review August/September.

Lahey, W.L. 1983. "Pricing Mechanisms for Ocean Dumping: A Viable Regulating Tool." Intern. Ocean Disposal Symposium. Ocean Waste Management: Policy and Strategies University of Rhode Island.

Massachusetts Institute of Technology Marine Industry Collegium. 1977 Electron Irradiation, Sewage Sludge and Aquaculture

Massachusetts Institute of Technology Marine Industry Collegium. 1983. Wastewater Management: Technical Alternatives and Regulatory Outlook.

McIntyre, A.D. 1977. "Effects of Pollution on Inshore Benthos." Ecology of Marine Benthos. B.C. Coull, (ed.). University of South Carolina Press.

McKay, D.W. et al. 1972. "Sludge Dumping in the Firth of Clyde " Marine Pollution Bulletin. 3:7-10.

Mearns, A.J. 1981 "Effects of Municipal Discharges on Open Coastal Ecosystems " Marine Environmental Pollution, 2. R.A. Geyer, (ed.). Elsevier Oceanography Series. Amsterdam.

Mearns, A.J. 1981. "Ecological Effects of Ocean Sewage Outfalls: Observations and Lessons." Oceanus. Vol. 24, No. 1.

Menzie, C.A. et al. 1983. "An Assessment of Research Needs Related to Future Ocean Disposal of Wastes." Intern. Ocean Disposal Symposium. Ocean Waste Management: Policy and Strategies. University of Rhode Island.

Mitchell, R. and H.W. Jannasch. 1969. "Processes Controlling Virus Inactivation in Seawater." Environmental Science and Technology. Vol. 3, No. 10.

Mitchell, R. and C. Chamberlain. 1974. "Factors Influencing the Survival of Enteric Microorganisms in the Sea: An Overview." Intern. Symposium. Discharge of Sewage from Sea Outfalls. London, England.

Montgomery, W.D. 1972. "Markets in Licenses and Efficient Pollution Control Programs." Journal of Economic Theory. 5, 395-418.

Morel, F.M.M. and S. L. Schiff. 1980. Geochemistry of Municipal Waste in Coastal Waters. Dept. of Civil Engineering, Massachusetts Institute of Technology, Report No. 259.

Mosley, J.W. 1974. "Epidemiological Aspects of Microbial Standards for Bathing Beaches." Intern. Symposium. Discharge of Sewage from Sea Outfalls. London, England.

Murchelano, R.A. and J. Ziskowski. 1982. "Fin Rot Disease in the New York Bight (1973-1977). "Ecological Stress and the New York Bight: Science and Management. Mayer, G.F. (ed.) Estuarine Research Federation. Columbia, S.C.

Murray, J.P. and G.A. Parks. 1980. "Poliovirus Adsorption on Oxide Surfaces." Particles in Water: Characterization, Fate, Effects, and Removal. Am. Chemical Society. Washington, D.C.

Mytelka, A.I. et al. 1982. "Management of Industrial Wastes." Ecological Stress and the New York Bight: Science an Management. Mayer, G.F. (ed.) Estuarine Research Federation. Columbia, S.C.

National Academy of Sciences. National Research Council. 1976. Disposal in the Marine Environment: An Oceanographic Assessment. Washington, D.C.

National Academy of Sciences. National Research Council. 1978 Multimedium Management of Municipal Sludge. Washington, D.C.

National Advisory Committee on Oceans and Atmospheres. 1981. The Role of the Ocean in a Waste Management Strategy: A Special Report to the President and the Congress. Washington, D.C.

National Oceanic and Atmospheric Administration. 1981. An Assessment of Great Lakes and Ocean Pollution Monitoring in the United States. Office of Marine Pollution Assessment. Boulder, Colorado.

Nixon, S.W. et al. 1975. "Nitrogen Regeneration and the Metabolism of Coastal Marine Bottom Communities." The Role of Terrestrial and Aquatic Organisms in Decomposition Processes. Blackwell Scientific Publishers.

Nixon, S.W. et al. 1979. "Phosphorous Regeneration and the Metabolism of Coastal Marine Bottom Communities." 11th Belle W. Baruch Symposium in Marine Science. Marine Benthic Dynamics. University of South Carolina Press.

National Oceanic and Atmospheric Administration. 1976. Evaluation of Proposed Sewage Sludge Dumpsite Areas in the New York Bight. NOAA Marine Ecosystems Analysis Program Office. Boulder, Colo.

National Oceanic and Atmospheric Administration. 1976. Contaminant Inputs to the New York Bight. Boulder, Colo.

National Oceanic and Atmospheric Administration. 1979. Assimilative Capacity of U.S. Coastal Waters for Pollutants. NOAA Environmental Research Laboratories. Boulder, Colo.

National Oceanic and Atmospheric Administration. 1981. Assessment Report on the Effects of Waste Dumping in 106-mile Ocean Waste Disposal Site: Dumpsite Evaluation Report 81-1. NOAA Office of Marine Pollution Assessment. Boulder, Colo.

National Oceanic and Atmospheric Administration. 1982. Summary of the Physical Oceanographic Processes and Features Pertinent to Pollution Distribution in the Coastal and Offshore Waters of the Northeastern United States, Virginia to Maine. NOAA-NMFS Northeast Fisheries Center. Woods Hole, Mass.

National Science Foundation et al. 1978. Sludge Management Planning in the Boston Metropolitan Area - A Case Study. Draft Final Report of Joint Agency Sponsored Study. Washington, D.C.

Norton, M.G. 1978. "The Control and Monitoring of Sewage Sludge Dumping at Sea." Water Pollution Control. 77:402-407.

Norton, M.G. 1981. "The Oslo and London Dumping Conventions." Marine Pollution Bulletin. Vol. 12, No. 5.

Norton, M.G. 1983. "Experiences in the United Kingdom on the Control of Discharge of Sewage Sludge to Estuarine and Coastal Waters, A Case Study. Ocean Disposal of Municipal Wastewater: Impacts on the Coastal Environment. E. P. Myers and E. T. Harding (eds.), MIT Sea Grant College Program, Cambridge, MA.

Norton, M.G. and M. A. Champ. 1983. "The Influence of Site Specific Characteristics in Determining the Effects of Sewage Sludge Dumping." 4th International Ocean Disposal Symposium. Devon, England.

Oates, W.E. 1981. "Corrective Taxes and Auctions of Rights in the Control of Externalities: Some Further Thoughts." Public Finance Quarterly. Vol. 9, No. 4.

O'Connor, J.S. and L. Swanson. 1982. "Unreasonable Degradation of the Marine Environment - What is it?" Oceans '82 Conference Proceedings. Washington, D.C.

O'Connor, T.P. et al 1983. "Projected Consequences of Dumping Sewage Sludge at a Deep Ocean Site Near New York Bight." Canadian Journal of Fisheries and Aquatic Sciences. Vol. 40, Supplement 2.

Odum, E.P. 1969. "The Strategy of Ecosystem Development." Science. Vol. 164.

Officer, C.B. and J.H. Ryther. 1977. "Secondary Sewage Treatment Versus Ocean Outfalls: An Assessment." Science. 197: 1056-1060.

O'Leary, W.A. 1959. "New York Sludge Goes to Sea - or to Parks." Civil Engineer. Vol. p. 242.

Olsen, C.R. et al. 1982. "Pollutant-Particle Associations and Dynamics in Coastal Marine Environments: A Review." Marine Chemistry, 11. Elsevier Scientific Publishing Company. Amsterdam.

Oviatt, C.A. et al. 1981. "Simulation of a Storm Event in Marine Microcosms." Journal of Marine Research. Vol. 39, No. 4.

Paul, J.F. et al. 1983. "Hazard Assessment Evaluation for Water Disposal at Deepwater Dumpsite 106." 4th International Ocean Disposal Symposium. Plymouth, England.

Paul, J.F. et al. 1983. "Probabilistic Approach for the Determination of the Potential Area of Influence for Waste Disposal at the 106-mile Ocean Disposal Site." 106-mile Waste Disposal Site Characterization Update Report. NOAA Technical Memorandum. Pearce, J.B. and D.C.Miller. (eds.)

Pearson, E.A. 1974. "Conceptual Design of Marine Waste Disposal Systems." International Conference. Discharge of Sewage from Sea Outfalls. London, England.

Pilson, M.E.Q. and S.W. Nixon, 1980. "Marine Microcosms in Ecological Research." Microcosms in Ecological Research. Technical Information Center, U.S. Department of Energy, Washington, D.C.

Quinn, R.J. and T. M. Leschine. 1983. "How Can Decision Analysis Aid the Process of Selecting Sites for Future Ocean Disposal Activities?" Intern. Ocean Disposal Symposium. Ocean Waste Management: Policy and Strategies. University of Rhode Island.

Rago, P.J. et al. 1983. "Assessing Impacts of Power Plants on Fish Populations: A General Strategy." Environmental Monitoring and Assessment. D.Reidel Publishing Co.

Redfield, A.C. 1958. "The Biological Control of Chemical Factors in the Environment." American Scientist.

Rose-Ackerman, S. 1973. "Effluent Charges" A Critique." Canadian Journal of Economics. Vol. 6, No. 4.

Rosenberg, M.L. 1976. "Shigellosis from Swimming." J. American Medical Association. Vol. 236, No. 16.

Rowe, G.T. et al. 1975. "Benthic Nutrient Regeneration and Its Coupling to Primary Productivity in Coastal Waters." Nature. Vol. 255.

Rowe, G.T. 1982. "Deep Ocean Disposal of Toxic Industrial Wastes." Oceans '82 Conference Proceedings. Washington, D.C.

Ryther, J.H. 1971. "Nitrogen, Phosphorus, and Eutrophication in the Coastal Marine Environment." Science. Vol. 171.

Sax, J.L. 1971. Defending the Environment: A Strategy for Citizen Action. Alfred A. Knopf. New York.

Schaub, S.A. and B. P. Sagik. 1975. "Associatin of Enteroviruses with Natural and Artificially Introduced Colloidal Solids in Water, and Infectivity of Solids-Associated Virions." Applied Microbiology. Vol. 30, No. 2.

Schwabacher, R.A. and H.S. Bolton. 1982. "The Tragedy of the Oceans: The 1981 Deadline Revisited." Oceans '82 Conference Proceedings. Washington, D.C.

Segar, D.A. 1982. "Ocean Waste Disposal Monitoring - Can It Meet Management Needs?" Oceans '82 Conference Proceedings Washington, D.C.

Shelton, R.G.J. 1971. "Sludge Dumping in the Thames Estuary." Marine Pollution Bulletin. 2:24-27.

Shelton, R.G.J. 1973. "Some Effects of Dumped, Solid Wastes on Marine Life and Fisheries." North Sea Science. Goldberg, E.D. (ed.) MIT Press, Cambridge.

Sindermann, C.J. et al. 1982. "Effects of Pollutants on Fishes." Ecological Stress and the New York Bight: Science and Management. Mayer, G.F. (ed.) Estuarine Research Federation. Columbia, S.C.

Smith, K.L.,Jr. et al. 1978. "Nutrient Exchange and Oxygen Consumption By Deep-Sea Benthic Communities: Preliminary In-Situ Measurements." Limnolog. Oceanogr. 23(5).

Springer, A,L. 1983. The International Law of Pollution: Protecting the Global Environment in a World of Sovereign States. Quorum Books. Westport, Connecticut.

Squires, D.F. 1983. The Ocean Dumping Quandary: Waste Disposal in the New York Bight. State University of New York Press. Albany.

Steele, J.H. 1979. "The Uses of Experimental Ecosystems." Phil. Trans. R. Soc. Lond. B.286, 583-595.

Stone, E.M. et al. 1971. "A Waterborne Epidemic of Salmonellosis in Riverside California, 1965: A Collaborative Report." American Journal of Epidemiology. Vol. 93, No.1.

Susskind, L. and A. Weinstein. 1982. "How to Resolve Environmental Disputes Out of Court." Technology Review. Vol. 85, No.1.

Susskind, L.E. 1978. Resolving Environmental Disputes: Approaches to Intervention, Negotiation, and Conflict Resolution. Environmental Impact Assessment Project. Laboratory of Architecture and Planning. MIT.

Swanson, R.L. and G. F. Mayer, 1983. "Steps Toward Improving Sewage Sludge Dumping." Intern. Ocean Disposal Symposium. Ocean Waste Management: Policy and Strategies. Univ. of Rhode Island.

Swanson, R.L. et al. 1978. "June, 1976 Pollution of Long Island Ocean Beaches." J. Environmental Engineering Division. ASCE. December

Swanson, R.L. and M. Devine. 1982. "The Pendulum Swings Again - Ocean Dumping Policy." Environment. Vol. 24, No. 5.

Swanson, R.L. et al. 1983. Sewage Sludge Dumping in the New York Bright Apex: A Comparison with Other Proposed Ocean Dumpsites. National Oceanic and Atmospheric Administration. Rockville, MD

UNESCO. Joint Group of Experts on the Scientific Aspects of Marine Pollution. 1982. The Review of the Health of the Oceans. United Nations, New York.

United States Environmental Protection Agency, 1977. Effects of Ocean Dumping Activity, Mid-Atlantic Bight - 1976. Interm Report. Lear, D. W. et al. (eds.) USEPA Region III. Philadelphia, PA.

United States Environmental Protection Agency. 1979. Comprehensive Sludge Study Relevant to Section 8002(g) of the Resource Conservation and Recovery Act of 1976. Office of Water and Waste Management. Washington, D.C.

United States Environmental Protection Agency. 1979. Final Environmental Impact Statement on the MDC Proposed Sludge Management Plan, Boston, MA. USEPA Region I, Boston.

United States Environmental Protection Agency. 1980. Physical Chemistry of Virus Adsorption and Degradation on Inorganic Surfaces: Its Relation to Wastewater Treatment. USEPA Municipal Environmental Research Laboratory. Cincinnati.

United States General Accounting Office: 1977. Problems and Progress in Regulating Ocean Dumping of Sewage Sludge and Industrial Wastes. CED 77-18.

Vaccaro, R.F. et al. 1981. "The Oceans and U.S. Sewage Disposal Strategy." Oceanus, Vol. 24, No. 1.

Walsh, J.P. 1981. "U.S. Policy on Marine Pollution: Changes Ahead." Oceanus, Vo. 24, No. 1.

Watling, L. et al. 1974. "Evaluation of Sludge Dumping Off Delaware Bay." Marine Pollution Bulletin 5: 39-42.

Wellman, K.F. 1982. "The Ocean Dumping Problem: Why So Difficult?" Aquasphere. Vol. 16, No. 3

White, H.H. and M.A. Champ. 1983. "The Great Bioassay Hoax, and Alternatives." Hazardous and Industrial Solid Waste Testing: Second Symposium. ASTM.

Zeitzschel, B. 1978. "Controlled Environment Experiments in Pollution Studies. Ocean Management 4: 319-344.

Zeitzschel, B. 1979. "Sediment-Water Interactions in Nutrient Dynamics: "Marine Benthic Dynamics: 11th Belle W. Baruch Symposium in Marine Science. Univ. of South Carolina Press. Columbia.

Zimmer, R.D. (ed.) 1980. Ocean Dumping: Issues and Answers Concerning Sewage Sludge Disposal. Report of a New Jersey Marine Advisory Service Conference. November.