CONTAINMENT ISLANDS IN NEW YORK HARBOR

Henry J. Bokuniewicz and Robert M. Cerrato

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CONTAINMENT ISLANDS IN NEW YORK HARBOR

ABSTRACT

In this report we will present information which indicates that the construction of large or medium-sized containment islands in New York Harbor is within the present technical ability, that containment can be achieved, and that environmental problems, such as effects on water quality, tidal flushing, and shore erosion, can probably be anticipated and ameliorated by proper design. The cost of such containment facilities is estimated to be between 2 and 3.5 times the cost of open-water disposal. The specific cost and unavoidable environmental impacts, however, cannot be determined until the facility has been designed and the facility cannot be designed until a site is chosen. At the present time, one obstacle to the selection of a site appears to be the presumed adverse ecological impact of the loss of bay floor. There are no standard procedures for assessing changes in those biological resources that are important to man due to the removal of specific areas of the bay floor from the subaqueous ecosystem. With the available data, however, areas of the bay floor may be found that seem to have relatively low population densities. If we assume that such impoverished areas are also relatively less important to the bays ecosystem, then these are the most likely sites for large containment islands. Three sites have been identified in the Lower Bay (Figure 17).

INTRODUCTION

The authors of the Mitre Report (Conner et al., 1979) concluded that the disposal of dredged sediment in containment facilities located in protected waters is a disposal alternative that is possible in special cases. They found that engineering constraints do not limit the use of this disposal alternative although it would undoubtedly be more costly than overboard disposal at nearshore, open-water sites (Conner et al., 1979). Some of the cost may be recovered by use of the land created by these facilities but the economic costs and benefits must also be balanced with environmental impacts. The more important of these impacts are the loss of bay floor, changes in the water circulation, and changes in the water quality. Because of the costs involved and the need for site-specific evaluation of environmental impacts, this alternative does not seem likely to be available for the disposal of large volumes of dredged sediment except in special cases (Conner et al., 1979)

The feasibility of using containment islands in protected shallow water was reviewed in the final environmental impact statement titled "Disposal of Dredged Material from the Port of

New York and New Jersey" (U.S. Army Corps of Engineers, 1983). The authors of this statement determined that containment in protected shallow waters, which includes the use of artificial islands in protected waters, was one of four alternatives to have the capacity to absorb 8 to 10 million cubic yards of dredged sediment annually. (The other alternatives were disposal in subaqueous borrow pits, contained upland disposal, and disposal at an open-water site, called the Mud Dump Site, about 12 miles outside of New York Harbor on the Atlantic shelf.) The adverse environmental impacts included (1) short-term water quality degradation due to construction activity, (2) loss of bottomland resulting in potential changes in the migration routes of finfish and in water circulation patterns, and (3) possible environmental contamination in the event of dike failure (U.S. Army Corps of Engineers, 1983). The authors point out, however, that "it is difficult to evaluate the exact unavoidable impacts which would result from this alternative until a specific project is proposed." They also stress the importance of proper site selection as a means of reducing adverse impacts and suggest that unless revenue could be generated through the use of the site, the alternative may be cost prohibitive (U.S. Army Corps of Engineers, 1983). After completing an analysis of all the alternatives, the authors conclude that "continued use of the Mud Dump is the preferred disposal alternative because the area is in the shellfish closure zone and has been adversely impacted by past dumping activities" (U.S. Army Corps of Engineers, 1983).

Both the Mitre Report (Conner et al., 1979) and the EIS (U.S. Army Corps of Engineers, 1983) contain the conclusion that containment islands in the Atlantic Ocean off the eastern shore of New Jersey or the southern shore of Long Island, NY are not considered feasible at this time. Such offshore islands would be costly and pose legal problems; before this option could be considered feasible the legal questions must be addressed, a mechanism for offsetting the cost must be developed, and the environmental impacts would have to be determined after site selection (U.S. Army Corps of Engineers, 1983).

Our report is a summary of the current information concerning one specific plan for the use of containment facilities--the construction of large or medium-sized diked containment islands in New York Harbor especially in the Lower Bay complex including Sandy Hook Bay and Raritan Bay. We will not attempt to re-invent, or even reassess, the state-of-the-art for building containment islands. The technical literature is already extensive and islands have been successfully constructed elsewhere. Instead we shall concentrate on identifying the critical obstacles to the construction of containment islands in New York Harbor. To do this we shall answer the following questions:

1. How large must the containment islands be?

2. Where should these islands be located?

3. Why must containment islands be diked?

4. Are large or medium-sized containment islands technically feasible?

5. Can these containment islands be designed to be environmentally acceptable?

6. If containment islands are technically feasible and environmentally acceptable, are they societally and politically acceptable at the present time?

7. Where are the most likely sites for containment islands in the Lower Bay complex?

In addressing each of these questions we will carry the analyses only as far as necessary to allow us to proceed to the next question. For example, before implementation, the cost of a containment facility must be calculated accurately and, of course, it will depend on many details of the design. For our purposes, however, it may be adequate to know that, for the types of islands considered here, the cost will be 2 to 3.5 times the cost of open-water disposal at the Mud Dump Site (Conner et al., 1979) and that for any particular design the costs could be estimated with sufficient accuracy to insure an adequate commitment of resources to the project. An example of a more detailed cost estimate is shown in Appendix I for three possible designs of a containment island in the vicinity of Hoffman and Swinburne islands in Lower Bay (Fig. 1, Howard et al., 1976).

HOW LARGE MUST THE CONTAINMENT ISLANDS BE?

There are both economic and technical advantages for large islands. As we just mentioned, the cost of disposal at a containment island is relatively high and without knowing the details of the design, accurate estimates cannot be made. The estimated cost of a proposed containment island at Hoffman and Swinburne islands in the Lower Bay exceeded one billion dollars (Appendix I; Howard et al., 1976). A containment facility in Long Island Sound covering 125 acres and intended to contain 7 to 10 million cubic yards has an estimated cost of $30,000,000 (D. Quinn, as reported by C. Coch, U.S. Army Corps of Engineers, NY District, 1983) and estimates of the cost of building containment sites for contaminated material range from $52,500,000 for a 200-acre site to $140,000,000 for a 500-acre site (C. Coch, per. com., 1983). Factors influencing the cost are the size and shape of the dikes, whether or not rehandling will be necessary, whether or not on-site material can be used for construction, whether or not the site will be lined, and, of course, the length of the perimeter to be diked.

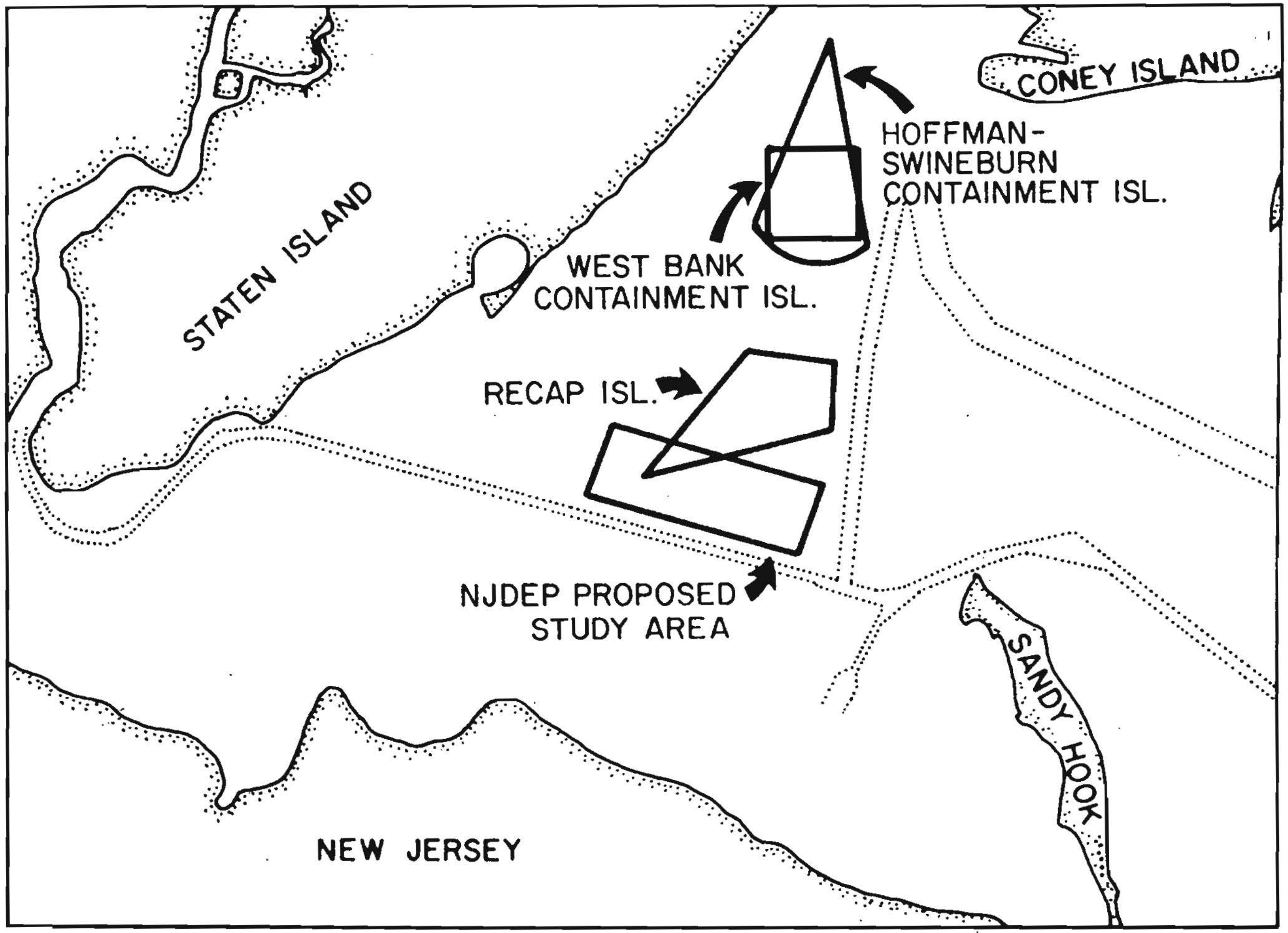


Figure 1. Locations of previously proposed containment islands and study areas.

The principal construction costs would be associated with building the dike. The construction of a dike in Connecticut 45 feet high and 2,500 feet long to withstand 8-foot waves would cost $3,000 per linear foot; a 12-foot dike 4,800 feet long to withstand 4-foot waves would cost $270 per foot (C. Coch, per. com., 1983). The principal cost, therefore, would be proportional to the length of the dike or, in other words, the perimeter of the island. This greatly favors the construction of large islands. One facility covering a square area of 400 acres would have a diked perimeter of 3.2 miles. If four 100-acre sites were constructed, their combined perimeter would be about 6.4 miles or twice as great. If all these hypothetical sites were to be constructed in the same depth of water, containing the dredged sediment in four individual sites, the cost would be twice as much as containing the same volume of dredged sediment in a single large site. In other words, doubling the area covered by the site would increase the cost of the dike by only about 40% or a site with four times capacity could be built for only twice the cost all other factors being equal. This appears to be the principal economic reason for preferring large sites. As a corollary to this argument, if small containment facilities are to be built, it would be advantageous to build peninsulas since by having the site attached to the shore, the diked perimeter could be reduced by about 25% although the capacity per unit area would decrease because the water depth would be less in most cases. The diked perimeter may be reduced by about 75% or more when one dike closes off a bay. The New England Division of the U.S. Army Corps of Engineers has estimated that the smallest cost-effective containment facility must have a capacity of about 300,000 cubic yards (U.S. Army Corps of Engineers, 1980).

In the long term, of course, some of the excess costs can be offset by the final use of the completed containment island. Although it is beyond the scope of this report, and probably premature, to consider what the final use of the newly made land should be, some revenue-creating activity would be desirable whether that activity be industrial or recreational.

There are also certain costs involved with the design and construction that would not be expected to vary much with the size of the island. Since these costs will be incurred in any event, it is clearly advantageous to build as large a facility as possible. Such costs might include the cost of baseline environmental studies and engineering studies, design costs, and the costs associated with obtaining permits, licenses, and certificates. The design costs include the cost of designing the containment dikes, the interior dikes, unloading facilities, and drainage and treatment systems. The magnitude of these costs will depend on the specific containment facility being proposed, but in general, these costs will not necessarily rise in proportion to the size of the proposed facility; and although these costs are not negligible, they would probably be small compared to the construction costs.

There are also technical reasons favoring larger sites. Craney Island in Virginia, although really a containment peninsula rather than an island, is one of the largest and oldest active containment facilities in the United States. Based on the management experience at Craney Island, it has been recommended that containment facilities should be divided internally into at least three compartments (Palermo et al., 1981). Each compartment should be capable of receiving material for one year. In any given year only one compartment would be used; it would then be allowed to consolidate and dewater for the next two years while the other compartments were used. The thinner the annual layers are, the faster they will dewater and consolidate. This procedure, therefore, gives the site its maximum containment potential while maintaining the efficiency of the facility to trap fine-grained particulates during operation.

In the Lower Bay complex, for example, a containment island is likely to be built in water that is at least 18 feet deep. Areas where the water depth is shallower than 18 feet are less desirable because the barges that would be used draw at least about 18 feet when loaded (A. Francis, 1983, Executive Board Member, International Union of Operating Engineers, per. com.). As a result, if at least one point on the perimeter of the containment area was not in water greater than 18 feet deep then an access channel would need to be dredged and the cost of the project would increase. In addition, it is advantageous to build the facility in the greatest water depth available in order to contain the largest volume while covering the smallest area. In the Lower Bay there are few places deeper than 25 feet. For this example, we might assume that the island will be built in water 25-feet deep and that the surface of the island will be built 20 feet above mean low water. This is not unreasonable; the Hart-Miller Island at Baltimore is expected to have a final elevation of 18 feet and Craney Island at Norfolk now has an elevation of 18 feet with plans to raise it to 32 feet. The total thickness of the hypothetical deposit is then 45 feet and an area of 14 acres would be needed for every million cubic yards to be contained. In the New York metropolitan region between 8 and 12 million cubic yards are dredged annually (U.S. Army Corps of Engineers, 1983). If we assume that the facility would contain only the most severely contaminated material, or about 1 million cubic yards annually and that each of three compartments would be used eight times giving the facility a lifetime of 24 years, then at least 336 acres would be needed for the facility. In practice the facility would need to be somewhat larger for two reasons. First, as the compartments near their capacity they become less efficient in trapping fine-grained dredged sediment, and they will need to be allowed to rest and consolidate at more frequent intervals to prevent unacceptably high turbidity in the effluent. The second reason is that the dikes would be sloping walls around the site, although the importance of this consideration depends on the specific design. If the slope of the dikes is 1:2, for example, then to enclose a 336-acre square in water 25 feet deep would cover a total area of a little more than 350 acres. If the slope of the dikes is 1:30, however, then to enclose a 336-acre square in water 25 feet deep would cover a total area of at least 600 acres. In any event, it seems clear that a containment island in Lower Bay would have to cover at least several hundred acres. Furthermore, there are good economic reasons for such a large facility.

There are many precedents for diked containment facilities of this size. Craney Island, VA, covers 2,500 acres and has been in use for 25 years (Palermo et al., 1981). At Pointe Mouillee in Lake Erie an artificial barrier island 3.5 miles long covering about 600 acres has been constructed of dredged sediments (McCallister and Kavalar, 1982). Other large diked containment facilities have been built in Chesapeake Bay, MD (1,110 acres), Jacksonville, FL (1,660 acres), Green Bay, WI (400 acres), Philadelphia, PA (298 acres) and Memphis, TN (425 acres) (Gushue and Kreutziger, 1977).

WHERE SHOULD THESE ISLANDS BE LOCATED?

The Fish and Wildlife Service has surveyed the area to assess the potential of siting large containment islands in the waters of the New York metropolitan area (Hamilton, 1982) and the following discussion is from their report.

The number of areas that are suitable for the construction of large containment islands in the New York metropolitan area is primarily limited by physical constraints. Areas to be excluded because of the lack of available space include the East River and the Hudson River. Upper Bay could hold a large island but the island would take up a significant fraction of the bay floor and it was suggested that this could not be done "without serious loss of shallow bay bottom habitat and possible disruption of the Hudson River currents." The situation was judged to be similar in Newark Bay with the additional complication that large islands may interfere with shipping there. Flushing Bay was suggested as a candidate for a containment facility connected to the land, but Jamaica Bay was an unlikely candidate because it is the site of a national wildlife refuge and the creation of new islands would have to "be reconciled with the loss of submerged habitat valuable to aquatic species."

The authors of a report representing the view of concerned citizens (New York Bight Restoration Working Group, 1984) conclude that the Upper Bay may be able to contain such sites and should be studied further. One possible site in the Upper Bay may be the shoal area along the west side of the Bay Ridge Channel. There are at least two important concerns as to the use of this site, however. One is that the shoal may be a source of invertebrate food for finfish. Even though there is no benthic data available for the site itself some information is available for a nearby shoal on the west side of the Upper Bay. That shoal area was found to support the most diverse and abundant benthic community of any of 36 stations between Bayonne, NJ and Piermont, NY (L. Schmidt, NJ Dept. of Environmental Protection, Letter to J. Mansky, U.S. Army Corps of Engineers, 17 December 1984). Other shoal areas in the Upper Bay may be similarly populated. Another concern is that the construction of a containment island may reduce the navigable waterway in the Upper Bay, or eliminate actual or potential anchorage sites in the heavily congested Upper Bay (H. Haff, NY Dept. of City Planning, letter to C. Coch, U.S. Army Corps of Engineers, 27 September 1984). Much of the general discussion presented in our report is applicable to the construction of large containment islands in the Upper Bay but the paucity of biological data for this region precludes the type of analysis we will present later in this report for the selection of candidate sites. As a result, we will concenterate on the Lower Bay here although the possibility of a site in the Upper Bay cannot be eliminated.

The Lower Bay complex remains a candidate that is large enough to contain a large island without substantially reducing the bay's area. The Fish and Wildlife Service report and the citizens' report (New York Bight Restoration Working Group, 1984), however, point out that the bay is extensively used by fishes and, again, the biological impacts of the loss of bay floor remain an open question. Physical constraints alone, however, seem sufficient to direct our initial consideration to the Lower Bay complex.

Within the Lower Bay complex the potential sites for large containment islands are limited primarily by the water depth. As we discussed earlier, in order to contain the largest volume while covering the smallest area, it would be beneficial to site the facility in the greatest water depth available, and the most likely sites should have water depths greater than 18 feet because of the draft of vessels that would operate at the access area of the containment facility. This constraint eliminates much of the bay floor along the Staten Island and New Jersey coasts, areas of the East Bank, Raritan Bay, and Sandy Hook Bay. The most likely candidate for large containment islands in Lower Bay would be in the western or southern areas, and indeed past proposals for creating islands have chosen sites west of Chapel Hill Channel or on the West Bank (Fig. 1). About 1972, the Hoffman-Swinburne Island was proposed to encompass the islands on the West Bank (Howard et al., 1976). The largest of three possible configurations for the Hoffman-Swinburne Island is shown on Figure 1. After completion it was intended to be used as a park but the lack of the need for alternative disposal sites and socio-political opposition at the time prevented its construction (D. Suszkowski, 1983, U.S. Army Corps of Engineers, N.Y. District, per. com.). The West Bank Containment Area was also suggested around 1972. It was to cover an area that had been previously mined for sand but was rejected because of poor circulation patterns that would result from its construction (Howard et al., 1976). An area near the intersection of the Chapel Hill South Channel and the Raritan Bay East Channel was proposed for Recap Island by a private company in 1971. It was intended both as a waste disposal area and the site of a resource recovery facility (Recap Island Company, 1974) but plans for its construction were abandoned apparently for economic and political reasons and because models showed that its construction could degrade local water quality (D. Suszkowski, 1983, U.S. Army Corps of Engineers, N.Y. District, per. comm.). In 1980, the same general area of Lower Bay was proposed for siting a large containment area by the New Jersey Department of Environmental Conservation and approved for study by the New York Department of Environmental Conservation.

Sites could be chosen in shallower water by limiting the sizes of barges that could service them, by pumping material to the site through a pipeline, or by dredging access channels. Because of the additional expense and the need to cover larger areas to contain the same volume, shallower sites should only be considered after no acceptable deeper water sites can be found.

Some other possible sites are less favorable for other reasons. For example, Romer Shoal is considered to be a valuable fishing area (Radosh and Reid, 1980; Colvin, 1980) and islands in the mouth of Lower Bay would not only have to withstand strong tidal currents but would most likely affect the tides and circulation to a greater degree than islands situated elsewhere. Wong and Wilson (1979), for example, found that changes in the tides were most sensitive to changes in the bathymetry in the mouth of Lower Bay. Although their calculations were done for hypothetical pits in this area the magnitude of the response to large islands should be similar but in the opposite direction. On the other hand, it is possible that islands in the mouth of the bay may reduce wave action in the bay and consequently ameliorate shore erosion on Staten Island. These latter considerations are speculative, however, and it appears that if an environmentally acceptable, large containment island can be built anywhere in the waters of the New York metropolitan area, it would be in the western or southern areas of the Lower Bay complex.

WHY MUST CONTAINMENT ISLANDS BE DIKED?

Not all containment islands need to be diked. Several sand islands have been constructed with dredged sand in Great South Bay, Long Island, NY, for example, without costly dikes. Containment islands in the Lower Bay complex, however, will need to be diked. These islands will be exposed to waves along their shores and, unlike the gentle waves in Great South Bay, waves in Lower Bay can cause considerable erosion. We only need to look at the east coast of Staten Island to appreciate this. The most destructive waves will not be those generated by local winds, but rather those that enter the bay from the ocean. To resist erosion, containment islands here will need to be diked and perhaps armored with large rocks to dissipate wave energy. A containment island that was intended to be located around Hoffman and Swinburne islands was either to be armored with sand and rock or to have a metal bulkhead incorporated into its dikes. The dikes were designed to withstand waves 15 feet high superimposed on a 12.3 foot storm surge (Howard et al., 1976). This is not impossible; Hoffman and Swinburne islands are man-made islands that have withstood conditions in Lower Bay for over 110 years and, in the Great Lakes where other disposal alternatives are lacking, artificial islands have been constructed to withstand comparably harsh conditions (McCallister and Kavalar, 1982).

Even in the more sheltered waters of Sandy Hook Bay or Raritan Bay, some protection will need to be afforded for artificial islands especially if the islands are to be made predominantly of fine-grained dredged sediment. Local winds can generate waves capable of significant shore erosion. A substantial stone breakwater, for example, is needed to protect the marina at Atlantic Highlands, NJ.

ARE LARGE OR MEDIUM-SIZED CONTAINMENT ISLANDS TECHNICALLY FEASIBLE?

This is perhaps the easiest question to answer--yes. It has been demonstrated many times that confined disposal facilities can be constructed in a wide range of environments (Hubbard and Herbich, 1977) including those where conditions are comparable to conditions in Lower Bay. For example, large containment islands have been successfully built to withstand adverse waves and ice in Lake Michigan (McCallister and Kavalar, 1982).

CAN THESE CONTAINMENT ISLANDS BE DESIGNED TO BE ENVIRONMENTALLY ACCEPTABLE?

There are four primary environmental issues to be addressed. These are (1) the potential for increased shore erosion, (2) degradation of the water quality due to restricting tidal flushing, (3) quality of the effluent from the site, and (4) impact on the bay's ecosystem due to the reduction in the area of the bay floor.

The effect of an island on shore erosion is difficult to predict even if we are dealing with a specific case. In general, a large island will undoubtedly alter the waves and currents in the bay and the pattern of wave and current energy reaching the shore will also be altered. In studies of the borrow pits on the West Bank, mathematical models of the waves and currents were developed which showed that the presence of the pits increased the tidal range along the Staten Island shore and slightly increased the wave energy reaching shore (Kinsman et al., 1979; Wong and Wilson, 1979). A large island would probably have the opposite effect, that is, it would cause a decrease in the tidal range along the western shore and a slight decrease in the wave energy reaching the shore. Both of these conditions would be favorable for reducing shore erosion. One large containment facility in Lake Erie was constructed specifically to protect a shoreside marsh from erosion (McCallister and Kavalar, 1982). The tidal currents might be expected to increase slightly which could partially negate the protective effect and it must be realized that the erosion of some areas of the shore may increase, even though the total erosion potential is decreased. For example, waves refracted around the island may increase erosion in shoreline areas at the edge of its shadow and the longshore drift of sand will be decreased in the island's wave shadow perhaps starving the downdrift beaches. The danger of increased shore erosion, however, would not seem to be an insurmountable obstacle; it is likely that the overall level of erosion will decrease and with proper design some erosion may be ameliorated.

The situation is similar when considering the degradation of water quality due to restricted circulation. Mathematical and physical models have been used to investigate the impact on tidal flushing for a variety of hypothetical large islands on the West Bank (Hydroscience, Inc., 1974). While some configurations may be eliminated, others, like a tearshaped large island in the vicinity of Hoffman and Swinburne islands, did not appear to cause significant degradation to the water quality as measured by changes in the concentrations of dissolved oxygen and coliform bacteria (Hydroscience, Inc. 1974). In any event, this consideration does not seem to rule out containment islands in the bay although, as was the case with shore erosion, the island would have to be designed to minimize the problem.

Experience at other sites indicates that the quality of the effluent, while cause for concern, probably can be adequately controlled (e.g. Chen et al., 1978; Barnard and Hand, 1978). Because shoreline hydraulic gradients tend to drive ground water offshore, it is virtually impossible for an offshore island to contaminate ground-water supplies and, if necessary, available methods, such as the use of impermeable liners, ponding systems, weirs, or the addition of polymers are available to control the leachate. In investigating the proposed Hoffman-Swinburne Island, sealing the dikes and floor of the area with an impervious liner was considered as a way to prevent the seepage of elutriates from the site (Howard et al., 1976).

The problems discussed so far most likely have engineering solutions; the loss of the bay floor, however, is unavoidable and may be unacceptable regardless of other considerations. Most of the studies of the biololgical resources of the Lower Bay have covered only limited areas and relatively short time periods.

The general state of knowledge concerning the biology of Lower Bay up to 1980 has been compiled from these local studies by Brinkhuis (1980) and more recently reviewed in brief by the Fish and Wildlife Service (Hamilton, 1982). Although 179 invertebrate taxa have been identified the density and diversity of macrobenthic invertebrates were found to be significantly lower when compared to other estuarine environments (Hamilton, 1982; Gandarillas and Brinkhuis, 1981). In addition, there are now some detailed long-term benthic data for a few sites in the Lower Bay associated with borrow pits on the West Bank (Cerrato and Scheier, 1984). Some recent regional benthic surveys have also been done in Raritan and Sandy Hook bays. The New Jersey Division of Fish, Game and Wildlife collected shellfish data at 107 stations in New Jersey waters (T. McCoy, per. com., 1984) to show the presence or absence of mussels, oysters, soft clams, and surf clams and also to show areas where hard clams are present and where hard clam abundances are high or moderate. Stainken (1984) and colleagues (Stainken et al., 1984) examined the macrobenthos at stations in Raritan Bay and the Lower Bay. Several studies have been done of the fishes in selected areas of the Lower Bay. Brinkhuis (1980) reviewed the earlier work and since that review was done, four other studies have been completed (Pacheco, 1983; Conover et al., 1983; National Marine Fisheries Service, 1984; and Figley, 1984). Lower Bay, including Raritan Bay and Sandy Hook Bay, is utilized extensively by nearly 70 species of fishes (Hamilton, 1982). When searching for potential sites for large containment islands in Lower Bay, shoal areas that are considered to be productive sportfishing grounds and the designated shellfish harvest area along the Staten Island coast might be eliminated from consideration for this reason.

We know of no widely accepted method, however, to quantify the effects of the loss of bay bottom on the ecosystem in general (Lunz and Kendall, 1982; Hansen et al., 1980; Klose, 1980). Applied ecologists have investigated the problem of quantifying ecological changes but many problems remain before generally applicable procedures are available (Gosselink et al., 1974; Shabman and Batie, 1980; Schamberger and Kumpf, 1980; Lunz and Kendall, 1982). Until such a methodology is established opinions concerning the value of the bay floor will be largely subjective. The effect can be minimized, however, by siting the island in an area of low productivity and arguing that the area covered is small compared to the bay as a whole. An island covering 500 acres will only remove about 0.8% of the floor of Lower Bay (including Raritan Bay and Sandy Hook Bay) and should have negligible influence on migratory fishes. The fraction of the benthic community lost by the construction of an island lacks any obvious importance to man unless it can be linked to other biological resources with human importance, such as fishes (Lunz and Kendall, 1982). It is not possible, however, to confidently forecast changes in the fish population to specific changes in their habitat (Livingston, 1980; Lunz and Kendall, 1982). In large part the difficulties are due to the extreme variability of feeding habits and to inadequacies in sampling. Diets not only vary among different species of fishes, for example, but the same species may change its diet as it grows in size (Hodson et al., 1981) or as it changes location (Overstreet and Heard, 1978, as reported in Lunz and Kendall, 1982) or even as the availability and abundance of food change (Powell and Schwartz, 1979; Miller and Dunn, 1980). Furthermore, studies are expensive and time consuming and the disadvantages are such that success cannot be guaranteed; the disadvantages include the selective and inefficient nature of the sampling (Lunz and Kendall, 1982), the mobility of fish populations, and their variability on both daily and seasonal time periods (Karr, 1981).

Although productivity and changes in productivity are virtually impossible to determine especially where migratory species are involved, it seems reasonable to assume that some areas of the bay floor should be less important to the ecosystem than others. One way to attempt to identify those areas would be to search for areas with lower biological populations. We will discuss this method in more detail later and use it to delineate three areas of the Lower Bay complex that are potential sites for containment islands.

Although the loss of bay floor may be unavoidable, as long as contaminants are well contained, there may be some mitigation of the loss depending on the design. Some of the area of the bottom that is covered by the containment island will be replaced by the dikes' subaqueous surfaces. If all or part of this surface is armored with rock, it is likely to behave as an artificial fishing reef. The use of artificial reefs to attract fishes is widespread and favorably reported. For example, at an artificial reef constructed in the Atlantic Ocean off the south shore of Long Island high population densities of fishes have been found (Woodhead et al., 1982); the mean density of adult cunner on the reef in the first year, for instance, was three fish for every square meter of the reef's 1,230 square-meter surface. Another reef at Murrells Inlet, South Carolina, increased the fish population 300 to 1800 times in the reef area (Shepard, 1974) and the fishing intensity over the reef in one year (1973) was almost 7,000 times the intensity over nearby rocky areas and 222,000 times that over sand (Buchanan, 1974). Other mitigating benefits may be gained by reducing both the amount and improving the average quality of dredged material disposed at the Mud Dump Site on the Atlantic shelf, although it would be a very difficult task to forecast and quantify the ecological changes that might occur.

IF CONTAINMENT ISLANDS ARE TECHNICALLY FEASIBLE AND ENVIRONMENTALLY ACCEPTABLE, ARE THEY SOCIETALLY AND POLITICALLY ACCEPTABLE AT THE PRESENT TIME?

This is also a difficult question to answer and would probably be addressed better by local politicians or others who are familiar with local public opinion. For the sake of completeness, however, we will discuss the question briefly here. Although public opinion may change because of economic pressures or the perceived benefits and uses of an island, it seems to us that committing several hundred acres of the Lower Bay complex to a containment facility may encounter formidable societal or political opposition. We have four reasons for this opinion:

1. A proposed containment facility on the shoals at Hoffman and Swinburne islands has been extensively studied (Howard et al., 1976; Hydroscience, Inc., 1974). Hoffman and Swinburne islands, however, are under the jurisdiction of the National Park Service as part of the Gateway National Recreational Area. The Park Service has notified the Army Corps of Engineers of their opposition to siting a large containment facility there because Hoffman and Swinburne islands are part of their 20-year development plan for recreational purposes and because of their concern for the natural and cultural resources there (Guthrie, undated).

2. Recent concern over the effects of sand and gravel mining in Lower Bay and the problems with overdredging at a borrow pit adjacent to the Chapel Hill South Channel led to an effective moratorium on sand mining outside of the channels. In particular there was vocal opposition to mining activity on Romer Shoal which is seen as a valuable sportfisheries area (see, for example, Scott Simons' "The Fighting Chair" in the Long Island Fisherman, 15 Nov. 1979, 29 Nov. 1979, 13 Dec. 1979, and 3 Jan. 1980).

3. The proposed project to partially fill a small area of one borrow pit had been brought to the courts. Again one of the principal concerns was the protection of a fisheries resource in the pit. Since the proposed project would commit only about 31 acres as compared to hundreds of acres for a containment facility it seems unlikely that a proposal for a large containment facility would go unchallenged.

4. The authors of a report by citizens who are concerned especially with the environmental issues conclude that attention should be focused on the Upper Bay in searching for containment island sites rather than on the Lower

Bay complex because "virtually all of the Lower Harbor, including Raritan and Sandy Hook bays, is actually or potentially productive biologically and serves a range of uses" (New York Bight Restoration Working Group, 1984).

On the other hand, the authors of the aforementioned report recommend that the Upper Bay should be studied for potential sites. Community leaders of the citizens of Monmouth County, NJ also encourage the continued investigation of containment islands and are concerned that alternatives to the use of the Mud Dump Site be found (e.g. J. D'Amico, Jr., Freeholder, County of Monmouth, Letter to Col. Griffis, U.S. Army Corps of Engineers, 10 January 1984).

WHERE ARE THE MOST LIKELY SITES FOR CONTAINMENT ISLANDS IN THE LOWER BAY COMPLEX?

The purpose of this section is to utilize available benthos and finfish data to identify preliminary sites in the Lower Bay for a containment island. In order to compare areas of the Lower Bay, we assumed that the biological information used in the analysis should be "mappable." That is, we felt that the data sets which would be most useful at this stage of the site selection process should cover a large portion of the Lower Bay, and that the coverage should be adequate enough to see gradients in the data. Of the data sets available for the Lower Bay, very few meet this criterion. The data that we chose to use were taken from three sources.

a. McGrath (1974) sampled 65 stations in the Lower Bay complex. Sampling was done in the winter with a 0.1 square meter Smith-McIntyre grab. Samples were sieved through a 1-mm screen. Samples were taken about 1 n. mile apart corresponding to about 1 sample per 1000 acres. The number of individuals and the number of species at each station were recorded in the original data set; a copy of these data was supplied by R. Reid of the National Marine Fisheries Service.

b. The New Jersey Department of Environmental Protection, Division of Fish, Game, and Wildlife conducted a survey of local fishermen concerning the locations of both commercial and recreational fishing grounds (Figley, 1984). The limitations of the study were discussed by Figley:

"It should be noted that these charts show the fishing grounds and not the distribution of each species. Fishing grounds represent only a portion of the geographic range of a species. Their extent is often limited by factors such as the density of fish, the suitability of an area for fishing, depth, regulations, pollution and distance from port. Furthermore, the charts depict only primary and secondary fishing grounds, areas where the majority of recreational and commercial fishing occurs; they do not include areas where rare or infrequent catches are made or where a species is taken as a bycatch of another species. In addition, fishing ground boundaries are not permanent. Fishing effort adapts to changes in fish distribution and the location of grounds can vary from year to year. The information contained on these charts must therefore be considered in the context of time. It must also be recognized that although the survey included a large and diverse sample of New Jersey's recreational and commercial fishermen, not all fishermen were interviewed. Therefore, some actively fished areas may have been omitted.

"The charts of Raritan/Sandy Hook Bay indicate the fishing ground of New Jersey fishermen only."

Despite these limitations, the study is both thorough and recent. Nine draft maps were examined. These showed:

1) the recreational fishing areas for sea bass, tautog, porgy, and spot

2) the commercial netting areas

3) the commercial eel pot and horseshoe crab dredge areas

4) the commercial blue crab dredging areas

5) the primary and secondary recreational fishing areas for bluefish

6) the primary and secondary recreational fishing areas for weakfish

7) the primary and secondary recreational fishing areas for summer flounder

8) the primary and secondary recreational fishing areas for winter flounder

9) the primary and secondary recreational fishing areas for striped bass

c. The New Jersey Division of Fish, Game, and Wildlife also collected shellfish data at 107 stations in New Jersey waters (T. McCoy, per. comm. 1984). These data were available on drafts of maps that show the presence or absence of mussels, oysters, soft clams, and surf clams; and also areas where hard clams are present and where hard clam abundances are high or moderate.

A total of 14 "mappable" data sets were obtained from these sources (Table 1).

Other data are, of course, available (e.g. Dean, 1975; Brinkhuis, 1980; Cerrato and Scheier, 1984; Conover et al., 1983; Pacheco, 1983; National Marine Fisheries Service, 1984). We did not use benthic data collected before McGrath's survey since McGrath's data were the most recent comprehensive data set available to us. Recent data that were not mappable can be considered in interpreting the available maps although it cannot be used directly in the approach described here.

To compare sites, the Lower Bay was divided into 280 boxes, or quadrates, of about 250 acres each. For each data map, quadrates were assigned a score from 0 to 3 based on the criteria listed in Table 1. As shown in this table, quadrates assigned higher scores are less populated than those given lower scores.

An example of an individual data map is given in Figure 2. In this figure, the distribution of striped bass fishing areas is displayed as a set of quadrate scores. This map was generated from data contained in Figley (1984). The negative numbers indicate land areas and regions not lying within the Lower Bay. The relationship between quadrate locations and geographical features in the Lower Bay is shown in Figure 3. Note that the primary fishing areas for striped bass tend to be concentrated at the entrance of the Bay and secondary fishing areas are located along Staten Island and Chapel Hill channel.

For any particular quadrate, a sum of its scores on each map can be found. These sums can be displayed for the entire set of maps or for any particular subset of them. For example, Figure 4 shows the quadrate sums obtained from the fisheries data in the Figley report. This figure was derived by summing the scores from data maps numbered 6 through 14 in Table 1. The distribution of total quadrate scores is summarized as a frequency histogram in Figure 5. Total quadrate scores in this particular case range from 13 to 27. Highest scores identify those locations least utilized as fishing areas based on the data in Figley (1984). For example, a score of 27 indicates that a quadrate was rated as a non-fishing area (3) on each of the nine data maps included in this case.

At this point, two non-biological constraints were included in the site selection process. In order to accommodate barges, water depths of 18 feet or more are needed on at least one side of a containment island. In addition, quadrates which include a

Table 1. Data sets and score assignments for the site-selection process.

DATA MAPS:

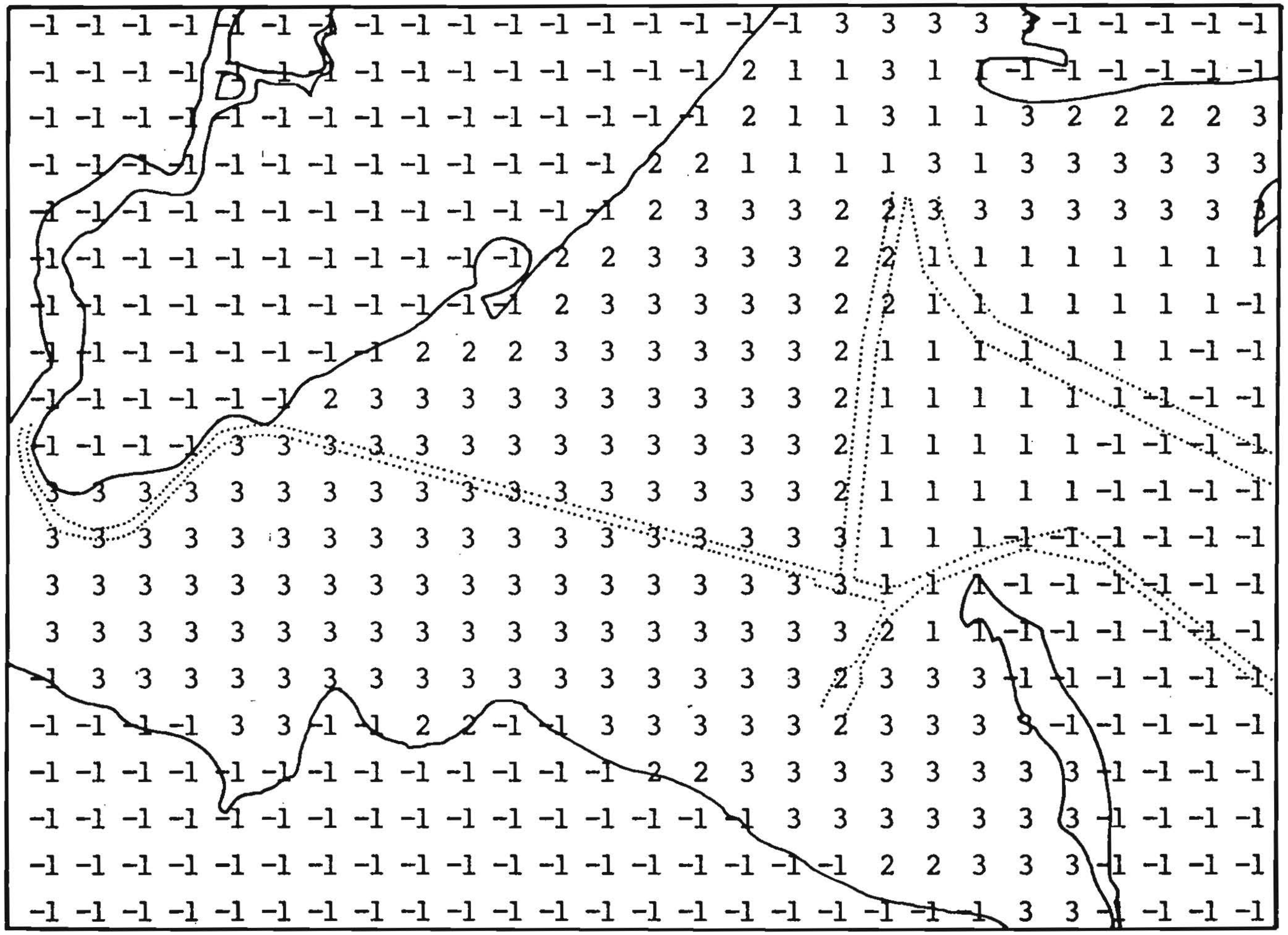
1. Benthic macrofaunal abundance
2. Benthic macrofaunal species richness
3. Distribution of hard clams (NJ only)
4. Occurence of mussels and oysters (NJ only)
5. Occurence of soft clams and surf clams (NJ only)
6. Fishing areas for sea bass, spot, tautog, or porgy
7. Commercial netting areas
8. Commercial eel pot and horseshoe crab dredge areas
9. Commercial blue crab dredging areas
10. Fishing areas for bluefish
11. Fishing areas for weakfish
12. Fishing areas for summer flounder
13. Fishing areas for winter flounder
14. Fishing areas for striped bass

SCORE ASSIGNMENTS:

Score:	0	1	2	3
Benthic data:				
Abundance	No data	>1000	100-1000	<100
Species	No data	>15	5-14	≤4
NJ Shellfish:				
Hard clam	No data	High to moderate	Occurrence	None
Other	No data	Fishing		Non-fishing
Fishing data:	No data	Primary fishing area	Secondary fishing area	Non-fishing

-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	3	3	3	3	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	1	1	3	1	1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	1	1	3	1	1	3	2	2	2	2	3
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	2	1	1	1	1	3	1	3	3	3	3	3	3
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	3	3	3	2	2	3	3	3	3	3	3	3	3
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	2	3	3	3	3	2	2	1	1	1	1	1	1	1	1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	3	3	3	3	3	2	2	1	1	1	1	1	1	1	-1
-1	-1	-1	-1	-1	-1	-1	-1	2	2	2	3	3	3	3	3	3	2	1	1	1	1	1	1	1	-1	-1
-1	-1	-1	-1	-1	-1	2	3	3	3	3	3	3	3	3	3	3	2	1	1	1	1	1	1	-1	-1	-1
-1	-1	-1	-1	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	1	1	1	1	-1	-1	-1	-1
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	1	1	1	1	-1	-1	-1	-1
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	-1	-1	-1	-1	-1	-1
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	-1	-1	-1	-1	-1	-1
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	1	-1	-1	-1	-1	-1	-1
-1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	3	3	-1	-1	2	2	-1	-1	3	3	3	3	3	2	3	3	3	3	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	2	3	3	3	3	3	3	3	3	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	3	3	3	3	3	3	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	2	3	3	3	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	3	-1	-1	-1	-1

Figure 2. Quadrate scores for striped bass. Based on information in Figley (1984).



-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	3	3	3	3	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	1	1	3	1	1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	1	1	3	1	1	3	2	2	2	2	3
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	2	1	1	1	1	3	1	3	3	3	3	3	3
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	3	3	3	2	2	3	3	3	3	3	3	3	3
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	2	3	3	3	3	2	2	1	1	1	1	1	1	1	1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	3	3	3	3	3	2	2	1	1	1	1	1	1	1	-1
-1	-1	-1	-1	-1	-1	-1	-1	2	2	2	3	3	3	3	3	3	2	1	1	1	1	1	1	1	-1	-1
-1	-1	-1	-1	-1	-1	2	3	3	3	3	3	3	3	3	3	3	2	1	1	1	1	1	1	-1	-1	-1
-1	-1	-1	-1	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	1	1	1	1	-1	-1	-1	-1
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	1	1	1	1	-1	-1	-1	-1
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	-1	-1	-1	-1	-1	-1
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	-1	-1	-1	-1	-1	-1
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	1	-1	-1	-1	-1	-1	-1
-1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	-1	-1	-1	-1	-1	-1
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-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	2	3	3	3	3	3	3	3	3	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	3	3	3	3	3	3	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	2	3	3	3	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	3	-1	-1	-1	-1

Figure 3. Quadrate scores for striped bass from Figure 2. A map of the Lower Bay has been superimposed on these scores to show the relationship between quadrate locations and geographic features.

-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	25	24	25	27	27	-9	-9	-9	-9	-9
-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	26	24	20	24	23	23	-9	-9	-9	-9	-9	-9
-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	25	23	22	23	23	25	27	26	24	25	25	27
-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	26	25	24	23	23	22	25	24	27	26	27	27	27	27
-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	25	22	22	24	24	23	24	27	26	26	27	27	27	27
-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	26	24	24	22	24	24	23	21	20	25	25	25	25	24	24	25
-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	22	24	22	24	24	24	23	22	18	23	25	21	21	22	23	-9
-9	-9	-9	-9	-9	-9	-9	-9	26	23	22	24	22	24	24	24	25	24	20	20	21	23	22	20	20	-9	-9
-9	-9	-9	-9	-9	-9	25	25	23	23	22	20	22	24	24	26	26	19	19	17	21	19	19	21	-9	-9	-9
-9	-9	-9	-9	26	23	24	24	21	22	23	23	23	23	23	26	24	18	19	17	17	21	21	-9	-9	-9	-9
24	27	27	25	20	25	25	25	23	21	21	21	20	20	20	21	22	19	15	17	15	17	19	-9	-9	-9	-9
22	22	23	24	26	24	24	24	23	22	22	22	20	20	20	20	20	19	15	17	17	-9	-9	-9	-9	-9	-9
25	25	25	24	24	22	24	24	24	21	22	22	20	20	22	19	18	18	17	17	15	-9	-9	-9	-9	-9	-9
25	25	25	24	24	21	21	21	22	22	20	19	19	19	19	16	14	15	14	13	13	-9	-9	-9	-9	-9	-9
-9	25	25	23	21	21	23	21	22	22	23	19	21	21	19	19	14	13	15	15	13	-9	-9	-9	-9	-9	-9
-9	-9	-9	-9	23	23	-9	-9	20	20	-9	-9	22	22	22	18	18	15	17	17	14	16	-9	-9	-9	-9	-9
-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	23	21	20	19	16	19	19	18	14	14	-9	-9	-9	-9
-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	22	23	20	22	20	20	14	-9	-9	-9	-9
-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	22	21	24	22	18	-9	-9	-9	-9
-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	23	21	-9	-9	-9	-9

Figure 4. Total quadrate scores obtained by summing data maps number 6 through 14 in Table 1.

SCORE	FREQ	SCORE	FREQ	SCORE	FREQ	SCORE	FREQ	SCORE	FREQ
1	0	11	0	21	25	31	0	41	0
2	0	12	0	22	36	32	0	42	0
3	0	13	4	23	33	33	0	43	0
4	0	14	7	24	42	34	0	44	0
5	0	15	8	25	30	35	0	45	0
6	0	16	3	26	13	36	0	46	0
7	0	17	11	27	16	37	0	47	0
8	0	18	8	28	0	38	0	48	0
9	0	19	19	29	0	39	0	49	0
10	0	20	25	30	0	40	0	50	0

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                   ******* *
                   ******* *
                   *********
                 * *********
               * ***********
              ** ***********
             *** ***********
             ***************
----------|---------|---------|---------|---------|
          10        20        30        40        50
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Figure 5. A frequency histogram for the total quadrate scores listed in Figure 4.

portion of a channel should be ignored. Those locations excluded by these constraints are displayed as hatched areas in Figure 6. Unhatched areas in this figure represent the remaining acceptable localities. It should be noted that while hatched areas were not considered further as the location for a containment island, information from these areas was always utilized in the analysis of the biological data.

To identify potential sites, individual data maps were combined, and we proceeded to identify those quadrates whose total scores were high when compared to other localities. This process was done sequentially, beginning with only the highest total score, then including the next lower score, and so on. In general, what we saw as we sequentially included lower scores is illustrated in the following specific example. In this example, the fisheries data derived from Figley (1984) and discussed earlier (Figures 4 and 5) will be used. In summing these nine data maps, total quadrate scores ranged from 13 to 27 (Figure 5). Quadrates with very high scores ($\geq$ 26) are indicated in Figure 7 by a pair of asterisks (**). Note that only isolated quadrates appear within the unhatched area of this figure. Since quadrates represent areas approximately 250 acres in size, these single, isolated quadrates are too small for a medium-sized containment island. An intermediate case, generated by adding slightly lower scores to those already used (i.e., total scores $\geq$24) is shown in Figure 8. In this figure, small patches have appeared within the unhatched area. Since these patches consist of two or more quadrates, they are large enough to accommodate a 500-acre containment island. Finally, as even lower scores are included, the patches tend to grow and coalesce. In Figure 9, total scores of 22 and above are shown. Note that rather sizable areas have appeared within the unhatched region.

In our analysis of the biological data, we decided to stop the selection process at a level comparable to that found in Figure 8. That is, lower scores would be added only until areas just large enough to accommodate a 500-acre containment island appeared in the unhatched region of the map. This process produces a fairly conservative selection of sites since we determined after many trials using different combinations of the data maps that the values included were always within the highest one-third of the range of scores.

One of our concerns in this analysis was whether certain data sets should be given more weight than others in the site selection process. For example, if we simply combined the data maps listed in Table 1, then the fisheries data from Figley (1984) would be counted most heavily since nine of the fourteen data maps were obtained from this source. Weighting effects were examined by dividing the available data maps into two groups (Appendix II). The first group consisted of the fisheries data maps obtained from Figley (1984). The second group combined the benthic data maps derived from the McGrath (1974) survey and the

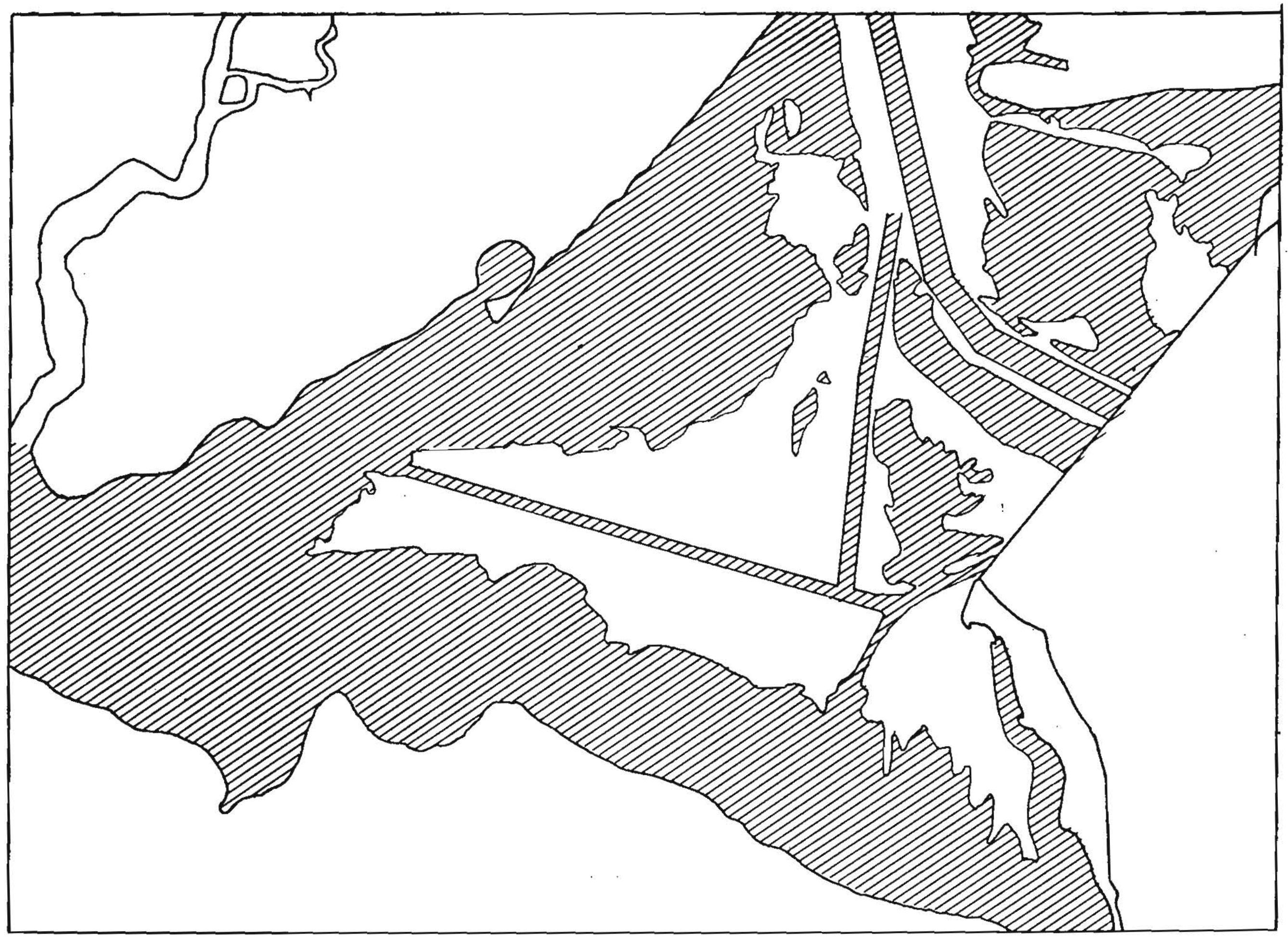
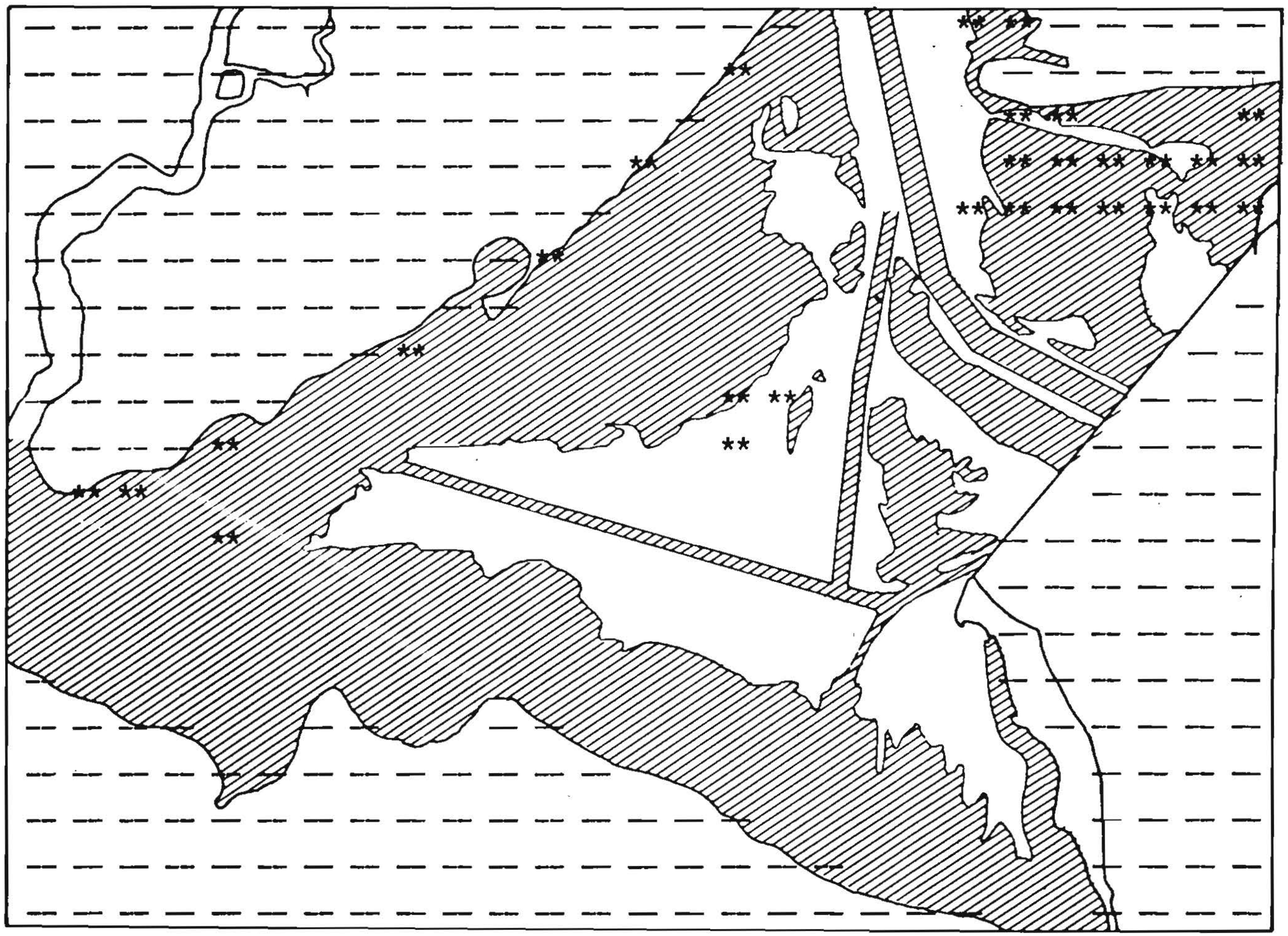
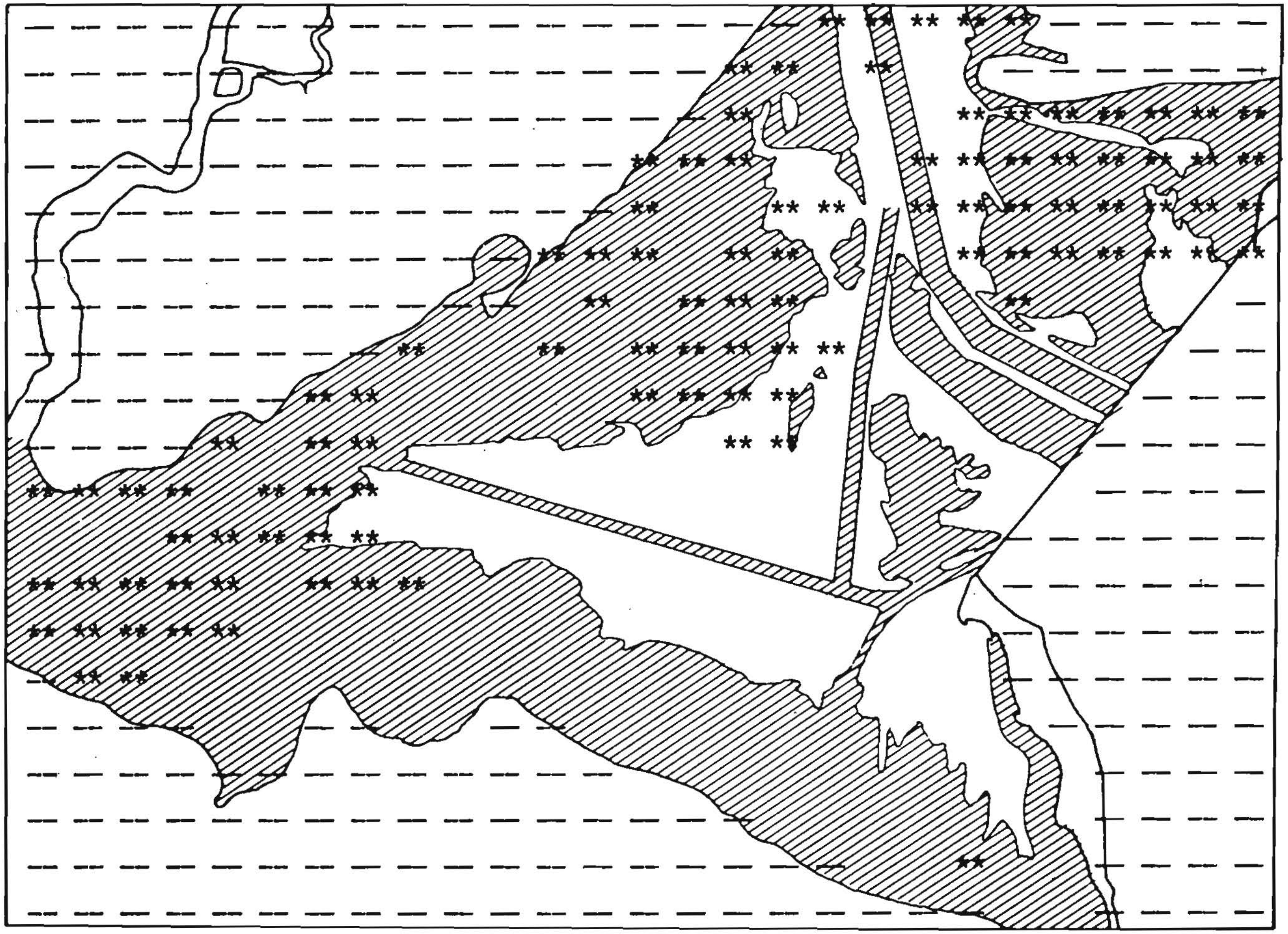


Figure 6. A Lower Bay map showing the locations of shallow areas (<18 ft.) and ship channels.



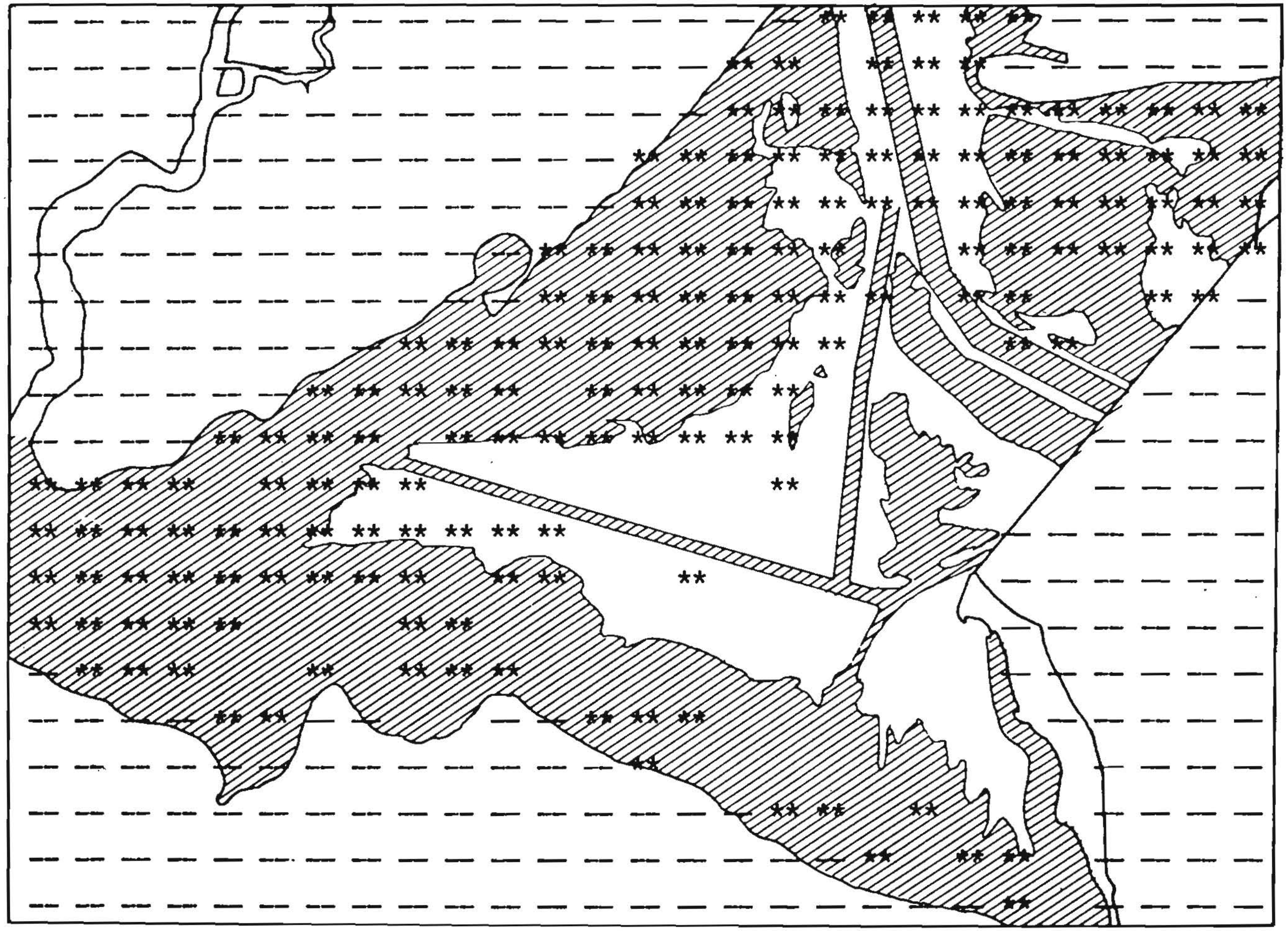
FISH DATA

Figure 7. Fisheries data from Figure 4. The symbol "**" indicates those quadrates with scores of 26 or higher.



FISH DATA

Figure 8. Fisheries data from Figure 4. The symbol "**" identifies those quadrates with scores of 24 or higher.



FISH DATA

Figure 9. Fisheries data from Figure 4. The symbol "**" identifies those quadrates with scores of 22 or higher.

shellfish survey conducted by the New Jersey Division of Fish, Game, and Wildlife. Since the data on the shellfish populations were limited to New Jersey waters, we decided to examine areas in New York and New Jersey waters separately and to combine the results.

Different weightings were explored ranging from assigning 100% of the weight to the fisheries group to assigning 100% of the weight to the group consisting of the benthic data maps. Intermediate weightings of the fisheries and benthic data groups of 75% to 25%, 67% to 33%, 50% to 50%, 33% to 67%, and 25% to 75% were also analyzed. These trials are presented in Figures 10-16. As a result of the trials, four areas persistently emerge in the Lower Bay:

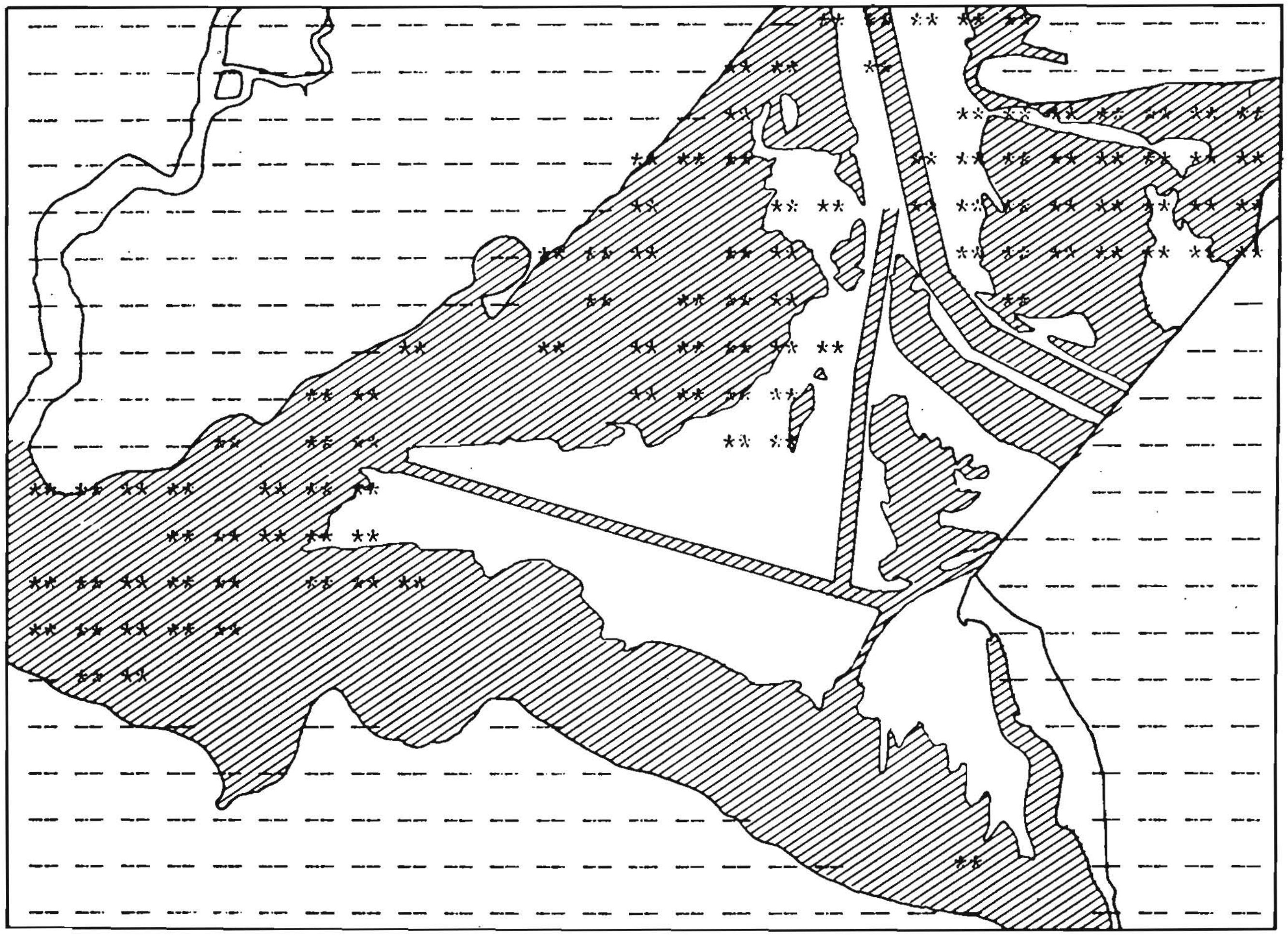
1) Site I is located north of Conaskonk Point along the 18-foot contour and south of the Raritan Bay Channel. This site appeared in every trial. Its location is in a muddy area of the bay floor and there is evidence to suggest that the layer of mud here could be thick.

2) Site II is north of the Raritan Bay Channel about midway between the Chapel Hill Channel and Old Orchard Shoal. This site also appeared in every trial. It is on a sandy bay floor and includes an area that had been used as a control site for both fishing studies and benthic surveys in recent years.

3) Site III is in a mined area east of and adjacent to the north reach of the Ambrose Channel. This site is based most firmly on the fisheries data and disappears when the benthic data are heavily weighted (i.e., compare Figures 15 and 16 to the others). However, the benthic data from McGrath (1974) had to be extrapolated to cover this area of the bay floor. As a result, it is questionable whether assigning heavy weight to the benthic data is valid for this area.

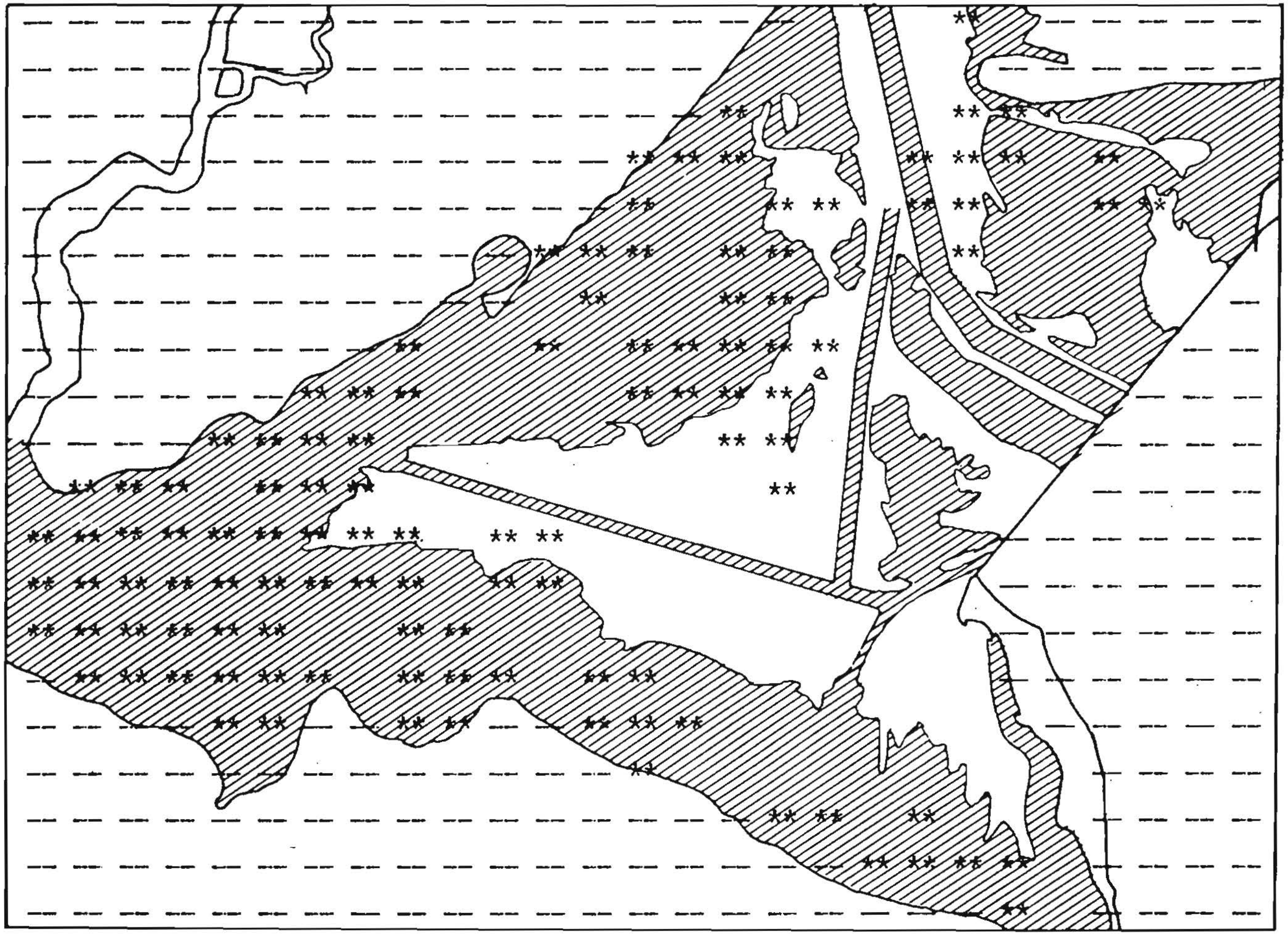
4) Site IV is located along the 18-foot contour in Sandy Hook Bay. This site appears only when the benthic data are assigned a weight of 50% or more. This location has recently been opened for shellfishing. Because of this and since it is not indicated by the fisheries data, we anticipate that this site will be excluded from further consideration.

Eliminating the Sandy Hook Bay site, the three remaining areas are outlined in Figure 17. The three sites identified by this process persistently appeared under various weighting combinations of the available data. Unless substantially different data sets are added to the analysis, it is unlikely that other possible sites will be found within the deep-water regions of the bay.



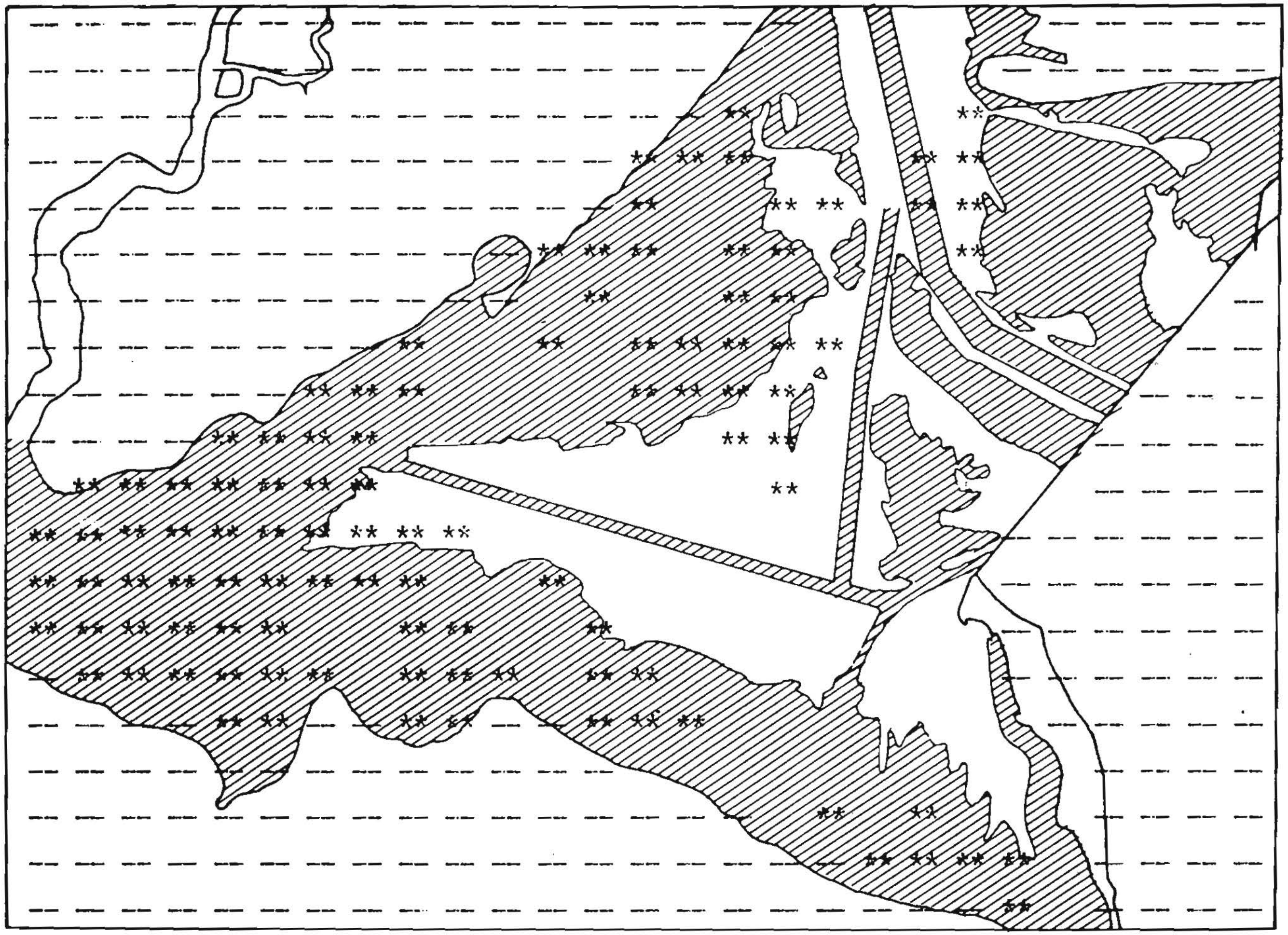
FISH DATA

Figure 10. Site identification (as described in the text) using only the fisheries data.



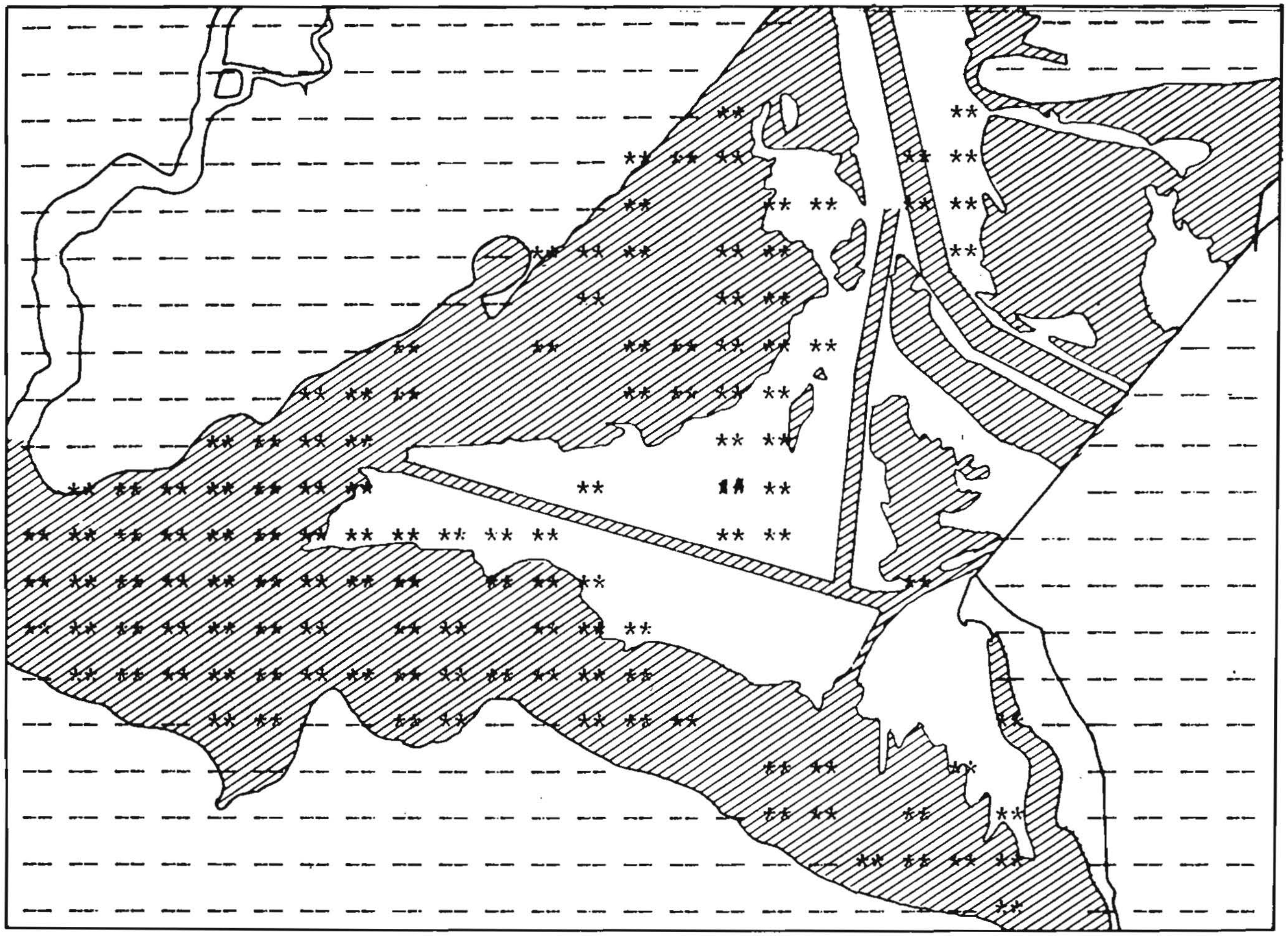
1/4 BENTHIC AND 3/4 FISH

Figure 11. Site identification (as described in the text) based on an unequal weighting of the fish and benthic data. This map assigns 75% of the scores' weight from the fisheries data and 25% from the benthic data.



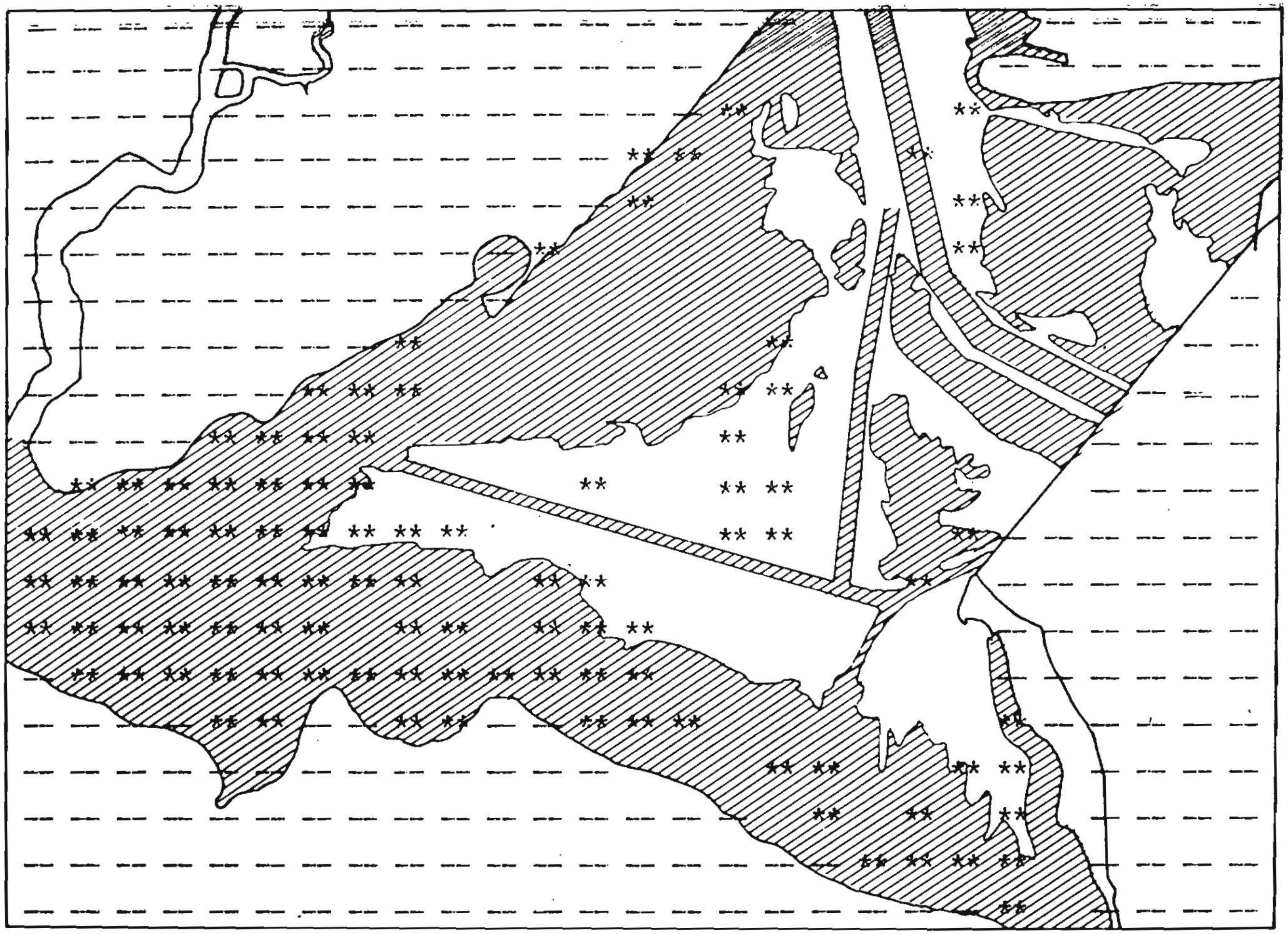
1/3 BENTHIC AND 2/3 FISH

Figure 12. Site identification (as described in the text) based on an unequal weighting of the fish and benthic data. This map assigns 67% of the scores' weight from the fisheries data and 33% from the benthic data.



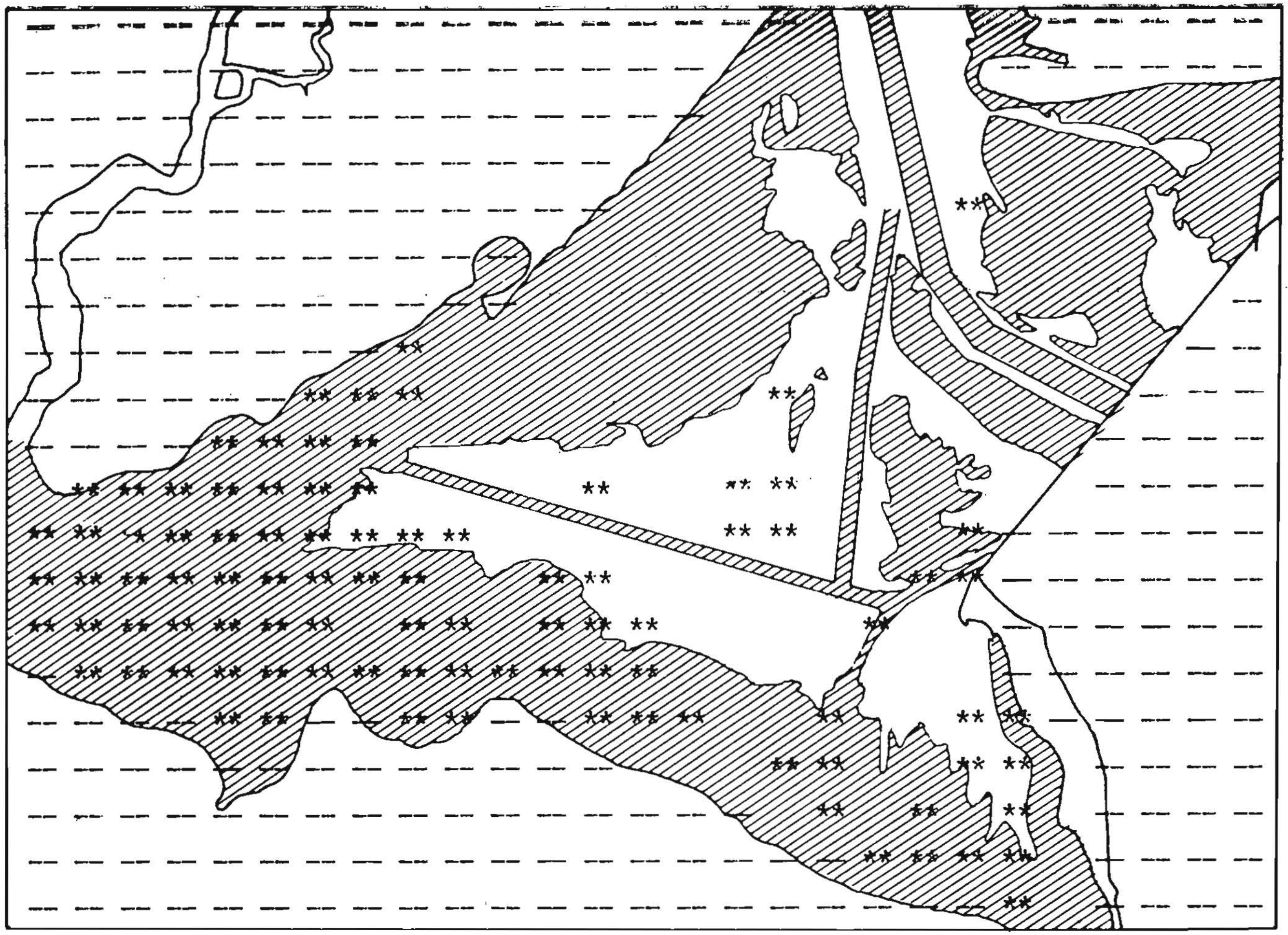
1/2 BENTHIC AND 1/2 FISH

Figure 13. Site identification (as described in the text) based on an unequal weighting of the fish and benthic data. This map assigns 50% of the scores' weight from the fisheries data and 50% from the benthic data.



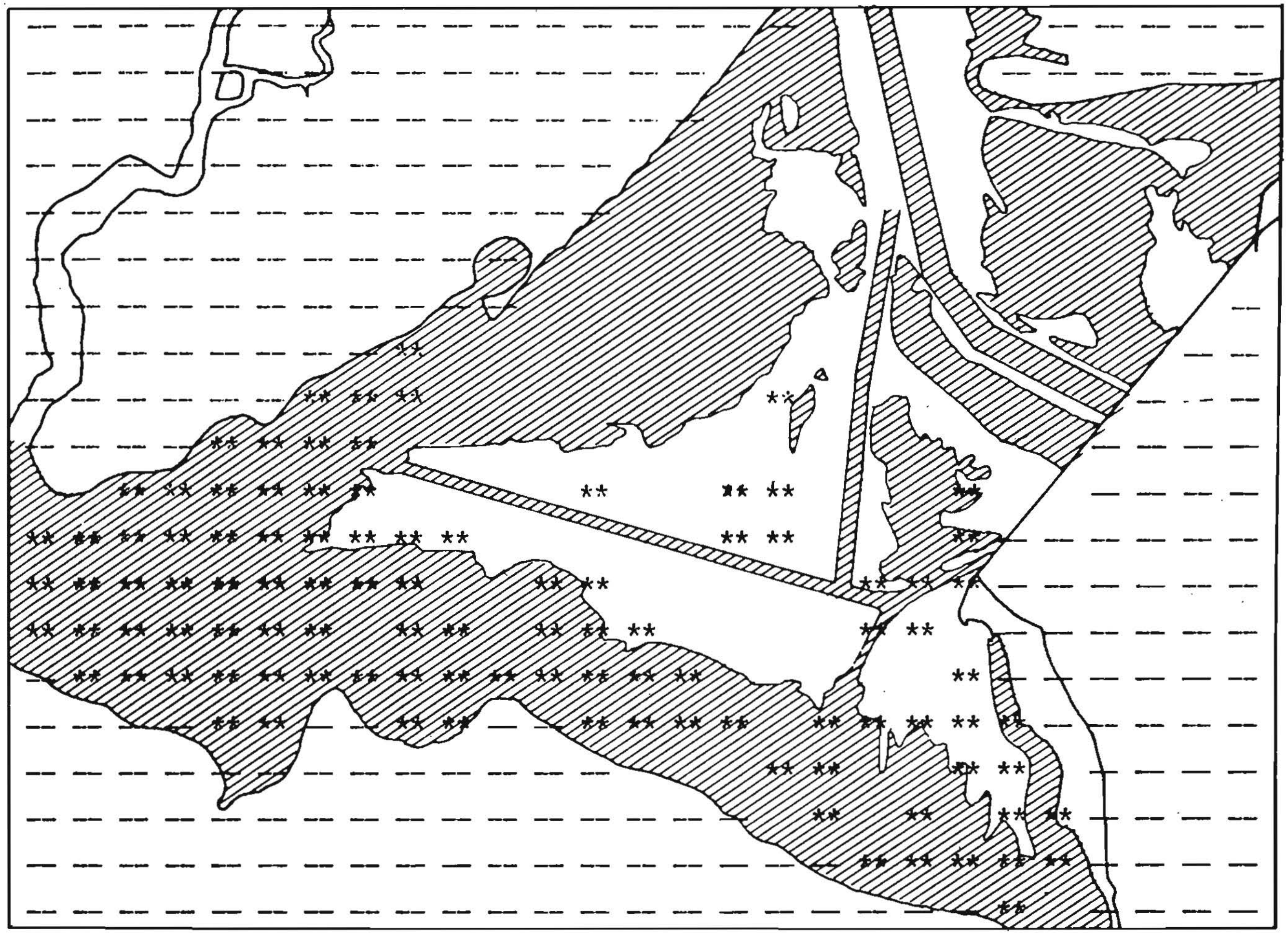
2/3 BENTHIC AND 1/3 FISH

Figure 14. Site identification (as described in the text) based on an unequal weighting of the fish and benthic data. This map assigns 33% of the scores' weight from the fisheries data and 67% from the benthic data.



3/4 BENTHIC AND 1/4 FISH

Figure 15. Site identification (as described in the text) based on an unequal weighting of the fish and benthic data. This map assigns 25% of the scores' weight from the fisheries data and 75% from the benthic data.



BENTHIC DATA

Figure 16. Site identification (as described in the text) using only the benthic data.

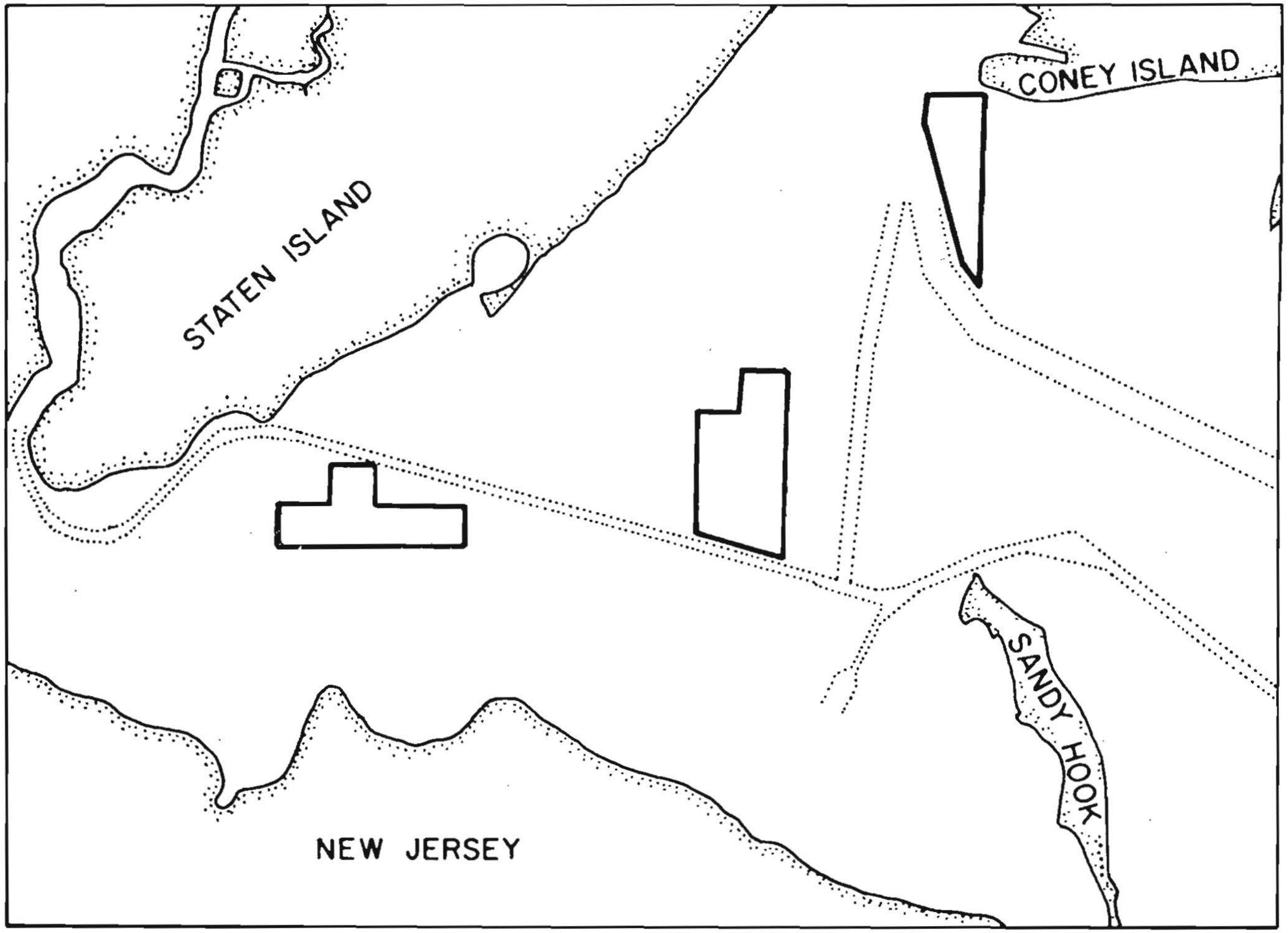


Figure 17. Potential containment area sites based on available data on biological resources and population.

REFERENCES

Barnard, W. D. and T. D. Hand. 1978. Treatment of contaminated dredged material. Rpt. DS-78-14. U.S. Army Corps of Engineer Waterways Experiment Station, Vicksburg, MS, 46 p.

Brinkhuis, B. H. 1980. Biological effects of sand and gravel mining in the Lower Bay of New York Harbor. An assessment from the literature. Spec. Rpt. 34, Marine Sciences Research Center, State Univ. of NY at Stony Brook, 193 p.

Buchanan, C. C. 1974. Comparative studies of the sport fishery over artificial and natural habitats off Murrells Inlet, S.C., in L. Colunga and R. Stone, eds. The Proc. of an International Conference on Artificial Reefs, Center for Marine Resources, Texas A&M Univ., TAMU-SG-74-103: 34-38.

Cerrato, R. M. and F. T. Scheier, 1984. The effects of borrow pits on the distribution and abundance of benthic fauna in the Lower Bay of New York Harbor. Spec. Rpt. 59, Marine Sciences Research Center, State Univ. of New York at Stony Brook, NY, 315 p.

Chen, K. Y., J. L. Mang, B. Eichenberger, and R. E. Hoeppel. 1978. Confined disposal area effluent and leachate control (Laboratory and Field Investigations) Rpt. TR DS-78-7. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 94 p.

Colvin, G. C. 1980. Letter to Mr. J. Zammit, U.S. Army Corps of Engineers, New York District, from Mr. Colvin, NY State Dept. of Environmental Conservation, 19 Nov 1980, 2 p.

Conner, W. G., D. Aurand, M. Leslie, J. Slaughter, A. Amr, and F. I. Ravenscroft. 1979. Disposal of dredged material within the New York District, Vol. 1, Present Practices and Candidate Alternatives. Mitre Technical Report MTR-7808, Vol. 1, The Mitre Corp. Metrek Div., McLean, VA.

Conover, D., R. Cerrato, H. Bokuniewicz, J. Bowsman, and F. Scheier. 1983. Effect of borrow pits on the abundance and distribution of fishes in the Lower Bay of New York Harbor. Unpubl. rpt. to NY Dist., U.S. Army Corps of Engineers, 42 p + appendices.

Dean, D. 1975. Raritan Bay macrobenthos survey, 1957-1960. NOAA, NMFS Data Report 99, 55 p.

Figley, W. 1984. Commercial and recreational fishing grounds of Raritan/Sandy Hook and Delaware bays. Unpublished report, N.J. State Dept. of Environmental Protection, N.J. Division of Fish, Game and Wildlife, Bureau of Marine Fisheries, Trenton, N.J. Prog. No. 3-340D, 33p. + figures.

Gandarillas, E. F. and B. H. Brinkhuis. 1981. Benthic faunal assemblages in the Lower Bay of New York Harbor. Spec. Rpt. 44. Marine Sciences Research Center, State Univ. of NY at Stony Brook, 129 p.

Gosselink, J. G., E. P. Odum, and R. M. Pope. 1974. The value of the tidal marsh. Pub. No. LSU-56-74-03. Center for Wetland Resources, Louisiana State Univ., Baton Rouge, LA, 30 p.

Gushue, J. J. and K. M. Kreutziger. 1977. Case studies and comparative analyses of issues associated with productive land use at dredged material disposal sites. Technical Report D-77-43. Environmental Effects Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Guthrie, J. (undated). Letter to D. Suszkowski, NY District, U.S. Army Corps of Engineers. Rec'd 16 February 1983.

Hamilton, P. P. 1982. Letter to Col. W. M. Smith, District Engineer, New York District, U.S. Army Corps of Engineers. May 13, 24 p.

Hansen, W. J. S. E. Richardson, R. T. Reppert, and G. E. Galloway, Jr. 1980. Wetlands' values - contributions to environmental quality or to national economic development. Pp. 17-26 in V. S. Kennedy, ed., Estuarine Perspective. Academic Press, NY.

Hodson, R. G., J. O. Hackman, and C. R. Bennett. 1981. Food habits of young spots in nursery areas of the Cape Fear Estuary, North Carolina. Trans. Am. Fish. Soc. 110: 495-501.

Howard, Needles, Tammen and Bergendoff. 1976. New York Harbor Phase 1 Feasibility Study for Dredged Material Disposal. Unpubl. rpt to NY District, U.S. Army Corps of Engineers.

Hubbard, B. S. and J. B. Herbich. 1977. Productive land use of dredged material containment areas: International literature review. Center for Dredging Studies, Rpt. 199. Texas A&M Univ., College Station, Texas.

Hydroscience, Inc. 1974. Preliminary evaluation of the effects of the Lower Bay area on water quality. Unpubl. report to the NY District, U.S. Army Corps of Engineers.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6: 21-27.

Kinsman, B., J. R. Schubel, G. E. Carroll, M. Glackin-Sundell. 1979. A suggestion for anticipating alterations in wave action on shores consequent upon changes in water depths in harbors and coastal waters. Spec. Rpt. 27, Marine Sciences Research Center, State Univ. of NY at Stony Brook, 39 p.

Klose, P. N. 1980. Quantification of environmental impacts in the coastal zone. Pp. 27-35 in V. S. Kennedy, ed., Estuarine Perspectives. Academic Press, NY.

Livingston, R. J. 1980. Onthogenetic trophic relationships and stress in a coastal seagrass system in Florida. Pp. 423-435 in V. S. Kenmnedy, ed., Estuarine Perspectives. Academic Press, NY.

Lunz, J. D. and D. R. Kendall. 1982. Benthic resources assessment technique, a method for quantifying the effects of benthic community changes on fish resources. Proc. Oceans 82 Conf. Marine Tech. Soc., Inst. of Electrical and Electronic Engs, and Council on Ocean Eng., Wash., DC: 1024-1027.

McCallister, P. and R. J. Kavalar. 1982. Confined disposal program for polluted maintenance dredged in the Great Lakes. Proc. Oceans '82 Conf.. Mar. Tech. Soc., Inst. Electrical and Electronics Engineers, and the Council of Ocean Eng., Wash., DC: 1042-1045.

McGrath, R. A. 1974. Benthic macrofaunal census of Raritan Bay--preliminary results. Proc. 3rd Symp. Hudson River Ecol., 27 p.

Miller, J. M. and M. L. Dunn. 1980. Feeding strategies and patterns of movement in juvenile estuarine fishes. Pp. 437-448 in V. S. Kennedy, ed., Estuarine Perspectives. Academic Press, NY.

National Marine Fisheries Service. 1984. Seasonal occurrence of finfish and larger invertebrates at eight locations in Lower and Sandy Hook bays 1982-1983. Unpublished report to the New York District, U.S. Army Corps of Engineers, 79 p.

New York Bight Restoration Working Group. 1984. An alternative strategy for disposal of dredged materials from the greater New York region: A citizens' proposal. October draft report of the Environmental Defense Fund, NY, 101 p.

Overstreet, R. M. and R. W. Heard. 1978. Food of the Atlantic croaker (Micropogonias undulatus) from the Mississippi Sound and the Gulf of Mexico. Gulf Research Reports 6: 145-152.

Pacheco, Anthony L. 1983. Seasonal occurrence of finfish and larger invertebrates at three sites in Lower New York

Harbor, 1981-1982. Unpubl. rpt. to NY Dist., U.S. Army Corps of Engineers, 49 p.

Palermo, M. R., F. D. Shields, and D. F. Hayes. 1981. Development of a management plan for Craney Island disposal area. Tech. Rpt. EL-81-11. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 170 p.

Powell, A. B. and F. J. Schwartz. 1979. Food of *Paralichthys dentatus* and *P. lethostigma* (Pisces: Bothidae) in North Carolina estuaries. Estuaries 2: 276-279.

Radosh, D. J. and R. N. Reid. 1980. Benthic macrofaune of Romer Shoal (Raritan Bay) in relation to sand mining. Natl. Mar. Fish. Service, Sandy Hook Lab. Tech Rpt. 80-2, 14 p.

Recap Island Company. 1974. The decision that cannot be deferred - a plan for solid waste disposal and resource recovery for the metropolitan New York area, 28 pp.

Schamberger, M. L. and H. E. Kumpf. 1980. Wetlands and wildlife values: a practical field approach to quantifying habitat values. Pp. 37-46 in V. S. Kennedy, ed., Estuarine Perspectives. Academic Press, NY.

Shabman, L. A. and S. S. Batie. 1980. Estimating the economic value of coastal wetlands: conceptual issues and research needs. Pp. 3-15 in V. S. Kennedy, ed., Estuarine Perspectives. Academic Press, NY.

Shepard, P. J. 1974. Texas' artificial reef program in The Proceedings of an International Conference on Artificial Reefs, L. Colunga and R. Stone, eds., Texas A&M Univ., TAMU-SG-74-103: 137-140.

Stainken, D. M. 1984. Organic pollution and the macrobenthos of Raritan Bay. Envir. Toxicol. and Chem. 3: 95-111.

Stainken, D. M., M. J. McCormick, and H. G. Multer. 1984. Seasonal survey of the macrobenthos of Raritan Bay. Bull. N.J. Acad. Sci. 29: 121-132.

United States Army Corps of Engineers. 1980. Long Island Sound Dredged Material Containment Study. New England Division, Waltham, MA.

United States Army Corps of Engineers. 1983. Final environmental impact statement, Disposal of Dredged Material from the Port of New York and New Jersey, New York District, NY, 222 p. + Appendix.

Wong, K-C and R. E. Wilson. 1979. An assessment of the effects of bathymetric changes associated with sand and gravel mining on tidal circulation in the Lower Bay of New York Harbor. Spec. Rpt. 18, Marine Sciences Research Center, State Univ. of NY at Stony Brook, 24 p.

Woodhead, P. M. J., J. H. Parker and I. W. Duedall. 1982. The coal-waste artificial reef program (C-WARP): A new resource potential for fishing reef construction. Mar. Fish. Rev. 44: 16-23.

APPENDIX I

COST ESTIMATE FOR CONTAINMENT ISLAND IN LOWER BAY

The following costs are based on the analyses presented by Howard et al. (1976) for three alternative containment islands each with a capacity of 118,000,000 cubic yards and a lifetime of 20 years. If we assume that the dredged sediment will compact 40% then such a facility could contain 192,000,000 cubic yards of dredged material. The cost estimates given by Howard et al. (1976) were given in 1975 dollars. These were converted to 1983 dollars by multiplying by a cost factor of 1.7.

COST IN MILLIONS OF DOLLARS

	Alternates*		
	A	C	D
Dike construction	$ 311.0	$ 254.8	$ 253.7
Unloading facility	14.3	16.2	14.3
Impermeability treatment	79.0	88.2	60.5
Subtotal	404.3	359.2	328.5
Contingency (10%)	40.4	35.9	32.9
Total construction	444.7	395.1	361.4
Engineering Design (8%)	35.6	31.6	29.0
Supervision and Administration (6%)	26.7	23.6	21.7
Interest during construction (9%)	40.0	35.5	32.5
20-yr maintenance	646.6	646.6	646.6
Total cost	$1,193.6	$1,132.4	$1,091.2

COST PER CUBIC YARD IN DOLLARS

	A	C	D
	$6.22	$5.89	$5.68

*Alternate A: 60-ft dike, sand and stone construction.
Alternate C: 20-ft dike, stone construction.
Alternate D: 60-ft dike, steel and sand construction.

Appendix II

The specific method used for examining weighted sets of data maps is based on the following. Let N be the total number of data maps used, and let S_i be a quadrate score for data map i, i=1,2,...,N. We can associate with the data maps certain weighting factors $W_1, W_2, \ldots, W_N$ depending on the importance assigned to each data map. If this is the case, then a weighted total quadrate score, S_T, is given by

(1)
$$S_T = W_1S_1 + W_2S_2 + \ldots + W_NS_N$$
$$= \sum_{i=1}^{N} W_iS_i \ .$$

For example, if we wish to weight each data map equally, then we could assign $W_i=1$, i=1,2,...,N, and we would have

(2)
$$S_T = \sum_{i=1}^{N} 1S_i = \sum_{i=1}^{N} S_i$$

where

(3)
$$W_1 + W_2 + \ldots + W_N = \sum_{i=1}^{N} W_i$$
$$= \sum_{i=1}^{N} 1$$
$$= N \ .$$

Now suppose that we partition the data maps into two groups. Let

B = the set of benthic survey data maps, and

F = the set of fisheries data maps.

Within each group, we will assign equal weights, i.e.

(4)
$$W_i = W_B \quad \text{for } i \epsilon B$$

(5)
$$W_i = W_F \quad \text{for } i \epsilon F$$

where W_B is the weighting factor assigned to each benthic data map, and W_F is the weighting factor assigned to each fisheries data map. Maintaining the constraint that the sum of the weights equal the total number of data maps used (Equation 3), we have that

(3)
$$W_1 + W_2 + \ldots + W_N = N$$

implies

(6) $$n_B W_B + n_F W_F = N$$

where n_B is the number of benthic survey data maps, and n_F is the number of fisheries data maps.

Finally, if p is the proportion of the total weight assigned to the benthic survey data, and therefore, (1 - p) is the proportion of the total weight assigned to the fisheries data, then the above analysis suggests that an appropriate weighting is assigned to the two groups when

(7) $$n_B W_B = pN$$

(8) $$n_F W_F = (1 - p)N \ .$$

Equations (7) and (8) when solved for W_B and W_F yield

(9) $$W_B = pN/n_B$$

(10) $$W_F = (1 - p)N/n_F \ .$$

DUE DATE