NATIONAL DEMONSTRATION PROGRAM THIN-LAYER DREDGED MATERIAL DISPOSAL

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GULFPORT, MISSISSIPPI

1991-1996

SUMMARY REPORT

U.S. ARMY ENGINEER DISTRICT, MOBILE

SEPTEMBER, 1996

NATIONAL DEMONSTRATION PROGRAM
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1.0 INTRODUCTION

This report and the accompanying appendices present the results of the National Demonstration Program, Thin-Layer Dredged Material Disposal which was conducted in Mississippi Sound, south of Gulfport, Mississippi between 1991 and 1995. Further, this report will make recommendations concerning the use of thin-layer disposal in the context of the Framework for Dredged Material Management (U.S. EPA and USACE, 1992).

2.0 AUTHORIZATION

Improvement of the Federal navigation project at Gulfport, Mississippi was authorized by the Water Resources Development Act of 1986 (Section 202(a), Public Law 99-662). This legislation stated that for reasons of environmental quality, dredged material from the project would be disposed of in open water in the Gulf of Mexico in accordance with all provisions of Federal law. For the purpose of economic evaluation of the project the benefits from such open water disposal were legislated to be at least equal to the costs of the disposal.

Section 4(n) of the Water Resources Development Act of 1988 (Public Law 100-676) modified the above to provide for the disposal of dredged material from the construction, operation, and maintenance of the project by thin-layer disposal in Mississippi Sound under a national demonstration program.

2.1 DEMONSTRATION PROGRAM.

During construction of the Gulfport Harbor navigation project, the Corps of Engineers was directed to carry out a demonstration program to evaluate the costs and benefits of thin-layer disposal in the Mississippi Sound of dredged material from construction of harbor improvements, including any operation and maintenance materials that were moved during construction, and for determining whether or not there were unacceptable adverse effects from such disposal on:

(i) human health or welfare, including but not limited to plankton, fish, shellfish, wildlife, shorelines, and beaches;

(ii) marine life (including the transfer, concentration, and dispersal of pollutants or their byproducts through biological, physical, and chemical processes), changes in marine ecosystem diversity, productivity, and stability, and species and community population changes;

(iii) esthetic, recreation, and economic values; and

(iv) alternative uses of oceans, such as mineral exploitation and scientific study.

In addition, the program was to determine the persistence and permanence of any such adverse effects and methods of mitigating these effects.

The Legislation further required that a plan be developed in consultation with a study team for carrying out the demonstration program. The plan was required to establish predisposal monitoring requirements, thin-layer disposal locations, the amounts of dredged material necessary for carrying out the demonstration program, the duration of thin-layer disposal under the program, the compatibility of the receiving habitat with the thin-layer dredged material disposal, the requirements for minimizing demonstration program impacts, the depth of thin-layer disposal, and the scope of the post disposal monitoring.

The Legislation also required that suitable material removed during the construction of the Gulfport Harbor navigation project be of sufficient quantity to determine the effects of thin-layer disposal in near shore areas of (i) dredged material from construction of harbor improvements, and (ii) any materials from operation and maintenance of harbor improvements dredged during the period of construction; except that the total amount of material to be used was limited to the lesser of 3,000,000 cubic yards of dredged material or the amount determined under the demonstration plan.

The study team was assembled to assist in the planning, carrying out monitoring, and reporting on the demonstration program and the results of the program. The study team was to include representatives of the Corps of Engineers, the Environmental Protection Agency, interested Federal and State resource agencies, and the local sponsor of the demonstration program.

Within 1 year after the date of completion of the demonstration program the Corps of Engineers acting through the Secretary of the Army, after consultation with the study team, was required to transmit to Congress and to the Administrator of the Environmental Protection Agency, a report on the results of the demonstration program together with recommendations concerning thin-layer disposal in near shore area of dredged material from construction, operation, and maintenance of future navigation projects. Approval or disapproval of the recommendations by the Administration of the Environmental Protection Agency is required no later than 30 days after receipt of the report and recommendations. If the Administrator disapproves the recommendations, not later than 30 days after the date of such disapproval, the Administrator shall notify Congress and the Secretary of the reasons for such disapproval together with recommendations for modifications which could be made to the recommendations to take into account such reasons. If the Administrator fails to approve or disapprove the recommendations within the 30-day period, the recommendations shall be deemed to be approved.

2.2 THIN-LAYER DEFINITION

Section 4(n)(4) further defined thin-layer disposal as the deliberate placement of a 6- to 12-inch layer of dredged material in a specific bottom area. In no case was a thin-layer to exceed a maximum of 12 inches of thickness.

2.3 STUDY TEAM

The National Demonstration Program Study Team was established in January 1988. The Study Team included representatives of the Mississippi Department of Marine Resources, Mississippi Department of Environmental Quality, Mississippi State Port Authority at Gulfport, U.S. Fish and Wildlife Service, National Marine Fisheries Service, U.S. Environmental Protection Agency, Region 4, U.S. Army Corps of Engineers, Waterways Experiment Station, and was chaired by the U.S. Army Corps of Engineers, Mobile District. A listing of study team members is provided in Appendix 1.

The role of the Study Team was varied and included:

- development of the thin-layer disposal demonstration program including the quantity of material to be disposed and the length of the monitoring effort;
- development of the specific monitoring programs including the macroinfaunal, water quality, and fishery studies and the requirements for the hydrographic surveys
- review and approval of the scopes of work for each of the monitoring programs;
- serving on the contract selection team for the macroinfaunal studies;
- review of technical products produced during the demonstration program;
- review and comment on the summary final report.

3.0 PLAN FOR THIN-LAYER DEMONSTRATION

3.1 IMPACTS OF THIN-LAYER DISPOSAL

The basic plan for the demonstration program, as approved by the Study Team, would provide information for answering a number of questions including:

- What is the physical impact of thin-layer disposal on larval fishes?
- What is the biological impact of thin-layer disposal on fishery resources?
- What is the thickness of the layer of dredged material placed on the bottom during the operation?
- What changes in water quality occur as a result of the disposal operation and how long is the period of recovery to ambient conditions?
- What has been the impact of historic thin-layer disposal of maintenance material on benthic communities?
- What is the level of impact and how extensive is the period of recovery of

macroinfaunal communities following thin-layer disposal of new work material?

3.2 STUDY TEAM CONSENSUS PLAN

The Study Team came to consensus on the following aspects of the demonstration program:

- Analysis of the impacts associated with the placement of new work dredged material, i.e. virgin material dredged during the channel deepening, and maintenance dredged material, i.e. material which has shoaled into the channel since the last maintenance dredging operation.
- Use of a maximum of 1 million cubic yards of new work dredged material and only that quantity of maintenance material required to be removed from the channel to expose the virgin new work material.
- Investigation of the temporal aspects of thin-layer dredged material disposal impacts by performing separate disposal events, one each in the spring, summer, and fall, with approximately 330,000 cubic yards of dredged material placed during a specified 10 day disposal event.
- Determination of the long-term impacts of thin-layer dredged material to be addressed by investigating the differences between areas of Mississippi Sound which have historically been subjected to thin-layering of dredged material to those which have not received dredged material.
- Determination of the ability of existing dredging equipment to meet the engineering requirements of thin-layer dredged material disposal.
- Investigation of impacts limited to three resource areas:
  macrobenthic infauna, larval and juvenile fishes, and water quality.
- Macroinfaunal studies to be conducted in two parts:
  (1) Determination of the response of communities to repeated disposal activities was restricted to sites which historically had been used for maintenance material disposal. These studies were required to be accomplished prior to initiation of construction and would also serve as the pre-disposal baseline for the recovery studies.
  (2) Recovery studies focused on the sites specifically used for new work disposal during the three temporal periods. These studies to span a two-year period following thin-layer placement.
- Water quality efforts to be focused on both maintenance and new work disposal and primarily on impacts occurring during and immediately following discharge (up to 6 months after).
- Traditional fish surveys measuring standing crop would be unlikely to provide useful information, because of the inherent variability of standing crop measurements among replicate samples and among years, and because tidal circulation would be expected to lead to rapid advection of planktonic and weakly swimming larvae, rapidly replenishing waters overlying the disposal site, and therefore limiting correlation of standing crop with the disposal event. Therefore, fishery studies were to be primarily laboratory focused, investigating the effects of suspended solids on feeding behavior

and predation using larval and subadult forms. *In situ* enclosure studies were proposed to verify the laboratory results. During the conduct of the fishery studies additional efforts were undertaken to: determine the survival of larval and juvenile fishes exposed to thin-layer deposition; and whether placement of dredged material in a thin-layer changed the acceptability of the substrate to foraging juvenile Spot.

4.0 HISTORY OF THIN-LAYER DISPOSAL IN THE MOBILE DISTRICT

Thin-layer disposal is the directed placement of dredged material in a thin, uniform layer in an attempt to provide environmental benefits or to reduce the environmental impacts that typically result from disposal of dredged material in a less controlled fashion (Nester and Rees, 1988). Several studies have investigated the deposition of dredged material on vegetated habitats (Wilber, 1993). The results of these investigations indicated that the immediate impacts of thin-layer placement and subsequent recovery/growth of the marsh was dependent upon the type and elevation of the wetlands involved, the type of dredged material, and the thickness of the dredged material layer placed on the wetlands. Wetlands located at the higher end of the wetland zone, i.e. high marshes, showed greater negative response to thin-layer disposal than did those located at the lower end of the zone. Placement of clumped dredged material or dredged material composed of large grained sediments resulted in greater immediate damage to the vegetative habitats as well as prolonged recovery periods. Wetlands responded most favorable to placement of thin-layers of fine grained dredged material up to 24 inches. Upland thin-layer placement applications are rare, but the USACE Vicksburg District has used dredged material layers of 2 - 3 feet to improve farmland along the Mississippi River (Wilber, 1996).

Although the maintenance of the Gulfport Channel historically resulted in the deposition of a thin layer of sediments on the bottom, this was due to the extremely fine grained nature of the sediments not a directed placement. The first directed placement of dredged material to achieve a thin-layer was performed in 1986 in Mobile Bay, Alabama as part of the maintenance of the Fowl River navigation channel.

4.1 FOWL RIVER, ALABAMA

4.1.1 Introduction. In 1986, the Mobile District initiated studies aimed at determining the impacts associated with thin-layer placement of dredged material into open-water sites. The basic premise behind these efforts was that if the placement of dredged material could be managed in such a way to mimic natural sedimentary disturbances, then the direct impacts to benthic infaunal communities and the indirect impacts to fish and crustaceans that feed upon the infauna would be reduced. Fowl River, is a small coastal stream on the western shore of Mobile Bay, Alabama (Figure X). Historically, Fowl River had been maintained utilizing open water disposal during which no attempt was made to restrict the height of the dredged material. Redistribution of the material following disposal was restricted to that which was caused by the natural processes of currents and waves. In 1985, the Mobile District requested that the State of Alabama recertify, pursuant to Sections 401 and 404 of the Clean Water Act, the maintenance of the Fowl River project in the same manner as had been practiced in the past. In response to the public notification of this request, many Federal agencies expressed their concern of the adverse impacts caused by open water disposal and recommended that the recertification be denied and that the maintenance of the project be dependent upon the location of an upland area which would be used for containment of the dredged material. Negotiations were undertaken over the next several months which resulted in a compromise plan utilizing a upland area for the maintenance of a portion of the project and the conduct of a study of the impacts associated with the deliberate placement of dredged material in a thin-lift in a specified area of Mobile Bay. The agencies further agreed that the study would include analysis of impacts on macroinfaunal communities, water quality and fishery resources of the area. During this study, the thickness of the dredged material layer was not to exceed 24 inches and no effort was to be made to place the material in a layer of consistent thickness within the disposal area. The plan was such that the impacts of differing thickness of dredged material would be determined with the ultimate goal of determining what was an acceptable thin-layer thickness.

A one year study was devised during which various aspects of the environment would be measured prior to disposal, during disposal, and at varying periods following disposal. Questions that were to be answered during the Fowl River Thin-Layer Study included:

- What constitutes an acceptable thin-layer disposal?
- What are the impacts to the macroinfaunal community from thin-layer disposal?
- What changes in water quality parameters occur during thin-layer placement, to what degree do they extend outside the boundaries of the disposal area, and how long are the changes evident following disposal?
- Does thin-layer disposal in an open water area discourage use by fishery resources?

Approximately 190,000 cubic yards of maintenance dredged material was removed from a portion of the Fowl River channel between July 26 to August 27, 1986. The material was predominately silty-clay and was placed in a 240 acre disposal area south of the channel in Mobile Bay, in water depths of 3.6 to 10.2 feet. A hydraulic dredge equipped with a 6-blade basket cutterhead pumped material through a 20 inch pipe approximately 4,000 feet to the disposal area. To allow movement of the dredge and discharge outlet, the discharge pipe passed through two steel vertical swivel ball joints, one about 640 feet from the dredge, the other about 180 feet from the outlet. A wing-mounted baffle plate was used at the outlet to spread the slurried material. Discharge occurred above the water surface. Placement of material was controlled by anchoring the barges holding the swivel joints and then moving the barge with the discharge outlet over an arc of up to 300 degrees and a 60-meter radius. Barges were relocated to different parts of the disposal area as needed.

Several types of monitoring data are available from the Fowl River Project. Precision bathymetry was measured before dredging and 6 and 20 weeks after dredging ceased. Sediment profile imagery was made before dredging, and 2, 6, 20, and 52 weeks post dredging. Water quality, primarily total suspended solids (TSS) and dissolved oxygen (DO), were measured before and during dredging. Infauna abundance, diversity, biomass, and recruitment were examined before dredging and 2, 6, 20, and 52 weeks post dredging. Fish abundance and diversity were examined at the same times as the infauna data. The following paragraphs summarize the studies conducted and their results (TAI, 1987).

4.1.2 Bathymetry. Monitoring the distribution of dredged material in an open-water thin-layer disposal project can be difficult. Under typical field conditions, the accuracy of precision bathymetry may equal or exceed the design thickness of the dredged material layer. In this study an additional technique, vertical sediment profile imagery, which will be discussed in detail later in this chapter, was also utilized to determine the thickness of the dredged material layer.

Contour maps were generated from over 23,000 data points providing a detailed map of the survey areas. These maps were utilized to define specific areas by the depth of the placed dredged material as well as how the dredged material responded to natural forces following placement.

Data generated from the first survey, 2 weeks predisposal, was used to determine background topography in the study area. The topography was relatively smooth with depths increasing from 2 feet near shore to 10 feet along the eastern boundary. Contour lines ran parallel to the shore with the channel itself only slightly deeper than the surrounding areas.

The second bathymetric survey, conducted 6 weeks after the disposal, showed clear evidence of sediment accumulation in the defined disposal area and adjacent areas to the south. The largest amount of sediment accumulation occurred in the southern portion of the defined disposal area and the area identified as the south fringe area. Sediment accumulation to a depth of 0.5-foot or greater covered a total area of 203 acres, 41% which was located in the disposal area and 59% in the fringe area, in the direction of the prevailing currents. Sediment accumulation exceeding 1-foot in depth covered 48.7 acres, 72% in the disposal area and 28% in the fringe area. Accumulation in excess of 2 feet covered 2 acres all within the defined disposal area. The point of discharge during the disposal operation was located in the disposal area despite much of the dredged material settling in the fringe areas. The presence of significant sediment in the fringe areas was likely due to current displacement and wave action during the actual disposal operation. Circulation of this area of Mobile Bay is primarily to the south which would account for the material dispersing out of the designated disposal area to the southern fringe area.

To further evaluate dispersion and sediment drift in the study area, a third bathymetric survey was done 20 weeks post disposal. Results showed that significant sediment accumulation was seen in both the disposal and fringe areas. Total sediment accumulation greater than 0.5-foot covered 151 acres, of which 50% was located in the disposal as well as the fringe areas. Sediment exceeding 1-foot covered 43.8 acres, of which 83% was found in the disposal area. Sediment accumulation exceeding 2 feet covered 1.65 acres within the designated disposal area.

The total area of sediment accumulation with a rise of 0.5-foot or greater showed a decrease of 52 acres (26%) between the 6 and 20 week surveys. Eighteen percent of the decrease occurred within the fringe area. Sediment accumulation exceeding 1-foot decreased by 10% between the two surveys. The volume of sediment exceeding 0.5-foot between the two surveys decreased by 74,000 cubic yards (24%).

Use of sediment profile imagery showed that dredged material covered about 319 acres. This discrepancy in acreage is not surprising since the imagery can detect thinner layers of dredged material. One year after disposal, sediment profile imagery indicated that the areal extent of the deposit had decreased by 10 to 20 percent.

4.1.3 Water Quality. Two weeks prior to dredging, eight evenly spaced stations within the disposal site and a reference site 2,400 feet up the bay north of the disposal site were sampled for dissolved oxygen (DO), salinity, temperature, and total suspended solids (TSS). Current speed and direction were also measured. A second survey was conducted during the actual disposal operation. During this survey a grid including 12 stations located around the point of discharge was established. One transect was set perpendicular to the current flow and one set parallel to flow.

Predisposal water quality parameters were highly variable as would be expected for a shallow estuarine system. Currents were relatively low, under 0.1 knots and a southerly flow was evident during both flooding and ebbing conditions. DO concentrations averaged 5.8 mg/l with a range from 1.6 to 7.9 mg/l with lower readings typical of early morning hours. DO exhibited a vertical gradient with a range of 3 to 4 mg/l difference between the surface and bottom readings, with lower values found at depth. TSS ranged from 5 to 34 mg/l with a mean of 8 mg/l. Tidal currents appeared to have no influence on TSS. Salinity and temperature were relatively constant with averages of 30.7 ^{0}C and 10.9 ppt, respectively. Both temperature and salinity were highly uniform at all stations sampled.

As would be expected, disposal operations had no impact on current speed or direction, water temperature, or salinity. During disposal operations, DO averaged 6.6 mg/l with range of 1.8 to 16.8 mg/l. Mean DO for individual stations ranged from 6.1 to 6.9 mg/l. The higher DO concentrations were likely due to increased phytoplankton activity. There was no correlation between DO and distance from the discharge point with exception of the reference station which averaged 8.9 mg/l. DO measurements were similar throughout the survey and showed no consistent variation due to disposal operations.

Significantly higher TSS concentration were recorded during the disposal operation. The overall mean for the disposal area was 164 mg/l, with a range from 5 to 4360 mg/l. Mean TSS concentration at individual stations ranged from 47 to 510 mg/l with the higher concentrations found 120 feet from the discharge in all directions. Background levels were generally reached 360 feet from the discharge. A similar pattern was seen for bottom waters except that TSS concentrations 90 feet from the discharge typically ranged from 400 to 600 mg/l and did not approximate background levels until 1200 feet from the discharge. TSS showed a decrease with increasing distance from the discharge source. TSS concentration also showed a distinct vertical gradient during disposal depending on distance from the discharge point.

Because several agencies had expressed concerns that plumes of dredged material would lead to hypoxic conditions detrimental to fish and other marine/estuarine resources, the relationship between TSS and DO was examined during the Fowl River study. DO concentrations were measured at the same locations and times as TSS measurements.. Contrary to what is often suspected, only a very weak inverse relationship occurred between DO and TSS concentrations. For the agency concerns to have been documented, a strong relationship between increasing TSS and decreasing DO would have had to be observed. Weak relationships among these parameters appear to be the norm for well-flushed areas (Lunz *et al.*, 1988).

4.1.4 Macroinfauna Response. Macroinfauna are primarily invertebrates which either live within or in very close association with the bottom. These organisms range from microscopic forms such as polychaete worms to very large commonly known forms such as sand dollars and sea stars. The successional stage of macroinfaunal communities can range from azoic (0), pioneering (I), intermediate (II) to climax (III) communities (Rhoads and Germano, 1986). Pioneering communities are dominated by smaller organisms with little ability to burrow more than a few millimeters into the substrate. The taxa are typically dominated by deposit feeding organisms with sucking types of feeding apparatus. Climax communities are dominated by larger invertebrates that are adapted to deep burrowing activities. The taxa contain many larger "top-down" feeders, i.e. the organism lives upside down in it's tube and actually feeds from the bottom of the burrow, and a large variety of predatory type organisms. Shallow areas which are physically controlled are typically populated only by pioneering communities whereas deep areas in which physical disturbance is not a controlling factor are typically populated by intermediate and climax communities.

The entire macroinfaunal sampling program was designed to test the hypothesis that there were no differences between disposal, fringe, and reference areas through time. Mean organism abundance of macroinfauna was relatively constant throughout the study, ranging from 800 to 1500 organisms per m^2. Seasonal fluctuations were noted with the peak abundance occurring in spring (April) and fall (September). Lowest abundance was noted in the fall during the 6-week post-disposal survey in October. The range of macroinfauna abundance in this study was similar to the range observed in lower Mobile Bay in previous studies (Vittor, 1982). The number of species encountered, 50 - 75 taxa per sample, was consistent with previous investigations that showed a mean number of taxa to be around 53 per station (Vittor, 1982). A large degree of spatial heterogeneity was observed for the macroinfauna community which was directly related to the variation in substrate type within the study area. Temporal variability, however, was observed to be greater than the spatial differences. The taxa found during the Fowl River study are characteristic of a middle salinity, Stage I or pioneering sere. The characteristics of such a community are that they sometimes have eruptive population growth, exhibit a high biomass turnover rate and are generally tolerant to a variety of physical and chemical perturbations in the environment. Thus, they are indicative of a "naturally stressed" community or a community exposed to large amounts of disruptive energies.

Organism abundance for the 2-week predisposal sampling showed a relatively healthy community with total abundance ranging from 800 - 1500 organisms per m^2. The abundance of organisms for the 2-week post disposal sampling also showed a relative constant community with total overall abundance ranging slightly higher from 1000 - 2500 organisms per m^2. However, slightly lowered average abundance were noted for the disposal area proper. This lowered average abundance for the disposal area was also observed to persist into the 6-week post disposal sampling when total abundance for all areas declined. A weak correlation appeared to occur between the thickness of the dredged material and total infaunal abundance. Relative thick deposits of dredged material (30+ centimeters) had fewer infaunal organisms 2 and 6 weeks post disposal than areas with less than 15 centimeters of dredged material. The observed decrease in total abundance, however, was not statistically verifiable by analysis of variance in either fixed or random station data. This lack of statistical significance was probably due to the large degree of spatial variability observed during all sampling efforts.

Variability in individual species could not be statistically related to the dredged material disposal. However, a slight increase in abundance of the polychaete *Mediomastus* was noted in some of the disposal stations, especially at the stations which had received the major portion of the disposal materials. Variation in community, as reflected in similarity analyses, was not found to be related to the disposal activity. Seasonal trends were most likely driven by changes in the natural environment, e.g.;. temperature, rather than changes brought about by the thin-layer disposal.

4.1.5 Sediment Profile Photography. A unique investigatory technique, vertical sediment profile photography, was utilized to get a cross-sectional *in situ* image of the thin-layer placement. This technique and the results are explained in some detail here and in the 1986 Gulfport Thin-layer Study described below as it was not used in the National Demonstration Program. This technique utilizes a coring device with a plexiglass plate on one side. A camera with internal light source sits within the coring device with the lens against the plexiglass plate. The coring device is lowered into the substrate and a photograph is taken which shows the sediment -water interface, a variable depth into the sediment, and any biotic structures which may be intersected by the plate. The purpose of the sediment profile photography was to document the thickness of the dredged material layer and the impact of the disposal operation on the sediment. A number of important measurements can be made using this technique including:

- Depth of penetration which is a good indicator of sediment type and compaction.
- Surface relief which gives an indication of bed roughness.
- Digitized Image Statistics are used for cross comparisons of images.
- Depth of Redox Potential Discontinuity (RPD) layer which gives a good indication of DO conditions in the bottom waters and the degree of bioturbation of the sediments.
- Color contrast of RPD which establishes the boundary of RPD and helps in understanding biologic and physical processes.
- Area of oxic and anoxic layers which gives a good understanding of RPD dynamics.
- Feeding voids which are a good indicator of deep living fauna and later stage succession.
- Other inclusions such as mud clasts or methane pockets which are helpful in understanding recent physical processes.
- Burrow presence which is an indicator of deep living fauna and succession stage.
- Surface features such as tubes, shell and other items which are indicative of recent biologic and physical processes.
- Sediment grain size which provides rough estimates of grain size distribution and sediment layering.
- Dredged material layers can be measured for thickness providing the best quantitative measure for relating impacts to macroinfauna.
- Successional stage which indicates the biological community development.

Vertical sediment profiling produced over 500 images of the surficial sediment in the reference, fringe and disposal areas. Prism penetration ranged from 5 - 10 cm for the majority of the study area with the exception of sandier northern reference area in which penetration depth was much less due to the density of the sediments. The study area showed much evidence of physical disturbance, and some evidence of biological reworking. Sandy inshore areas demonstrated wave ripples from 1 to 2 cm in height while muddy areas often demonstrated physical cycling of the upper sediment.

The infaunal communities of all of the areas investigated in the Fowl River study were classified as Stage I pioneering community typical of a physically dominated system, as described earlier in this chapter. The general nature of the infaunal community did not change throughout the study and as early as 3 weeks after disposal there was evidence that the fauna was burrowing through (up or down) and had recolonized the surface of the dredged material. At no time during the study were azoic, i.e. devoid of organisms, areas found indicating that the thin-layering of dredged material does not result in a total defaunation of the disposal area.

A broad scale recolonization event occurred following the thin-layer placement was seen in 2 week post disposal survey. The entire surface of the study area was colonized by a tube dwelling polychaete. The thickness of the tube mats made by these organisms did vary from station to station but they were present in all areas. Areas that received dredged material were similar to those that did not receive dredge material. By November (10 weeks post dredging) the tube mats were gone, however the entire study area was still classified as Stage I.

4.1.6 Fisheries Studies. During the Fowl River and the subsequent 1986 Gulfport thin-layer study, fishery research efforts were aimed at identifying impacts to standing crop of adult forms. As has been mentioned earlier, these efforts were not particularly rewarding but were utilized in the planning for the National Demonstration Program to produce more valuable research concerning the effects of thin-layer disposal on fishery resources.

A total of 6944 fishes, representing 54 species, contained within 27 families were collected over the 5 field efforts. The most abundant species were the fringed flounder, Atlantic croaker, and spot. For each survey period, different species dominated the totals with catfish dominating the predisposal survey. The post-disposal surveys were dominated by the 3 species mentioned earlier. Statistical analysis of temporal and spatial differences among fish species over the three sampling areas (disposal, north and south fringe) separated pre and post disposal fish collections. For the predisposal survey, a clean spatial separation was present for all three areas. Post-disposal survey spatial separation was less obvious with the southern fringe linked with the disposal area. This trend continued throughout the 4 post-disposal surveys with the southern fringe area linked with the disposal area leaving the north fringe area separate. This is likely linked to the macroinfaunal community present in these areas as many of these fish species feed on the macroinfauna. The overall fisheries resource had no observable long-term impact, and short-term impacts were limited. No overall changes in study area utilization appeared to have taken place which reflects on the highly active and motile nature of this portion of the estuarine community.

4.1.7 Conclusions. Based on the results of the bathymetric surveys and vertical sediment profiling imagery, dredged material was detected and measured throughout the entire year long study. There was evidence from both methodologies that the dredged material was slowly drifting out of the designated disposal area and was being reworked by physical and biological factors. Transient impacts to water quality were observed during the actual disposal operations primarily in terms of elevated total suspended solids. The impacts, however, were localized to a small area around the discharge point. Both the bathymetric and water quality investigations demonstrated that rapid settling of the solids in the discharge slurry occurred within the disposal area. This was further confirmed with the sediment vertical profile imagery results. The macroinfauna community of the Fowl River area of Mobile Bay was dominated by a pioneering (late) type I fauna characteristic of middle estuarine areas. Community characteristics include a dominance of smaller opportunistic organisms with a high biomass turnover rate. Some larger polychaete worms were collected and noted in the vertical sediment profile images, but no "head-down" feeding type organisms were observed. The major variables which contributed to community heterogeneity were depth and sediment grain size. A slight reduction in total macroinfauna abundance was observed following the dredged material disposal within the designated disposal area. Community changes attributable to dredged material disposal were not observed with either the community analyses on the biological data or with community observations seen with vertical sediment profiling. Variation both spatially and temporally was more attributable to the physical and chemical changes which are naturally observed on a seasonal basis in this estuarine environment. Impacts of the dredging operation were apparent for only a limited portion of the fisheries resource. This impact was short-term, such as fringed flounder being attracted into the disposal and southern fringe areas by high numbers of recolonizing *Mediomastus*. Decreases in post disposal abundance noted for several dominant fishery taxa were correlated to seasonal recruitment patterns and so were not directly attributable to impacts of dredged material disposal. The overall fisheries resource had no observable long-term impact, and short-term impacts were limited. No overall changes in fishery utilization of the area appeared to have taken place.

4.2 1986 THIN-LAYER DISPOSAL, GULFPORT, MISSISSIPPI

4.2.1 Introduction. Because thin-layer disposal had been discussed as a means of disposal for materials removed during the improvements to the Gulfport Harbor, the Mobile District seized on an opportunity to evaluate the impacts of thin-layer disposal of new work material during the 1986 maintenance of the Gulfport Harbor (TAI, 1988). Between December 25 - 26, approximately 50,000 cubic yards of virgin material were removed from the northern portion of the Mississippi Sound channel following maintenance and placed in a small unused disposal area to the east of the channel. The methods of evaluating the impacts were the same as those used previously for the Fowl River study and will not be repeated. The only exception involved the water quality investigations. Pre-disposal investigations were completed, but because the disposal operation only lasted 2 days over the Christmas holiday, during disposal investigations were not conducted due to logistical problems. To ensure that this problem did not exist during the National Demonstration Program, the demonstration plan specified the time frame for the disposal operation and the cubic yards to be removed as well as the number of days that the disposal operation was required to cover.

4.2.2 Bathymetric Studies. The predisposal bathymetric survey showed the topography of the study area to be relatively smooth with depths gradually increasing from 10 feet in the north fringe to 11 feet in the south fringe. The 10.5 foot contour line was located at the center of the disposal area running east to west.

A second survey conducted 2 weeks post-disposal showed clear evidence of sedimentation accumulation within the study area. The area of greatest sediment deposition was centered within the disposal area with the fringe regions receiving only small amounts of sediment accumulation. The area of sedimentation exceeding 0.5 foot was located generally in the western half of the disposal area. The maximum rise throughout the study area was less than 1 foot A third survey was conducted 6 weeks post-disposal to evaluate the effects of dispersion, compaction and sediment drift. Evidence of a sediment mound within the study area was still present. The area and volume of the sediment deposition showed a net decrease of 55% and 62%, respectively during the 4 weeks between the two surveys. This decrease was presumably due to sediment migration and dispersion from turbulence and wave action. A final survey was conducted 20 weeks post-disposal. The distinct sediment mound present in earlier surveys was not found indicating movement or compaction of the sediments over time.

4.2.3 Macroinfauna Response. Again the sampling regime was designed to test the hypothesis that there are no differences between disposal, fringe, and reference areas. Sampling of the macroinfaunal community at the Gulfport site revealed a diverse community with the number of organisms generally in the range of 2000 - 3000 organisms per m^2. The area was characterized as late Stage II - Stage III community. Several large tube-dwelling and head down feeder organisms were collected predisposal including brittlestars.

Abundance of organisms during the 2-week and 6-week post disposal surveys showed a distinct reduction in areas of the site which had received dredged material. This was a highly significant difference in abundance and could be directly attributable to the disposal operation. By the 6-week post disposal period, abundance had recovered somewhat and by 20 weeks post disposal abundance had returned to predisposal levels and was similar to areas which had received no dredged material. In terms of number of taxa per sample, a trend similar to the decrease in abundance was noted except that by 6 weeks the number of taxa had returned to values similar to the reference stations and by 20 weeks there was no distinguishable difference. Analyses of the abundance of individual taxa, indicated that except for pioneering types of taxa all macroinfauna were equally affected by the material discharge. This implies that the impact was of a physical nature since there was no selectivity in terms of reducing certain community members.

Recovery of the area in terms of the macroinfauna was primarily mediated by rapid adult migration into the area as well as some survival and subsequent migration through the disposed materials. No large scale larval recruitment was noted but this was due more perhaps to seasonal factors since the recovery period covered the winter months during which larval recruitment is not expected.

4.2.4 Sediment Profile Photography. Overall the entire surface area consisted of homogenous sediments. The sediments were categorized as silty-clay and were uniform over the study area. The grain size of the disposal sediment was very similar and thus did not add any heterogeneity to the sediments. Surface relief from all sampling dates was generally less than 1 cm. Overall sediment relief increased from 2 weeks post-disposal to the 20 week survey indicating the sediment was physically disturbed throughout the survey period. The depth of the reduced potential discontinuity layer (RPD) varied over the study area. Shallowest RPD values occurred at stations with disturbed surfaces and stations with little evidence of biogenic features. The deepest values were associated with burrows of macroinfaunal organisms. The disposal material signature slowly disappeared over the survey periods. Disposal material was only detected at 2 stations during the 20 week and 52 week survey. Disposal sediments had either been advected out of the study area or been worked into the original sediments, either by biological or physical factors.

The infaunal community at this study area is an advanced Stage II to Stage III community characteristic of areas where physical disturbance is not a controlling factor. Several large tube-dwelling and head down feeder organisms were collected including brittlestars and sea cucumbers. These organisms are known for their intense burrowing behavior which probably contributed to the rapid recovery and reworking of the dredged materials due to some upward migration through the thin-layer of dredged material. The sediment profile photography also indicated a transient shift in the community as the result of disposal. The 2-week post disposal survey showed some areas impacted by the disposal operation to be of early Stage I type community with dense polychaete tube mats similar to the Fowl River studies. Other areas during this survey were in late Stage I to Stage II based on the amount of burrowing activity. Even during the 2-week post disposal there were signs of advanced recolonization at some of the stations impacted by dredged material disposal. These observations are suggestive of an upward migration of the larger fauna through the thin-layer of dredged material. By the time of the 20-week post disposal survey, the community was again classed as a Stage III community. As with the Fowl River studies, it should be emphasized that no azoic, i.e. devoid of organisms, areas were found at any time in the study.

4.2.5 Fisheries Study. Again, standing crop of fishery resources was targeted in the monitoring effort. During all fisheries surveys a total of 111,768 fishes were collected representing 38 species in 23 families. The most abundant species was the bay anchovy, hardhead catfish was the next most abundant, the Atlantic croaker was third. Over the course of the monitoring periods, distinct variations in species composition and abundance were noted. However, statistical analysis indicated that the dominant species showed highly significant temporal distribution i.e. the abundance was responsive to the time of year not as response to the disposal operation. Only one species, hardhead catfish, had a significant spatial distribution with lowest abundance occurring in the southern fringe area. The overall fisheries resource had no observable long-term impact, and short-term impacts were limited. No overall changes in study area utilization appeared to have taken place which reflects on the highly active and motile nature of this portion of the estuarine community.

4.2.6 Conclusions. The depth of the thin-layer placement was between 6 - 12 inches based on the precision bathymetric surveys and slightly greater than 6 inches based on sediment profiling. Detection of dredged material was difficult by the 20-week post disposal survey. Observations indicated that the dredged sediments were being reworked into the natural bottom sediments by biological processes as well as being transported out of the designated disposal area by currents and wind generated waves. Impacts to the macroinfaunal community were observed in terms of lowered abundance and slightly lower numbers of species at the areas directly impacted by the disposal operation. This observation was corroborated with the biomass data and the vertical sediment profile images in terms of successional stages of the benthos. By 6 weeks, some recovery of the benthic community was observed in both an increase in the numbers and kinds of organisms at the disposal location. By 20 weeks, no differences between the disposal and control areas could be discerned. This recovery paralleled the disappearance of the dredged sediments observed by the bathymetric data and the sediment profile imagery. In part, the disappearance of the material could be directly attributable to the biological reworking of the dredged sediments, incorporating them with the underlying sediments. However, evidence of large scale physical events were also noted in the vertical sediment images which may also contribute to the disappearance of the dredged material signature. Recovery of the area in terms of the macroinfauna was primarily mediated by rapid adult migration into the area and some survival and subsequent migration through the dredged material. No large scale recruitment was noted but this was probably due to seasonal factors since the recovery occurred through the winter months. The impacts of the new work dredged material disposal appeared to have been confined to a limited portion of the fisheries resource, namely Atlantic croaker and least puffer. This impact was short-term as populations that were noticeably low during the 2 week post disposal monitoring had returned to normal by 6 weeks. There was no observable impact on the fisheries resource as a whole, either short or long term.

The differences in responses reflects the differences in the community types of the benthic macroinfauna and fisheries resource populations. The relatively sessile benthic population displayed more sensitivity to the area-limited perturbation of thin-layer disposal in terms of a reduction in the abundance of some of the major taxa, total number of organisms, number of species and in total biomass. This impact was temporary and within 20 weeks, the macroinfauna community had recovered so that the impacted area was no longer distinct from the surrounding areas.

5.0 OVERVIEW OF MISSISSIPPI SOUND IN THE VICINITY OF GULFPORT

Mississippi Sound is a shallow coastal lagoon about 80 miles long between Mobile Bay, Alabama, and Lake Borgne, Louisiana, and 7 - 15 miles wide (USACE, 1989). The Sound is separated from the Gulf of Mexico by a series of east-west tending barrier islands. Mean depth is 10 feet below MLW, and less than 1% of the Sound is deeper than 20 feet. The Sound receives saline water from the Gulf of Mexico and freshwater from rivers and streams that drain approximately 20,000 square miles. The Pearl River, 30 miles west of the study area, is the major source of freshwater to the Sound, followed by the Pascagoula River, 27 miles to the east. Freshwater also enters the Sound from the Mobile River, via Mobile Bay, and from the Mississippi River when the Bonnet Carre Spillway is opened to relieve extreme flood waters into Lake Pontchartrain and Lake Borgne.

The Sound's circulation is controlled by tides, winds, and freshwater inflows. Tidal waves typically enter the Sound through Horn Island Pass, near Pascagoula, Mississippi, and split into eastward and westward progressing waves. The tidal range is typically about 1.5 feet and can be affected significantly by winds and weather fronts. In the study area, currents generally flow towards the west and southwest, but westerly winds frequently reverse this general pattern. Northern and southern winds can induce localized effects and may even cause eddies in the Sound's shallow areas. Sustained northwesterly winds in summer and winter often push much water out of the Sound, exposing large areas of oyster reefs and sand and mud bottoms. Current speeds typically range from 0 to 0.8 feet per second (Kjerfve, 1983). Significant salinity stratification occurs at various times during the year, and detectable salinity wedges may extend to 20 miles upstream in the rivers. Salinities range from about 3 ppt shoreward to 24 ppt at the barrier islands during January (at times of high river flow). During summer, salinities range from 27 ppt at the shore to 35 ppt at the barrier islands. Water temperatures range from 10 - 14 °C in the winter and from 27 - 29 °C in the summer (Christmas, 1973).

The Gulfport Harbor navigation channel extends about 20 miles; beginning at the port, extending through the Sound between Cat and Ship Islands, and into the Gulf of Mexico (Figure 1). Before deepening, the South channel was 220 feet wide and 30 feet deep. Plastic clays, poorly graded sands, and silty sands are common in the channel. Occasional pockets of clayey sands and silty sands are also presents. Historically, maintenance material was disposed in dispersive, open-water sites along the western side of the channel. The channel improvements deepened the channel to 36 feet at the existing width.

6.0 SUITABILITY OF THE GULFPORT DREDGED MATERIAL FOR OPEN WATER DISPOSAL

One of the first questions which must be asked prior to determining a disposal methodology is whether the material is suitable for open water disposal from a chemical contaminant standpoint. Material from the Gulfport channel was subjected to chemical and biological analyses prior to the initiation of the National Demonstration Program (USEPA, 1987). Sediments from the channel were determined to exhibit no toxic characteristics with respect to marine organisms. Although the sediments were determined to contain measurable levels of heavy metals and aliphatic and aromatic hydrocarbons in excess of the reference site, there was no evidence that organisms allowed to live within these sediments bioaccumulated any of these contaminants in quantities which were significantly different from animals which were allow to live within the reference sediment. Based on these results and following the guidelines for determining suitability of dredged material for disposal in open water it was determined that the sediments were determined suitable for uncontrolled open water disposal.

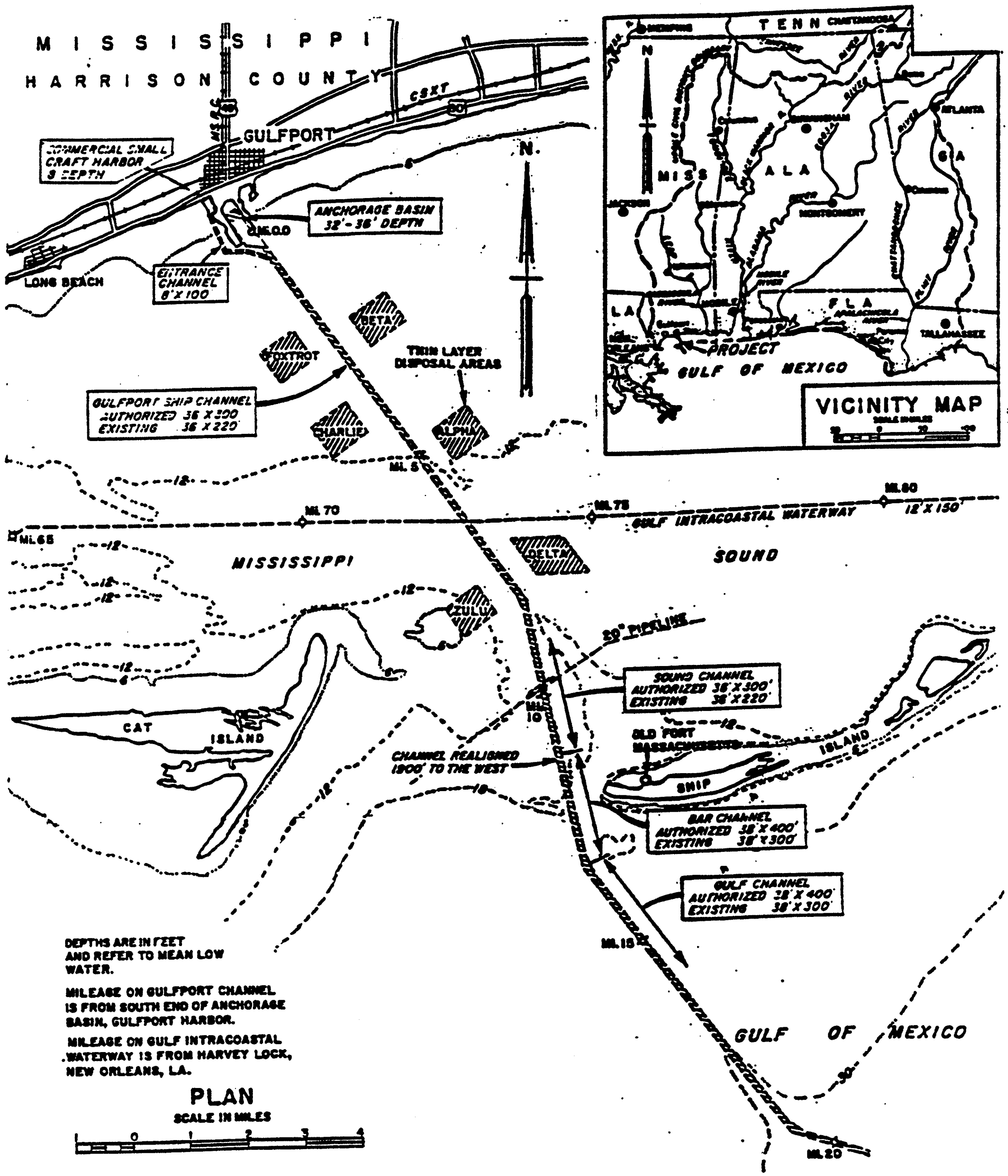

Figure 1. Gulfport Harbor Federal Navigation Project.

7.0 GULFPORT, MISSISSIPPI THIN-LAYER DISPOSAL NATIONAL DEMONSTRATION PROGRAM

7.1 INTRODUCTION

Although many of the questions raised concerning the impacts of thin-layer disposal were answered by the Fowl River and 1986 Gulfport studies, several questions remained and new questions concerning the impact to larval and subadult fishery resources had been raised. In addition questions concerning the applicability of the results from small scale operations to a full-scale operation had been raised. Based on the success of the earlier thin-layer studies, the Water Resources Development Act of 1988 authorized the Gulfport Thin-Layer Disposal National Demonstration program, the first large-scale, production-mode examination of whether thin-layer disposal reduces environmental impacts from conventional open water disposal or whether it could be used to provide benefits to the estuarine system. Macroinfauna, fisheries, and water quality were the major components of the program, and they were accomplished by the Mote Marine Laboratory (Sarasota, Florida), National Marine Fisheries Service Beaufort Laboratory (Beaufort, North Carolina), and USAE Waterways Experiment Station (WES, Vicksburg, Mississippi), respectively. Bathymetric results of the thin-layer were determined by Great Lakes - Gulfcoast Trailing Joint Venture and USACE District Mobile, Operations Division.

As mentioned earlier, 330,000 cubic yards of new work material and an equal amount of maintenance material was to be utilized during each of three disposal operations. Six thin-layer disposal areas were identified (Figure 2) for use, the new work disposal areas restricted to the eastern side of the channel which typically does not receive dredge material during the maintenance of the project. Maintenance thin-layer disposal areas were restricted to the western side of the channel. The schedule for use of the sites is presented in Table 1.

7.2 THIN-LAYER DISPOSAL METHODOLOGY

To ensure the placement of dredged material in a relatively smooth layer no thicker than 12 inches above the ambient bottom, the Contractor, Great Lakes - Gulfcoast Trailing Joint Venture, was required to submit a disposal plan for approval by the Contracting Officer. The Contractor initially surveyed the designated disposal area and divided it into lanes, approximately 1500 feet long by 400 feet wide. The Contractor then computed the time to dredge the reach containing the required material, the anticipated production rate, the acreage required if the maximum 'theoretical' thin-layer (12 inches) was to be obtained, and the thickness of material if the total discharge area was used to contain the designated amount of dredged material. The contractor then calculated the speed range that the discharge barge would be required to move at within the disposal lane given the above information. The pattern was initially defined by determining the

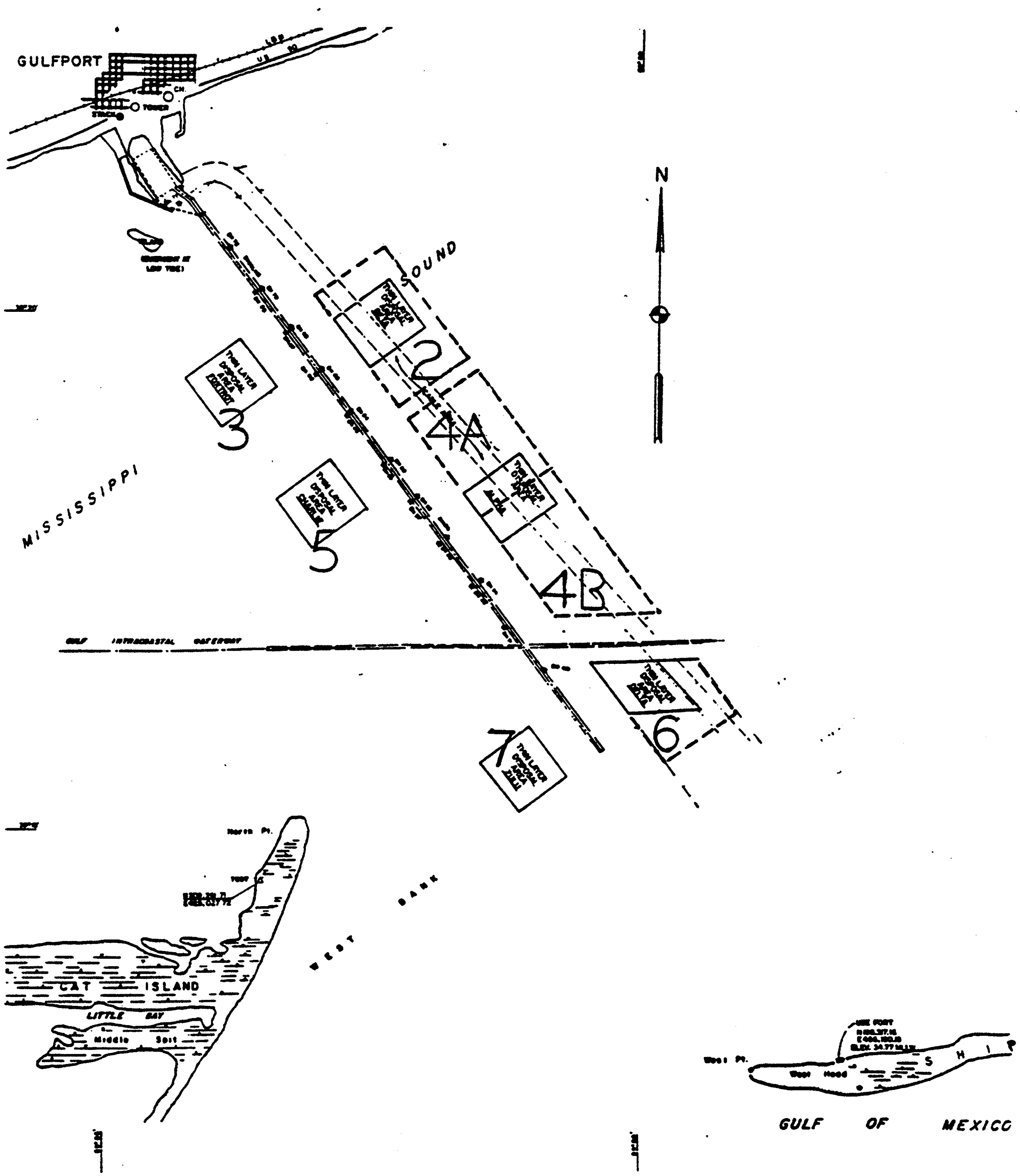

Figure 2. Thin-Layer Dredged Material Disposal National Demonstration Program Study Areas.

length of time the barge would remain at any one spot within the disposal lane and deposit 12 inches or less of material. This pattern was input into the computer system onboard the barge. The system would then direct the dump foreman to adjust the winch system moving the barge along the disposal arc and within the discharge lane.

TABLE 1. Thin-Layer Disposal Schedule And Study Parameters

Disposal Area	Material Type	Disposal Dates	Monitoring Parameters
ALPHA	New Work	3 - 14 Aug 1992	LTB, Macroinfauna, Fishery, Bathymetry
CHARLIE	Maintenance	*	*
BETA	New Work	26 Sept - 5 Oct 1992	WQ, LTB, Macroinfauna, Fishery, Bathymetry
FOXTROT	Maintenance	15 - 24 Sept 1992	WQ, LTB, Fishery, Bathymetry
DELTA	New Work	4 - 8 May; 11 - 25 May 1993 **	WQ, LTB, Macroinfauna, Fishery, Bathymetry
ZULU	Maintenance	20 - 27 March; 10 - 14 April 1993 **	WQ, LTB, Fishery, Bathymetry

WQ = Water Quality Studies; LTB = Studies on the long-term effects of thin-layer disposal; Macroinfaunal = Studies on the impacts of thin-layer disposal of new work material; Fishery = Fishery Studies; Bathymetry = Bathymetric Surveys

* The reach of the channel adjacent to the Charlie site did not contain any maintenance material requiring removal therefore disposal and subsequent monitoring of this site was not conducted.

** Consistent bad weather, problems with the dredge equipment, and slower than expected production by the dredge caused deviation from the planned 10-day duration disposal, subsequently disposal was reinitiated.

The discharge barge is free floating, anchored to a swivel barge by a pontoon dredge line. The barge has a real time positioning system operational at all times during the operation and is manned by both the barge foreman (winch operator) and a computer operator. The barge foreman has an enhanced color schematic of the predisposal survey visible at all times, with the computed minimum and maximum travel speed displayed as well as the position and actual speed of the barge traveling along the discharge arc. Additionally, the discharge barge is equipped with fore and aft trisponders reading data into the computer along with fore and aft lead lines for quality control. The discharge arc is changed by moving the swivel barge to the next predetermined position within the discharge lane. The spreader barge moves in the disposal arc and advances within the disposal lane with the help of left and right anchors which are attached to the deck mounted winch. The pipeline anchors as well as the anchors on the bow of the spreader barge are moved by tender tug. The tender tug works the pipeline continuously to assist the spreader barge in making the appropriate advance within the disposal lane.

Although a provision was made to use a drag bar to smooth any peaks greater than 12 inches in height, this operation was not required during the demonstration program.

Discharge during the demonstration program was accomplished with submerged discharge, i.e. baffle plate submerged beneath water surface due to State requirements concerning open-water disposal.

7.3 BATHYMETRY

The basic question to be answered by the bathymetric studies was what was the thickness of the layer of dredged material placed on the bottom during the national demonstration studies. Indirect questions which were also answered include whether existing equipment and techniques are sufficient to control the thin-layer placement of dredged material and if not what recommendations could be made to ensure that future thin-layer placements are accomplished according to contract specifications.

Bathymetric surveys of the designated disposal areas were conducted prior to initiation of thin-layer placement, during the placement operation, and immediately following placement to ensure that the thin-layer placement met the contract requirements of no thicker than 12 inches. Based on these surveys, it appears that the actual thin-layer placement resulted in a rather uniform layer approximately 6 inches in depth. At no location did material placement result in a layer thicker than 12 inches.

The plan prepared by the Contractor was adequate to ensure that the contract specifications were met. The thin-layering of maintenance material turns out to be much easier than that of new work material. There is still a requirement to move the spill barge when dealing with fine grained maintenance material but it is not as much or as fast in the arc movement and in the movement within the disposal lane than when dealing with new work or heavier grained maintenance material.

Existing equipment are suitable for accomplishing a defined thin-layer disposal. Time of year, i.e. the thin-layer placement into areas Delta and Zulu were hampered by the fickle weather patterns which confront this part of the coast during the spring; depth of water; and nature of the material to be dredged and thin-layered all have to be taken into account in planning a successful thin-layer operation. These and other recommendations are presented in Chapter 8 of this report.

7.4 MACROINFAUNAL RESPONSE LONG TERM DISPOSAL ANALYSIS

7.4.1 Introduction. The basic question asked was what is the impact of long term repetitive thin-layer disposal on the macroinfaunal community. The 30-foot navigation channel at Gulfport was initiated in 1932 and completed in April 1950. Construction and subsequent maintenance of the channel segment within the Mississippi Sound was performed by hydraulic dredge with unconfined open water disposal in sites adjacent to the channel. The channel requires maintenance about every 18 months and the material removed is primarily very fine grained, high water content silt and clays. Some sandy material exists in the southern reach of the channel. In recent history, only the sites on the western side of the channel were used for disposal. This is due to sediment movement which is predominately westward, therefore use of sites on the east would result in the material being moved directly back into the channel. For all practical purposes sites on the western side of the channel had been used for disposal of maintenance material on an 18 month basis for over 25 years. In addition, due to the nature of the material a thin-layer disposal was accomplished even though it was never contemplated. This provided an excellent opportunity to answer questions concerning long-term effects which would not have been possible otherwise.

Macroinfauna are good indicators of the health of an estuarine system and are useful in determining changes since the factors affecting their distribution are well known (Collard and D'Asaro, 1973). Substrate type is paramount in determining the composition of the benthic community of a given area. Salinity fluctuation and range, wave shock and tidal exposure follow in importance. The structure of a community and how it changes through time are important determinants in assessing impacts from various stresses. As mentioned earlier, the successional stage of the macroinfauna can range from azoic, pioneering, intermediate, to climax communities (Rhoads and Germano, 1986). Pioneering communities are dominated by smaller organisms with little ability to burrow more than a few millimeters into the substrate. The taxa are typically dominated by deposit feeding organisms with sucking types of feeding apparatus. Climax communities are dominated by larger invertebrates that are adapted to deep burrowing activities. The taxa contain many larger "top-down" feeders and a large variety of predatory type organisms. Shallow areas which are controlled by physical events such as storms and waves are typically populated only by pioneering communities whereas deep areas in which physical disturbance is not a controlling factor are typically populated by intermediate and climax communities. Diversity which is a measure of the distribution of individual organisms among the various species is another tool in assessing the health of a community. Low diversity is typically a good indicator of stress, either natural or manmade, while high diversity is generally indicative of stable communities rich in taxa with relatively few dominant species. For example, a stage I or pioneering community would be characterized by low diversity, i.e. you would expect to find lower numbers of taxa with high dominance of a few of the taxa. On the other hand, a stage III or climax community would be relatively high in diversity, containing variable numbers of taxa but with a tendency toward equal distribution of individuals among the taxa.

Diversity, however, is not a good descriptor of the value of the community as a resource, i.e. food source for higher trophic individuals. For example, the Stage I, low diversity, community, is an excellent resource because of the tremendous numbers of individuals and high turnover rate. Therefore to determine the overall health and value of a community, all community descriptors must be used in determining the significance of any impacts to the benthic community.

7.4.2 Methodology. To accomplish task of identifying the impacts from the long-term thin-layer placement of dredged material, 6 locations were identified along the Mississippi Sound reach of the Gulfport Channel . Three of the areas were on the west side and would provide data relative to long-term disposal; the other three areas were located on the east side of the channel and were used as reference sites to compare the west side locations against as well as to provide 12 months pre-disposal data to be used in the upcoming new work investigations. Subsequent to this one site of the east was subdivided into two sites. Each area was sampled monthly for a period of one year beginning in June 1991. In addition to biotic sampling, DO, temperature, salinity, conductivity, current speed and direction, and sediment parameters were recorded at each station. Biotic measurements included taxonomic analyses and biomass determination.

7.4.3 Results

7.4.3.1 Sedimentary Parameters. Previous sediment classifications in the region of Gulfport describe a roughly oval basin of silt and clay mud bounded by sandier sediments both on the mainland and near the barrier island passes (Upshaw, et al., 1966; Markey, 1975). These reported patterns of regional sediment distribution were similarly evident in the current studies. With the exception of area 7 (Zulu) and somewhat in areas 3 (Foxtrot) and 5 (Charlie) sediments were relatively unconsolidated with large percentages of silt and clay and relatively small percentages of sand.

During the first three months of the study areas 3 and 5 showed sand percentages ranging between 18 - 22 % and 25 - 40 %, respectively. Beginning in October (4th sampling period), sand percentages in both sites were reduced to less than 10 % and overall sedimentary parameters were similar to those of the sites on the east side of the channel for the rest of the study. For the first three months, sand percentage at area 7 stations ranged between 25 - 40 %, in October percent of sand increased to 55% and stayed high for the remainder of the year. Sand percentages at areas 2 (Beta), 4A, 4B (Alpha) and 6 (Delta) were low (< 10 %) for the entire study. The location of area 7, near the tidal inlet, suggests the probable reason for high sand content since this area is subject to higher currents and is closer to an offshore sand source. One could also expect that area 6 would have similar characteristics, however a look at the map reveals that area 6 (Delta) is sheltered by West Ship Island therefore the fine-grained characteristics determined by the study are not unexpected. The variation at areas 3, 5, and 7 for the first three months of the study are likely due to climatic events in the Pearl River basin earlier in the year. As mentioned earlier, flows from the Pearl River are a significant source of freshwater and suspended sediments to western Mississippi Sound. It will be interesting to note what differences, if any, are revealed for the macroinfauna for this period at these sites.

With the exception of the first three months of data, it appears that the repetitive long term use of thin-layer disposal has had no long lasting effect on sediment texture of the area. Sites which have been disposed on are similar to those which have not experienced thin-layer placement, the difference between areas on the west of the channel and those on the east is likely due to hydrodynamic features, the sedimentary characterization of the area is in agreement with previous studies, and the sediments of area 7 are characteristic of areas within the tidal inlet. The variation of sites associated with the historic thin-layer placement of dredged material are within the natural variation of the system and therefore not a result of the thin-layer placement.

7.4.3.2 Water Quality Characteristics. No significant differences existed between the east and west areas in terms of water quality characteristics. Temperature, salinity, and DO were all within normal ranges for the entire study. There were also no tidal variations with east-west trends. No long-term impacts to the water quality of the area were identified which were the result of the repetitive thin-layer placement of dredged material.

7.4.3.3 Macroinfaunal Studies. A total of 418,000 individuals were collected during the year-long effort representing 409 taxonomic categories. Abundance of organisms varied from a low of 1341 per m^2 at station 5 in July to a high of 21,845 per m^2 at station 2 in February. Sixteen species accounted for 80% of the individuals, thirty-four species accounted for 90% of the individuals. The study was dominated by *Mediomastus* spp., a small Stage I polychaete, and *Balanoglossus aurantiacus*, a large Stage III hemichordate, comprising 22% and 18% of total abundance, respectively. Polychaete species dominated the study comprising over 53% of the individuals and 40% of the taxa identified. Of the thirty-four species, 44% are classified as motile omnivores, 18% as motile carnivores, 18% as sessile deposit feeders, 15% as sessile omnivores, and 6% each as motile deposit feeders and sessile filter feeders. No herbivores were encountered during the study. With the exception of area 7 (Zulu), the benthic community was dominated and perhaps structured by hemichordates.

Hemichordates were highly seasonal as well as extremely abundant. As mentioned earlier hemichordates were noticeably absent from area 7 due primarily to the sandy nature of the substrate. Represented by only one species, hemichordates attain a relatively large size and have a structuring effect on the substratum due to their burrows and deposit feeding activity. At all the other areas, especially 2, 4A and B, and 6, the substratum below the layer of floc resembled a honeycomb, with hundreds of closely packed burrows. *Balanoglossus* constructs mucus-lined tubes with posterior openings to the surface (i.e. a head down feeder). Other species which may also provide structure to the substratum include the tube building polychaetes, *Myriochele oculata* and *Owenia* sp. A, and the relatively large brittlestars, *Hemipholis elongata* and *Micropholis atra*, whose long arms twist through the sediment. Burrows of bottom dwelling organisms have been shown to affect physical and chemical processes occurring within the substratum and at the sediment water interface (Rhoads, 1974; Aller, 1988; Kristensen, 1988; Pelegri et al., 1994). The burrows play an important role in oxygenation of the substratum and recycling of nutrients and enhance the rate at which these activities take place. There was an absence of hydrogen-sulfide odor from all sampling areas which was somewhat of a surprise since the 1986 vertical profile imagery showed the reduced potential discontinuity (RPD) layer to consistently occur between 0.5 cm and 5.0 cm of substratum depth. The reduced nature of sediments, either man-made or natural, is evidenced by the hydrogen-sulfide (rotten egg) smell. This is significant in that it suggests that biological or physical working of the sediments resulted in significant oxygen content at all layers of the sediments.

More species were consistently found at area 7 (Zulu) although densities were generally average or below average. This resulted in higher diversity at area 7 than other areas. Area 3 (Foxtrot) was also relatively diverse, although the number of taxa was lower. Distribution of individuals among species indicated less faunal dominance by a few species. Species diversity was comparable among the other sites and not significantly different from area 3. Numbers of individuals collected from each area were large and variability among samples was high. Faunal densities were higher in January and February, 1992, and lowest in July, 1991. Over all sampling events, areas 3 and 7 had the least individuals and area 2 the greatest number. The other areas had intermediate densities and were relatively similar to one another.

Examining seasonal variation for taxa and abundance data revealed several trends. Seasonal differences in number of taxa was greatest for the eastern areas with large differences occurring in fall/winter. Although areas 3 (Foxtrot) and 7 (Zulu) were the most frequently different from other areas, they exhibited less seasonal variation.

An investigation of the differences in abundance and number of species among areas is another way of separating areas. Theoretically, if all areas behaved similarly, the sampling data for a specific area would be uniformly mixed with the sampling data for all other areas. Based on this investigation area 7 and to a lesser degree area 3 were different from the other areas.

Similarity analyses, however, only revealed the difference of area 7. Grouping data by season, i.e. spring (March - May); summer (June - August); fall (September - November); and winter (December - February) and investigating trends based on faunal abundance and presence/absence of individuals presents an interesting pattern. Analysis of faunal abundance during the spring revealed greatest similarity within an area between months while presence/absence data indicated a greater similarity between areas, i.e. areas 2 and 3, and 4 and 5. Area 6 was more similar to itself but also more similar to areas 4 and 5 than to 7. During the summer both similarity analyses revealed a pattern in which areas clustered together by month. Fall analysis of faunal abundance indicated high to moderate similarity between all areas and months except area 7 which was substantially dissimilar. Presence/absence data indicated a higher similarity between areas on the east of the channel and a similarity between areas on the west with the exception of areas 6 and 7 which showed a low level of similarity to each other. Winter analyses are even more confusing, however a relatively high level of similarity is noted between all areas except area 7 based on faunal abundance and a moderate to low level of similarity based on presence/absence. One aspect of the data which is very clear is the 'outlier' nature of the July 1991 data and to a lesser degree the August data for all areas.

Subsequent re-analysis of the data paying particular attention to the July/August 1991 data set indicate that the number of taxa were low for all areas during July as was biomass. Abundance was low at all areas except area 7 during July. Hemichordate abundance was low at all areas from July to September, except area 5 which showed an increase in September. It is probable that some event occurred prior to July which effected the entire area. During July/August area 7 is interspersed among the other areas. After October, area 7 is always an outlier to the other areas. Recovery of the area is mediated by the September/October time frame, however the response of area 3 and to a minor extent area 5 is not as rapid as in the other areas. This correlates well with the sedimentary parameters except that areas 2 , 4, and 6 were relatively homogeneous throughout the year whereas areas 3 and 5 showed higher percentages of sand for the July through September time frame and area 7 showed lower percentage of sand during this time frame.

Size class distribution results showed that the majority of individuals were found within the 0.5-1.0 mm range. Seasonal trends point to two peaks, an increase in abundance in December through February, followed by a decline in April, and a second peak in June. Corresponding to declines within the smallest size classes were increases in the larger size classes. The largest size class also exhibited seasonal trends but, this class composed only a small fraction of the overall fauna. Areas 4, 5, and 6 exhibited a greater percentage of individuals within the 0.5 - 1.0 mm size class and fewer individuals within the larger size classes than did areas 2, 3, and 7. This would allude to more natural disturbance within some areas than in others, the disturbance being evidenced in the small size class - recruitment size - individuals.

7.4.3.4 Comparison to Historical Studies. In addition, to comparing areas on the same temporal scale, a comparison of historic data are possible since areas sampled in this effort were correlated with areas sampled previously. In a 1974 effort, Markey (referred to as Markey, 1975) compared the impacts of disposal of maintenance dredged material in areas on east to west transects across the Gulfport channel. It is possible to qualitatively compare the results of the 1974 study with areas 3, 5, and 7 of the current study (Table 2). A predisposal study undertaken in June 1974 resulted in the lowest number of taxa, abundance of species and diversity of all the studies undertaken in the Gulfport area. Post disposal sampling undertaken in December 1974 shows an increase in all these parameters. Number of taxa identified in December 1974 was similar to that in December 1991. Although faunal abundance increased in December 1974 it is impossible to compare to the similar period in 1991 because the 1974 study only accounted for organisms larger than 0.6 mm while the 1991 study includes all organisms larger than 0.5 mm. Diversity comparisons between the two studies are mixed. A major event in the 1974 study was the short term increase in cumaceans. This crustacean, who's predisposal 1974 abundance was similar to December 1991, is known to be an opportunistic colonizer of disturbed habitats. It is probable that the increase in 1974 was a short lived phenomenon and had sampling occurred for a time following this increase it is likely that cumacean abundance would have decreased to pre-disposal levels. Another noticeable difference between 1974 and 1991 is the difference in abundance of hemichordates and echinoderms. Analysis of intermediate studies in 1986 (TAI, 1988) show these forms to be progressively more abundant with each study. These species are part of a long-term climax community requiring a stable substratum and long period of establishment. This area of Mississippi Sound was impacted by the passage of Hurricane Camille in 1969. This hurricane, which was a Class 5 storm, crossed the mainland approximately 10 miles east of the Gulfport area. Although data are not available to confirm the impact to the Mississippi Sound system, it is likely that significant disturbance of the bottom and possible changes in sedimentary parameters occurred during the passage of the storm. The lack of hemichordates and echinoderms from the area in 1974 may possibly be in response to these natural perturbations.

Table 2. Comparison of Historic Data from Areas 3, 5, and 7 to Current Study

Taxa	Jun 1974	Dec 974	Dec 1986	Jan 1987	Dec 1991 / Jan 1992	Jun 1992
Polychaeta	68 *	59	74	48	45	55
Nemertea	12	5	9	25	8	8
Mollusca	10	5	4	16	6	10
Arthropoda	9	29	4	4	2	11
Hemichord.	0 **	0 **	3	0 **	31	12
Echinoderm.	2	2	5	5	4	3

* Values are the percent of individuals comprising a particular taxa

** Although hemichordata were encountered in this study the percentage was less than 1 and therefore not recorded.

7.4.4 Conclusions. It is evident that long-term faunal shifts have occurred in the area which are not related to disposal of dredged material. Between 1974 and 1992, percentage of annelid individuals has decreased while hemichordates has increased. This shift is indicative of the aging of the community from Stage I to Stage III and is probably due to the lack of a major disturbance or stress on the system. Hurricanes Camille in 1969, Frederic in 1979, and Elena in 1985 and intervening high water events are probably the major factors responsible for the benthic community shift over time.

Number of taxa and abundance of species recorded from the current studies are comparable to earlier studies of the western Mississippi Sound area and other estuaries along the northern Gulf coast (Vittor, 1982; TechCon, 1980; Taylor, 1978). The major exception was data from the study by Markey in 1974 which showed significantly fewer taxa and fewer numbers of individuals (Markey, 1975). These differences, however, may be due in part to different techniques rather than actual differences in abundance. The temporal pattern of increase seen in the long-term studies was not unexpected, since most of the numerically important taxa collected in the study are known to have late winter - early spring periods of recruitment in the Gulf of Mexico (Harper, 1977; Johnson, 1980; Science Applications, Inc., 1980)

Evaluation of the macroinfaunal data in light of the scheme developed by Rhoads and Germano (1986), i.e. Stage 0 represents an azoic community, Stage I pioneering, Stage II intermediate, and Stage III representing climax, one would expect that an impacted community would be represented classified as either Stage 0 which would indicate total defaunation or Stage I which would indicate beginning recovery from the impact. Since the sites on the west side of the channel are used repetitively on an approximately 18 month basis and assuming that the thin-layer placement of dredged material causes a negative impact, then the benthic community of these sites should be populated with species who's life histories are representative of Stage I and possibly some species that could be classified as Stage II. Very few or no Stage III species would be expected. The sites east of the channel, assuming no other adverse impacts other than placement of dredged material, should be populated primarily by species with life histories compatible with a Stage III classification. The data collected between July 1991 and June 1992, do not support this contention. To the contrary, the similarity analyses performed utilizing both presence and absence of species as well as abundance of species indicate high to moderate similarity between stations on the west and east sides of the channel, with the main determinant being the temporal factor. The major exception to this is station 7 which is an outlier in most of the analyses. Of the thirty-four species making up over 90% of the total individuals encountered in the study, approximately 47% represent Stage II organisms, 38% represent Stage I, and 15% represent Stage III. This then indicates that the continual placement of dredged material in a thin-layer has not had long-term negative impacts on the marine ecosystem of Mississippi Sound in the vicinity of Gulfport.

Station 7, as mentioned earlier, is located in the tidal pass area and is characterized as primarily sandy in nature in contrast to the other 6 sites. Benthic macroinfaunal assemblages are comprised of ubiquitous and/or restrictive faunal components. The ubiquitous component consists of taxa that are either opportunistic (generalists) in their ability to exist within a habitat or variety of habitats, or characteristic specialists found within a particular habitat type. Opportunistic species are generally eurytolerant to fluxes within their environment, but more important they are early and successful primary colonists due to their reproductive capacity and dispersal ability. These species often undergo eruptive population peaks depending on their adaptive ability to withstand varying environmental conditions and exploit an open niche while avoiding any competitive interactions (Boesch, 1977; Oliver et al., 1977, McCall, 1978). Opportunistic species are generally small-bodied, surface deposit feeders with high turnover rates. Within the ubiquitous component they may be widely distributed in high abundance and often dominate one or more habitats. Moreover, opportunistic species may be widely distributed, but only found in low to moderate abundance at the time of sampling. Examples of widely distributed opportunistic species found throughout the area include the polychaetes *Mediomastus* spp., *Paraprionospio pinnata*, *Myriochele occulata*, and *Owenia fusiformis*, and the cumacean *Oxyurostylis smithi*. Other ubiquitous species which are widely distributed over a variety of habitats include the nemerteans, and the polychaetes *Lumbrineris verrilli* and *Sigambra tentaculata*. There latter species are considered carnivores or scavengers and do not fall within the typical definition of opportunistic species. In general, the distribution of ubiquitous species are least influenced by sediment gradients. The restrictive faunal components of the benthic macroinfauna assemblages are comprised primarily of taxa (some opportunists) that are characteristic of specific habitats. An example of a restrictive faunal taxa is *Branchiostoma* sp., a cephalochordate, which is restricted to the high sand content area 7. Hemichordates, e.g. *Balanoglossus* cf. *aurantiacus*, are notably absent from area 7, being restricted to those areas of high silt and clay content. In both these cases, the restrictive fauna are characteristic of Stage III organisms and are typically located in areas in which disturbance by physical forces is minimal. It is likely that the long-term placement of dredged material in a thin-layer is viewed by these organisms as being within the normal fluctuation of the sedimentary parameters for the estuarine system. Since *Branchiostoma* sp. was not found in great abundance at area 7, it is likely that the natural climatic and physical features of the tidal pass area play a large role in population dynamics for this area.

Based on the diverse and healthy community present at the historically used disposal areas and the presence of significant numbers of the hemichordate *Balanoglossus* and other Stage III organisms, it is evident that the disposal of dredged material in a thin-layer at Gulfport has not had a significant or lasting impact on the macroinfaunal communities.

7.5 MACROINFAUNAL STUDIES

7.5.1 Introduction. The methodology described here is a description of techniques used in all three of the new work material disposal operations. Each month for a period of two years measurements were collected at 30 random stations for the disposal area and a total of 10 stations for the control areas. Startup times have been purposely staggered to examine seasonal effects on disposal operations and recovery. The control areas varied over the three operations with Alpha and Beta consisting of a north and south control site(5 stations each) while Delta had only a south control site (10 stations). Abiotic measurements recorded at each station included DO, temperature, salinity and conductivity. Measurements were collected using an electrodes induction salinometer at 3 depths: surface, mid-depth, and near-bottom. Tidal and current velocities were also recorded for each station.

Macroinfaunal samples from the same stations were collected using a box core or a PONAR grab. Upon retrieval, surface water overlying the core was passed through a 0.5 mm sieve to retain any floating organisms. A subsample of the top 8 cm was removed for sediment grain analysis. The remainder of the box core was processed for macroinfaunal macroinfauna. First the top 5-10 cm of flocculent material was removed and taken back for sorting. The remaining sediments were passed through a 0.5 mm sieve to remove organisms which were then preserved in formalin for laboratory processing. In laboratory procedures, macroinfaunal sediment samples were processed for percent solids, specific gravity, and particle grain size. Percentage of grain types were recorded as well as sorting coefficients, skewness and kurtosis. Macroinfaunal samples were divided into size classes by passing the collected organisms through series of stacked sieves for 6.35, 3.35, 2.0, 1.0, and 0.5 mm. Wet-weight was acquired for each taxonomic group and the most abundant species. Ash-free dry weight was also measured and converted into biomass data for area and taxonomic group comparisons.

Because of the number of organisms contained within each of the samples, the Contractor was unable to complete the sorting and identification of all samples within the required time frame. The following samples have been analyzed:

Alpha - July 1992 thru December 1993
Beta - October 1992 thru January 1994
Delta - April 1993 thru March 1994; March 1995

The remaining samples have been archived for further study as necessary. In all cases, enough samples have been analyzed to determine the period of recovery.

A number of community parameters were determined and statistical analyses were performed on the data. Major efforts were taken to separate seasonal effects from spatial effects including the effects due to the thin-layer placement of dredged material. Community composition was compared utilizing similarity and clustering techniques. Two important descriptive tools utilized were diversity and evenness or equitability. Diversity is a measure of the variability of species present in a defined unit and depends upon the number of species present and the evenness with which the individuals are apportioned among the species. To describe a community's diversity merely in terms of its diversity index is to confound these two factors; a community with a few, evenly represented species can have the same diversity index as one with many, unevenly represented species. It is obviously desirable to keep distinct the two ingredients of diversity, the number of species and the evenness. In the following reference to diversity is the reference to the number of species. The evenness of the distribution of individuals among the species is referred to as equitability.

7.5.2 Alpha Disposal Operations.

7.5.2.1 Introduction. Approximately 330,000 cubic yards of new work material were placed within the Alpha disposal site between 3 - 14 August 1992. Prior to disposal the Alpha disposal area would have been characterized as having a silty-clay substrate based on the predisposal efforts aimed at answering questions concerning effects of long term disposal. These data are not in total agreement with sediment data collected earlier (Markey, 1975; Vittor, 1982; TAI, 1988), however this is not surprising since benthic sediment data are typically collected from the top 6 - 12 inches and this area of the estuarine bottom may be subjected to physical forces associated with waves and currents. Variability of this sort is normal in a coastal estuarine setting and because macroinfaunal species abundance and distribution may be directly correlated with sediment texture, community characterization will also vary naturally. This makes the determination of impacts due to the disposal of dredged material very complicated and a number of statistical analyses and community parameters must be investigated. Other factors, which may or may not be known, can also cause shifts in community distribution. For example, during the July 1992 time frame, i.e. immediately before disposal, analysis of sediment texture data and community parameters for the Alpha disposal area and the North and South Control areas indicated that although the sediment parameters were strongly similar for all three areas, the community similarity was greatest between samples from the Alpha disposal area and the South Control area, with the North Control area being an outlier.

7.5.2.2 Sedimentary Parameters. First and foremost, the disposal process brought on changes in the sediment composition. Prior to disposal, Alpha showed only minor monthly changes regarding sediment composition. Grain size analysis at Alpha following disposal showed that the area was not uniformly affected by disposal operations. For collections during the post-disposal months, 65% of the samples exhibited coarser mean grain size than the controls, 9% showed finer grain size, and 26% were within one standard deviation from the control mean. This data was used to separate impacted areas from non-impacted areas.

During predisposal sampling, Alpha disposal had sediments which averaged a mean grain size of 9ϕ (silty clay). This mean was lowered to around 7.5ϕ from the addition of dredged material. Over the course of the sample year, the mean grain size steadily decreased to around 5ϕ (sands). The control areas showed no decrease in mean grain size throughout the sampling year. Along with grain size differences, disposal operations also increased sediment textural variability within the disposal site. Grain size variability was consistently higher for the disposal site when compared to the control sites. The makeup of the disposal site sediments changed after the disposal operations as well. Percentage clay and silt, which dominated the surficial layer of the predisposal sediments, dropped considerably from 50% and 40% to 30% and 10% respectably. Sand content increased from 5% to around 30% and percent solids increased from 30% to 50%. This increase was not seen at the control sites where composition remained similar to predisposal percentages. The disposal site had higher temporal and spatial variability among sediments compared to the control sites. These increases were caused from the addition of sandy material at the disposal site.

7.5.2.3 Water Quality Parameters. Overall, the spatial variation of temperature, salinity, conductivity, and DO were very low. The water column showed little surface to bottom stratification for these parameters. Temperature exhibited a typical seasonal cycle with ranges from 10-31 °C. Salinity exhibited little spatial variation and minimal stratification. Lower salinities were found in winter and spring with higher values in late fall. DO levels remained high throughout the sampling year. Most samples were more than 90% saturated with lower levels occurring in bottom waters. The differences between disposal and control sites were greater than random sampling would produce which was surprising given the narrow range of values measured for any particular sampling event. Examination of the data indicated that the narrow ranges of values would actually enhance the ability to detect relatively small differences, therefore the significance of these differences is questionable.

7.5.2.4 Benthic Macroinfauna Analyses. Over the first twelve months of sampling, 180,000 individuals were collected representing 411 taxa. There was a pronounced reduction in abundance for Alpha disposal immediately following disposal operations. However, disposal abundance rebounded to levels equivalent to controls after only 1 month and remained similar throughout the remainder of the first sampling year. Seasonal trends were similar for the disposal and control sites with peak abundance in winter, a spring decline, and a second peak in summer. For taxonomic groups, most followed the overall pattern of abundance, except for abundance of molluscs in the disposal area which continued to increase after equaling the abundance in the controls.

There was also a pronounced decrease in the number of individuals per taxa immediately following the disposal. By the September sampling (1 month post disposal), however, the numbers had rebounded to equal control numbers. Throughout the next year there was a decline in number of individuals per taxa compared to the pre-disposal sampling, but this decline was similar for the disposal and control areas and therefore unlikely to be caused by the thin-layer placement.

For the disposal site, diversity, which is a measure of the distribution of individuals among taxa, exhibited a sharp decline immediately following disposal. This means that immediately following disposal there were relatively few taxa , i.e. species, with large numbers of individuals and very many taxa with few individuals. Diversity recovered to equal control diversities and within one month surpassed control site diversity for the remainder of the sampling period. This is undoubtedly in response to the increase in variability of the sediment parameters at the Alpha disposal area. Following disposal equitability increased for the disposal area. After one month, however, equitability of the disposal area decreased to the same level as the control sites and remained essentially the same. The disposal area did however exhibit a greater variability in equitability than did the control areas.

Of the 411 taxa collected during the study of Alpha, 45 taxa accounted for 90% of the total fauna. Three species of polychaetes, *Mediomastus, Owenia,* and *Paraprionospio*, were the most dominant. Immediately after disposal operations, there was a drop in relative abundance for nemerteans and molluscs while polychaetes, echinoderms, and arthropods taxa increased. Overall when compared to the control sites, the polychaetes displayed the most dramatic species enhancement from disposal operations. *Owenia, Paramiphinome*, and *Spiophanes bombyx*, all polychaetes showed significant positive response to the disposal on Alpha. With the exception of *Owenia*, which is a sediment generalist, the other two species are well known to prefer sandier sediments. These three species as well as *Mediomastus* and *Paraprionospio* are characterized as Stage I organisms and would be expected to be dominant in an area controlled by physical factors or following a stress to the system.

Several species rapidly colonized the disposal site which were not found at the control sites. This was likely caused by the sediment grain size shift and possibly because of a reduction in competition for space and food. A large juvenile (possibly larval) recruitment period took place around November when many small sized animals appeared. This was followed by a subsequent increase in the number of medium and large size individuals. In addition, a few medium to large class individuals were found in the disposal area soon after disposal, e.g. the hemichordate *Balanoglossus*. The presence of this form probably indicates survivors that were able to burrow to the surface of the dredge material.

As mentioned earlier, the similarity of the communities is another measure used to look at community change. Prior to disposal, Alpha disposal area and the South Control were more similar and the North Control was an outlier. Following disposal and throughout the period investigated, Alpha disposal area was typically dissimilar from the North and South Controls. Even so, the North and South Controls were rarely very similar to each other. The dissimilarity of the Alpha disposal area is due to the change in sediment texture and subsequently the addition of species from those preferring sandier environments in lieu of those preferring fine grained environments. . Many of the ubiquitous opportunistic species, however, remained in the disposal area following the thin-layer placement.

7.5.2.5. Conclusion. In a strict sense Alpha disposal experienced "environmental impact" in that the post disposal faunal community was altered to a state different from it's original state and different from the Control sites. The meaning of this 'environmental impact" however is unclear. Alpha disposal showed a very rapid recovery following thin-layer placement. For many benthic invertebrates the spawning cycle initiates in the early spring as the coastal waters warm. Summer and fall are peak benthic recruitment periods with planktonic larvae settling from the water column. The rapid recovery of Alpha may be due to the summer and fall recruitment period as there was evidence of both planktonic and adult recruitment at this area. Adult recruitment can be both by organisms which were occupying the site prior to disposal, survived the thin-layer placement, and burrowed to the surface, as well as by organisms which migrate into the site from adjacent areas. By the end of the first year, Alpha disposal exhibited a greater faunal diversity and abundance than the control areas and greater than the predisposal studies. The benthic community composition was also more complex and spatially heterogeneous than before. Classically diverse systems are considered 'healthy' and the more diverse a system, the more healthy and more resilient. Therefore, although the community has changed due to impacts from the thin-layer disposal, the changes are not considered negative and would not result in adverse impacts to the estuarine system.

7.5.3 Beta Disposal Operations.

7.5.3.1 Introduction. Approximately 330,000 cubic yards of new work material were placed on disposal area Beta during the period 26 September thru 5 October, 1992. Thin-layer placement was completed as scheduled.

7.5.3.2 Sedimentary Parameters. Mean grain size collected from predisposal surveys showed Beta disposal to have silty clay sediments with an average grain size of 9ϕ. After disposal took place the sediments in Beta disposal were found to contain finer grained material than the control sites. The mean grain size increased to 11ϕ, which represents a finer grain size average. Compared to the control stations, 15 of the samples from the disposal area contained finer sediments, 4 contained coarser sediments, and 11 were within one standard deviation of the control sites. Composition of the disposal area sediments significantly changed from the addition of dredged sediments. Percentage silt initially dropped from 40% to 20%, but recovered to predisposal levels after one month. Percentage clay rose from 50% to 75% immediately after disposal with a subsequent drop to 60% within 1 month. For the next 8 months clay percentages decreased slightly to around 55 %, then decreased markedly to pre-disposal levels. With the rise in finer particles, sand dropped from 10% to 3% returning to predisposal levels after several months. Long-term trends of grain size from the pre-disposal survey showed an increase towards finer sediments which continued through the first post disposal survey (October) at the control sites. After October, both Beta site and the control sites began a decreasing trend of grain size and by 7 month post disposal (May), area Beta was identical in mean grain size to both the north and south controls. Similar trends were noted in percent silt and clay, with the inverse noted for percent sands. Percent solids, a measure of the water content of the sediment, showed no impact from the thin-layer placement of dredged material.

7.5.3.3 Water Quality Parameters. The measured water quality parameters showed no alteration attributable to disposal operations. Overall, the spatial variation of measured parameters was very low. Temperature followed the typical seasonal cycle for all three areas, ranging from 12 to 31 °C. Salinity varied according to seasonal conditions as well, with higher levels occurring in fall and lower values in winter and spring. DO remained high throughout the year except for August 1993 when bottom waters of the control sites reached biologically critical levels of 3 mg/l. DO returned to normal levels by September. Since the drop in DO was seen only in the control areas, disposal operations were not considered responsible. Measured parameters varied little with water depth, only seasonal variation was consistent.

7.5.3.4 Macroinfauna Analysis. Predisposal surveys indicated an increasing trend in both the number of taxa and abundance of individuals present at the areas 2 and 4A which represented much of the Beta disposal survey. Number of taxa predisposal ranged from a low of 16 to a high of 48, while abundance ranged from 2000 to 13,000 individuals per m^2. Comparison of the October pre-disposal information to October post disposal (one month), the control areas were very similar to pre-disposal both in number of taxa and abundance of individuals, approximately 32 taxa and 8000 individuals per m^2, respectively. The Beta disposal area, however, was characterized by a reduction in both community measures, 16 taxa and 3000 individuals per m^2. Although a significant reduction, these are still within the natural range of variation seen during the pre-disposal survey and the variation of the control areas.

Abundance remained lower in the disposal area as compared to the control sites until August (10 months post disposal) at which time the disposal area reached abundance similar to control sites and slightly surpassed the controls during later months. Though abundance between areas was different the variability of the data from each of the areas overlaps therefore a determination as to the significance of the differences cannot be made. The disposal and control areas exhibited similar seasonal variation with peaks in December and late summer and an intermediate decline in early spring.

Comparison of individual species abundance from the pre-disposal survey areas to the control areas indicates a change in dominance in a number of taxa. For example, the hemichordate *Balanoglossus* cf. *aurauntiacus* was extremely abundant pre-disposal, however abundance in the controls was reduced approximately 4 fold. The polychaete *Myriochele oculata* which averaged approximately 1600 individuals per m^2 pre-disposal was not present in the control sites. Conversely, a number of species were present in the control sites at greater abundance than pre-disposal including the polychaetes *Prionospio perkinsi* and *Malmgreniella maccraryae*, the cumacean *Eudorella monodon*, and the echinoderms *Hemipholis elongata* and *Micropholis atra*. Because of these differences, it is most appropriate to compare species abundance from only the control and disposal areas.

A drop in abundance was noted was noted for all major taxonomic classes, especially bivalves, nemerteans, and echinoderms. Immediately following disposal, the disposal and control areas were dominated by polychaetes, with hemichordates as the next most abundant. Recolonization of the disposal area began immediately with a number of species, especially the polychaetes *Prionospio pinnata*, *Carazziella hobsonae*, *Malmgreniella taylori*, and *Gyptis crypta*, the molluscs *Odostomia* sp. I and *Mulinia lateralis* and the cumacean *Eudorella monodon* having significantly higher abundance than the controls. Within approximately 4 months, abundance of gastropods, and arthropods was comparable to control sites. Although there was an initial slight decrease in the hemichordate *Balanoglossus*, it appears that these forms were able to migrate upward through the thin-layer of dredged material as there was little difference in abundance between controls and disposal areas. A significant increase in hemichordates occurred at the Beta disposal area in August following disposal which was not noted in the control sites. Bivalve abundance reached control levels within 7 months and with the exception of the echinoderms all abundance of all taxa was comparable to controls within 10 months.

Number of taxa exhibited similar trends to individual abundance. Overall number of taxa declined immediately following disposal from 32 per sample to 16 per sample. After 11 months, number of taxa increased slightly beyond the number of taxa in the control sites. The reduced number of taxa for Beta disposal area did not affect percentage composition of the macroinfaunal community, as it remained similar to control site composition throughout the year. Annelids dominated with 45% of the total, with arthropods having the second highest percentage of 15%. There was not a significant shift in any taxonomic category except a slight drop in echinoderm abundance. There were however major shifts in the dominance of species between the disposal and control areas as species moved in to fill vacant niches left by the dredged material placement.

Diversity dropped for the disposal area immediately after disposal was complete. The diversity index for the control sites increased to above predisposal levels following disposal remaining higher for about 5 months whereas the disposal area regained predisposal diversity levels after 5 months. Ten months following disposal, diversity in the disposal area increased above control sites and predisposal levels. Equitability increased immediately following disposal for all three sites. The disposal area remained similar to the control sites with all three exhibiting levels higher than predisopsal levels throughout the sampling year.

Abundance of macroinfauna was dominated by *Mediomastus* for all surveys; predisposal, disposal and control areas. *Mediomastus* accounted for 25% of the overall abundance, *Balanoglossus* was the second most abundant organism, however it's numbers varied greatly throughout the sampling period. The predisposal abundance of *Balanoglossus* accounted for 20% of the total, whereas abundance during the post disposal survey was significantly less in both the disposal and control areas, 13% and 6%, respectively. Since the majority of the decrease in abundance was noted in the control areas, it is believed that this was due to natural fluctuations and not the impact of thin-layer disposal of dredged material. In fact, it appears that *Balanoglossus* was able to migrate up through the thin-layer of dredged material. A similar decrease in abundance was noted for *Myriochele oculata*, which accounted for 13% of all individuals during predisposal and only 3% post disposal. The majority of the individuals however were recovered from the disposal area. On the other hand, *Prionospio perkinsi*, which accounted for only 5% of the total abundance predisposal increased to 14% in the control areas in the post disposal surveys and remained at 5% in the disposal area.

A large larval recruitment event was noted in both the disposal area and control areas in July. A smaller recruitment period was also noted in early winter, however species composition between the recruitment events was different. The summer recruitment was followed by an increase in the number of larger organisms found in both the disposal and control areas.

Although similarity was greatest between stations within the control areas, there was a moderate level of similarity between the control area group and portions of the Beta disposal area. In addition, areas within the disposal area clustered into groups of differing levels of similarity indicating the increase in heterogeneity of the macroinfaunal community following disposal. Approximately 9 months following disposal, the high similarity among the control area stations began to break down, indicating a return of the disposal macroinfaunal community to that characteristic of the control areas.

7.5.3.5 Conclusions. As with Site Alpha, we again see an impact to area sedimentary parameters. In this case, however, finer grained sediments were placed on the site during the thin-layer placement. Theoretically the introduction of fine grained particles could have had a significant impact on macroinfaunal community structure and recovery by choking out filter feeders or making mobility by surface dwelling organisms more difficult due to the soft and shifting nature of the deposited sediments. Likely, this is not the case at area Beta since immediate recolonization by filter feeding surface dwelling organisms was observed. More than likely the length and cyclic nature of the recovery is due primarily to the temporal aspects of the thin-layer placement. As mentioned earlier, summer and fall are peak larval recruitment periods to the macroinfauna and this is a major means for many species, especially those considered to be representative of Stage I to repopulate themselves. Since disposal took place between late September and early October, it is possible that many of the fall recruitment class were buried by the thin-layer deposit and due to their small and fragile nature were not able to migrate upward through the dredged material. Recolonization by a number of species did begin immediately following disposal however this was likely due to migration from adjacent areas or possible upward migration through the dredged material of larger individuals more motile individuals. The basis for this is that similar recruitment events were not noted for these same species in the control areas therefore a large scale larval recruitment is an unlikely cause for the recolonization. Following the summer recruitment in May - June, which was seen at both the disposal area Beta and the control areas, the macroinfaunal community of the disposal area began to mimic that of the control areas, although neither area was compatible to that seen in the pre-disposal survey. Upward migration of at least one Stage III species, *Balanoglossus*, was noted to occur immediately following disposal. Other Stage III species, the echinoderms, were absent from the area, probably due to the increase in fine grained sediments since they are positively associated with sandier sediments. Only Ophiuroidea spp. and *Micropholis atra* had recovered to near control abundance by one year following placement. *Hemipholis elongata* abundance in the disposal area, however, was more similar to those from the pre-disposal survey areas than the control areas.

7.5.4 Delta Disposal Operations.

7.5.4.1 Introduction. Contract specifications required that the thin-layer placement at area Delta occur between March 15, 1993 and April 15, 1993, however equipment problems caused the initiation of placement to be delayed to 4 May 1993. Placement was again interrupted on 8 May by bad weather and was resumed on 11 May and completed 25 May 1993. Approximately 330,000 cubic yards of new work material were placed at the Delta site during this period. Sampling of macroinfauna at Delta began on 20 - 23 April, before dredging began, therefore this sampling is considered a baseline sample. In addition, the first post disposal sampling (25 - 27 May) was actually begun the day the thin-layer placement operation finished. For certain parameters the May sampling may be more representative of baseline conditions than post disposal conditions and will be discussed below.

7.5.4.2 Sedimentary Parameters. Sediment composition for Delta disposal and its control site were relatively homogenous during the predisposal survey and were classified as silty clays with only a small percentage of sand (less than 10%). Although area Delta is located in the southern portion of Mississippi Sound near the tidal inlet, it is sheltered from the Gulf of Mexico by West Ship Island and therefore is not exposed to conditions which would make the substrate sandy in nature. The placement of dredged material at site Delta resulted in a change in sediment grain size and composition in the disposal area. All these changes were evident in the May sampling event therefore we can say that the physical change to the environment, if it occurs, from the thin-layer placement is an immediate impact. Mean grain size increased from 9ϕ for the predisposal to 6.5ϕ immediately after disposal. One month following disposal, grain size at Delta had decreased to 8ϕ and then varied between 7.5 and 8ϕ over the next 10 months. The control area varied between 8 and 9ϕ over the same period of time. Percent silt decreased from 45% to 30% immediately after disposal but returned to 40% within 1 month and fluctuated between 35 and 45% for the remainder of the survey. The control site varied between 40 and 50% for the same period. Percentage clay decreased from 50% to 25% immediately after disposal but returned to 40% within one month and varied between 30 and 40% for the remainder of the survey, the control site fluctuated between 40 and 45% over the same period. Percentage sand increased with disposal from 5% to 50% but decreased within one month to 25%, fluctuating between 20 and 35% for the rest of the study. The control remained low in sand throughout the study at approximately 10%. The pattern of fluctuations in all the parameters are similar between the control and Delta sites. Variability in the data was extremely high indicating significant heterogeneity between the sampling stations within the control area and within the Delta area.

7.5.4.3 Water Quality Parameters. All water quality parameters exhibited a typical annual cycle with no apparent differences attributable to the disposal process. Temperature for both areas displayed a seasonal cycle with a range of 8 to 28 °C. Salinity also followed an annual cycle at both areas with higher values in fall and lower values during early spring. DO remained high all year with little variation among areas except for August where bottom water DO dropped to biologically low levels, but recovered to normal levels after one month. The DO decreases, in both dissolved oxygen as mg/l and as percent saturation, were greater in the control areas than in the Delta area proper. Since the hypoxic conditions during August were seen for both disposal and control sites, as well as in the area Beta controls, the effects were attributable to natural phenomenon and not the thin-layer placement operation.

7.5.4.4 Macroinfauna Analysis. Between the last pre-disposal sampling effort at area 6 and the April 1993 sampling effort at area Delta and control there was a significant change in the macroinfaunal community parameters of number of taxa and abundance. The pre-disposal values were ranged between 17 - 50 taxa and 2000 - 10,000 individuals per m^2. The respective April 1992 values were 33 taxa and 5000 individuals per m^2 while those in the April 1993 baseline sample were 17 and 25 taxa for Delta and control, respectively and approximately 1000 to 2000 individuals per m^2. For this reason, it is more valid to compare Delta disposal to Delta control initially and then to compare the trends in the 1993 sampling to the 1992 trends.

Analysis of macroinfaunal community parameters number of taxa and abundance of individuals indicates that there were no negative (i.e. decreases) impacts to either of the parameters from the thin-layer placement. Both number of taxa and abundance increased through June for both the control and Delta areas. The increases in taxa were significantly lower in the Delta disposal area than the control area, while the increase in abundance although not identical was similar. Both control and Delta areas experienced a decrease in abundance through the July time frame with the control decrease being such that the July values were almost identical for the two sites. Following this decrease, abundance at the Delta disposal area began to increase significantly such that abundance in February 1994 was over 30,000 individuals per m^2. Abundance of the control areas continued to decrease until October at which time increases were observed so that February values were on the order of 10,000 individuals per m^2. The response of the control area through time was similar to that observed during the pre-disposal sampling.

Following the June sampling, number of taxa within the control area began to decline and by July (2 months following disposal) number of taxa in the Delta disposal area approximated that of the control area (number of taxa within Delta disposal was increasing at this time). Through August a slight decrease was noted at both areas with the decrease in taxa at the control being greater than at the disposal area. Following this decrease both areas showed basically increasing trends in numbers of taxa such that by February the Delta disposal area was represented by 57 taxa while the control contained 50. These trends are somewhat similar to pre-disposal however the absolute number of taxa at both the Delta disposal and control areas are greater than similar time frames for the pre-disposal survey. Seasonal variation in the number of taxa was seen at the control site but not at the disposal site were taxa numbers increased monthly through most of the sampling year.

Diversity increased at both the Delta disposal and control areas following disposal. The initial diversities between the two areas were different in large part due to the larger number of taxa at Delta disposal. By August (3 months following disposal) the diversities were similar between the two areas. Although through time, the diversity measurement of the two areas varied somewhat independently, the differences were not significant. Diversity followed a normal seasonal trend similar to the predisposal period with a peak in diversity during July and lower values during the winter months.

Equitability between the two sites was similar initially, however by September (4 months following disposal) equitability for Delta disposal was less than the control in response to high abundance of a relatively few number of species. Equitability of both the Delta disposal and control sites decreased below similar measurements from the predisposal survey beginning in September but by February of the next year the values were again similar. Since both the disposal and control sites responded similarly, it is likely that these shifts in community structure are natural and not a response to the thin-layer disposal.

The major taxonomic groups, annelids, molluscs, and arthropods all exhibited increased abundance in Delta disposal area over the control area 4 months after disposal was completed, a trend which continued throughout the sampling period. Species which experienced significant increases tended to be ones which preferred a sandy sediment bed such as the polychaetes *Myriochele oculata*, *Mediomastus* spp., *Prionospio perkinsi*, and *Owenia* sp. A. The most dominant *Myriochele*, which was almost non-existent during the predisposal survey, accounted for over 31% of the total abundance at Delta disposal and 24% at the control sites (total abundance of this species, however was significantly different at the two areas). Other species which showed increased abundance in the disposal area compared to the control were the echinoderm, Ophiuroidea spp., the gastropod, *Nassarius acutus*, and the polychaete, *Sigambra tentaculata*. These species accounted for a combined 76% of the total abundance as compared to 53% for the control sites. It appears that the initial altering of sediment composition from silty sediments to sandy sediments allowed these species to expand into niches which were previously not available.

On the other hand, several species which were relatively abundant in the control area were absent from the Delta disposal at least immediately following disposal. The echinoderm, *Micropholis atra*, represented approximately 5% of the total abundance at the control area between April through July when it disappeared from the control. This species was present in very low abundance at the Delta disposal before and after disposal but it's abundance had begun to increase in February. Other species showing similar responses were the polychaetes *Malmgreniella maccraryae* and *M. taylori*, and the bivalve *Mysella planulata*. It is unlikely that the variation in abundance at either site is due to thin-layer placement because of the variability in abundance at both locations over time.

For size class comparisons, both disposal and control areas received a large influx of small animals (< 0.5 mm) during the late summer months although species composition of these recruitment classes was very different. A second peak was seen in the winter months similar to the first and again the composition of the recruitment class was different. The recruitment of the larval individuals into the community immediately following the thin-layer placement is likely responsible for the lack of negative impacts to the Delta disposal area. This in combination with a second recruitment in the early winter months and the increased heterogeneity of the sediments is likely responsible for the significant increases in abundance and number of taxa within the disposal area.

Although similarity among stations within the control group was typically highest, the similarity between stations from the disposal area and the control areas varied throughout the sampling year. Prior to disposal (April), the two groups were very dissimilar. Immediately following disposal (May) , stations from the two areas showed moderate similarity, however the following month the areas were again very dissimilar. This is likely due to the recruitment of large numbers of polychaetes into the disposal area stations which preferred sandier sediments (e.g., *Owenia*, and *Myriochele*), while those preferring finer sediments (e.g. *Malmgreniella*) recruited into the control areas. This pattern persisted for approximately 6 months at which time the sediments became mixed and species became established, the two areas became more similar with one another.

7.5.4.5 Conclusions. If negative impacts to a community are assumed to result in decreases in number of taxa and abundance of individuals or in decreases in the diversity measurement, then the thin-layer placement at area Delta did not result in any negative impacts, short or long-term. On the other hand, there were differences in the makeup of the community as a result of the thin-layer placement and similar to site Alpha it would be correct to state that in a strict sense Delta experienced an "environmental impact". The importance of this impact however is positive in that the response of the macroinfaunal community to the thin-layer placement resulted in an increase in the biomass and an increase in diversity. It appears that the thin-layer disposal which caused an increase in the heterogeneity of the sediments is responsible for these increases.

7.5.5. Summary and Conclusions

Dredge and disposal activities are not the only sources of physical disturbance to the benthos affecting macroinfaunal populations. Storm waves, tidal scour, vessel traffic, and trawling activities of commercial bottom fisheries all act to disrupt and suspend the finer sediments in estuarine and nearshore waters. These short-term perturbations, along with the constant sediment discharge of the Pearl and Mobile river systems, are much more common and, although not as disruptive in volume of sediment moved or deposited locally, are geographically wide-spread and equally as unpredictable to the infauna as dredging and disposal activities. Impacts resulting from natural phenomenon cause similar dramatic fluctuations in populations as seen in these studies and have been documented for the tidal pass habitat at the mouth of Mobile Bay, which responded to extreme low river flow (high salinity), hurricane force winds and tides (sediment alteration), and extreme high river flow (low salinity) within an 18-month period (Johnson, 1980; TechCon, 1980).

These unpredictable, repeated disturbances act to keep the system in a state of continuous succession and high productivity. Following any disturbance to the benthos resulting in partial or total defaunation, colonization of shallow water marine sediments progresses in similar fashion. This has been shown for dredging and disposal activities (Salia *et al.*, 1972; Oliver *et al.*, 1977; and Rhoads *et al.*, 1978), pollution abatement studies (Dean and Haskins, 1964; Pearson and Rosenbert, 1976), storm-related bottom disturbances (Frankenburg, 1971; Boesch *et al.*, 1976; McCall, 1978; Maurer and Aprill, 1979; and Johnson, 1980), hypoxia (Harper *et al.*, 1981) and even the toxic effects of red tide (Simon and Dauer, 1977). Early succession begins within a few days of the cessation of the disturbance with the arrival of swimming crustaceans (i.e. amphipods and cumaceans) and more motile polychaetes and echinoderms which immigrate into the area as adults from adjacent areas. Also forms which survive the disturbance and capable of burrowing through the disrupted sediment layer add to initial recolonization effort. More importantly, the larvae of relatively opportunistic polychaetes and bivalve molluscs settle randomly or preferentially onto the new substratum from the overlying water column during seasonal recruitment periods. The latter are characterized by short generation times, small size, high fecundity, and high larval availability. These species most commonly experience high mortality and may disappear locally as a result of competition and/or predation from the more motile immigrants to an area.

In the absence of additional disturbance, latter phases of succession are usually characterized by the gradual re-establishment of the Stage II/Stage III community which previously inhabited the undisturbed area or, in the case where sediment composition is severely altered, a new fauna recruited from outside areas (McCall, 1978). Stage III colonizers are represented by the less mobile crustaceans, molluscs, and miscellaneous phyla (Hemichordates, Echinoderms) and less opportunistic polychaetes. These species, in contrast to Stage I colonizers, maintain more or less constant, relatively low population densities, are usually larger in size and exhibit lower fecundity and recruitment potential. Individuals of these species may persist over long periods of time in the absence of severe perturbations. Stage II species are intermediate in their mode or stage of colonization and life history strategies as described for the more extreme Stage I and III.

Estuarine and nearshore areas subject to chronic natural disturbance through wave-induced substrate motion or periodic sedimentation are among the most resilient benthic ecosystems (Copeland, 1970; Holling, 1973; Boesch, 1974; Rhoads et al., 1978). This is because rapidly colonizing opportunistic species are likely to be present continuously. In the benthic assemblages delineated in this and earlier studies (Vittor, 1982), this appears to be true. For example, *Mediomastus* spp., *Myriochele oculata*, and *Prionospio perkinsi* are be expected to be an early colonizers. These species, along with a number of other small, opportunistic tube-dwellers (i.e. *Owenia fusiformis*) may rapidly colonize and dominate large areas of the benthos for some time due to their competitiveness for space (as tube dwellers) (Woodin, 1974) and their ability to stabilize, through the physical presence of their tubes, the soft sediments from further low amplitude wave disturbance (McCall, 1978). Other suspected Stage I colonizers include a number of small crustaceans (*Acanthohaustorius uncinus* and *Oxyurostylis smithi*) and small pelecypods (i.e. *Mulinia lateralis*). Stage II species are larger, more errant (free-moving), surface and subsurface burrowing animals comprised of less opportunistic polychaetes, echinoderms, gastropods, and nemerteans. Trophically, the majority of species in this group are carnivores, presumably preying on the dense concentration of Stage I species in the area. These include the echinoderms, *Hemipholis elongata* and *Micropholis atra*, the gastropods *Nassarius acutus* and *Haminoea succinea*, and the polychaetes, *Sigambra tentaculata*, *Cossura soyeri*, and *Glycinde solitaria*. Stage III organisms include the hemichordate *Balanoglossus aurantiacus*, the gastropod *Caecum johnsoni*, and the bivalve *Macoma tenta*.

Odum (1969) has postulated that if a disturbance is regularly repeated after the initial recruitment period (i.e., colonization of Group I species), the system may be maintained in a state of continuous recruitment and high productivity. A good example of this multiple-disturbance scheme is evident in fluctuating water level ecosystems such as intertidal zones. These areas are naturally maintained in an early relatively fertile stage by the tides, which provide the energy for rapid nutrient cycling. In deeper parts of the estuary, the disturbance may be in the form of storm generated sediment resuspension. It should be emphasized that the concept of pulse-stability works only if there is a complete community adapted to the particular intensity and frequency of the perturbation (Odum, 1971). In this system, necessary human disturbance of ecosystems, such as dredging activities, can be managed in such a way as to enhance productivity while maintaining a degree of environmental resiliency (Rhoads *et al.*, 1978).

As mentioned earlier animal-sediment relationships are of significant importance in the structuring of macroinfaunal communities. An even temporary shift in the sand-silt-clay percentage distribution of sediments can result in significant changes in the community structure of an area. From the three thin-layer placement operations discussed above, two (Alpha and Delta) resulted in a increase in the sediment grain size of the disposal area compared to the control (i.e. the sediments became sandier) and one (Beta) resulted in an decrease in sediment grain size (i.e. the sediments became finer).

As a result of thin-layer placement at area Alpha during August, the sediments were sandier and more heterogeneous. Through time, area Alpha continued to become even more sandy so that at the end of 12 months the disposal area contained approximately 25% sand while the control area was approximately 5%. It is likely that this increase in sand content is not related to the disposal event but to some natural variability in the estuarine system. The result of this increase in sand content, however, is very significant in terms of the macroinfaunal community. Although there was an initial reduction in organism abundance, number of taxa, and diversity of the community, recovery to levels observed at the control sites was evident within 1 month following disposal. This initial recovery was mediated by larval recruitment as well as survival of the larger more motile Stage II and III organisms. A significant larval recruitment event was noted during the October - November time frame at both the disposal and control sites. Within one year of the disposal event, area Alpha was characterized by significantly more taxa and greater abundance of organisms as compared to the control areas. In addition, the community was more diverse with a good distribution of Stage I, II, and III species. Following classic ecological theory, the disposal area would be more healthy, more resilient to change, and more productive following the disturbance created by the thin-layer disposal.

Thin-layer placement at area Delta in May resulted in a somewhat similar but also a very dissimilar response to that of area Alpha. The sand content and heterogeneity at area Delta was increased initially, but after one month sand content declined somewhat but still remained greater than the control area for the duration of the study. Heterogeneity of the habitat remained but probably was not as great as at area Alpha. Even though abundance of organisms was similar, the disposal and control areas were very dissimilar with regards to number of taxa and diversity immediately prior to thin-layer placement and data from both areas was very dissimilar to the information collected during the 1992 pre-disposal survey. The thin-layer placement at Delta did not result in any initial negative impacts. Both abundance of organisms and numbers of taxa began to increase within one month, however the increases in number of taxa were not of the same magnitude as the similar increase at the control area. Recruitment events were seen in summer and winter at both locations, with the summer recruitment being much more important. Following the July recruitment, organism abundance at the disposal Delta began to increase significantly over that at the control while increases in number of taxa although larger were not as significant. In contrast to the Alpha thin-layer placement, initial larval recruitment into the area occurred during the early summer, immediately after placement, which is the prime growth season along the northern Gulf of Mexico. This would have allowed the organisms to feed and grow thereby increasing predation capacity which recruits larger benthic organisms into the area. This increase in larger more motile organisms possibly resulted in an increase in bioturbation and homogenization of the sediments and this providing a more stable environment in a shorter time frame. Ultimately the macroinfauna community at area Delta disposal was characterized by very high abundance of a number of taxa so that diversity was also high. The control on the other hand was characterized by lower abundance but also high diversity. Based on the high diversity, high abundance of primarily Stage I and II organisms, the community that resulted from the thin-layer placement at area Delta was at least as healthy as that of the control area but extremely more productive.

The response and recovery of area Beta is different from that described above for two reasons: the habitat was made more fine grained and than the control and second and perhaps more important the disposal activity was timed to occur in September - October time frame. The initial response of area Beta to the thin-layer placement was an increase in the clay component of the sediment. The slight initial decrease in silt content was ameliorated within 1 month but the clay content continued to be higher in the disposal area than the controls for approximately 7 months. A reduction of organism abundance, number of taxa, and diversity were noted immediately following disposal. Some recolonization of the community began immediately but this was probably mediated through immigration of organisms from adjacent areas and upward migration of those organisms that survived the thin-layer placement. The winter larval recolonization event, although evident in the data, was either not sufficient to cause immediate recovery of the disposal area or the conditions at the disposal area (increase in clay content and subsequent shifting sediments) were not conducive to establishment of many of the larval forms. Diversity of the macroinfaunal community at the disposal area became similar to that of the control area within 5 months while organism abundance did not recover for 10 months which was immediately following the summer recruitment period. Following the June recruitment period, organism abundance at the disposal area increased to that of the control areas. At the end the disposal area was slightly more diverse than the control with slightly greater abundance and number of taxa. A healthy community was seen to exist at both the control and disposal areas. In this case the thin-layer placement had a greater initial impact due to the length of time required for recovery but even so the community was able to recover to pre-disposal conditions within 12 months.

7.6 FISHERY STUDIES

7.6.1 Introduction. Two basic questions were raised concerning the impact of thin-layer disposal on fishery resources:

- What is the physical impact of thin-layer disposal on larval fishes?
- What is the biological impact of thins-layer disposal on fishery resources?

Previous fish research at the thin-layer site for Fowl River, Alabama had demonstrated that fish standing stocks were rapidly restored to the thin-layered site, if indeed they were ever diminished. The mobility of most fishes and their ability to fully exploit their environment would seem to make that response to thin-layering likely in a general sense. Even more or less planktonic, larval fishes might be expected to be advected over thin-layered sites by tidal currents. The National Demonstration Program, therefore, decided to address other questions concerning potential effects of thin-layer deposition on fisheries resources, questions which have more to do with fish behavior and ecosystem function than with ecosystem structure.

A four pronged research effort was developed by the National Marine Fishery Service, Beaufort Laboratory, each addressing a different potential effect of thin-layer disposal on fishes (Colby, 1996). The first was conducted in Mississippi Sound off Gulfport, while the other three were accomplished at the Beaufort Laboratory of the Southeast Fisheries Science Center. Additional support in FY 1995 allowed continuation of the second, third and fourth projects for higher replication. It also allowed us to refine our methods with information gained through exploration of questions that had arisen in the course of carrying out the planned work.

The first research effort was to compare the feeding success of fishes confined over thin-layered sites with those confined over adjacent, 'control' sites in Mississippi Sound. Since this effort extended from August 1992 to October 1993, it allowed assessment of "recovery" of thin-layered sites in terms of their provision of food for benthic fishes.

The second research effort examined the potential direct effects of dredged sediments falling through the water column on the well-being of smaller and more fragile fishes that might lack the mobility to avoid the discharge plume during a thin-layer deposition. This was done in the laboratory using novel equipment especially designed for the purpose of simulating the deposition plume.

The third research effort compared different species' feeding responses to a range of variation in turbidity and prey concentration. Again, novel equipment was required to maintain kaolin (clay) in suspension during tests, and also to prevent phototactic behavior of prey from biasing results.

The fourth and final research effort examined the ability of fishes to assess the profitability of foraging over food-rich and sterile sediments and respond accordingly. The general idea behind this work is that if a feeding fish can distinguish sediments relatively low in food resources (e.g. perhaps thin-layered sites), it is less likely to 'waste' foraging effort over them and therefore impacts to fish production will tend to be thereby minimized.

7.6.2 Comparisons of Feeding Success in Mississippi Sound. The general approach for evaluating the effect of thin-layering on fish feeding success was to compare the gut contents of fishes placed in specially designed cages on the sea floor for approximately 3 hours. Four expeditions were made to Gulfport to compare feeding of fishes on the Gulfport thin-layer disposal sites (experimental sites) and nearby areas that did not receive dredged material (control sites). The dates these experiments were conducted and the thin-layer disposal site(s) investigated are listed in Table 3.

Table 3. Fish Feeding Success Study Dates and Areas

FIELD INVESTIGATION DATES	THIN-LAYER DISPOSAL SITES USED
August, 1992	Alpha
March/April, 1993	Zulu
July, 1993	Alpha, Delta, and Zulu
October, 1993	Alpha, Delta, Zulu, Beta, and Foxtrot

The deployment of an individual juvenile Spot in a cage on the floor of Mississippi Sound as a sort of bioassay of the benthic food resources seems to have been a viable approach. Some fish were found to have a hundred or more prey in their guts when recovered. This suggests the general method might have applications in other types of situations, including studies of other approaches to dredged material disposal. While the March-April 1993 expedition suffered from the absence of juvenile Spot to use, an opportunity was missed for useful comparisons of feeding on the Zulu site immediately before and after the thin-layer was deposited. This is the often the fate of applied biological research out there in nature if one tries to couple experimentation with a major engineering operation.

The data obtained from 460 cage deployments of juvenile Spot during 1992 and 1993 revealed that the fish were as likely to have fed if deployed on a thin-layered site, as they were if deployed on adjacent areas of the sea floor. Examination of their diet compositions showed that in the first few months following the thin-layer deposition, the feeding profiles of fish from experimental and control sites may differ, but that within about a year, they converge. The data from the study failed to reject the null hypothesis that fish placed in cages on control and experimental sites would have an equal probability of having fed during their period of submergence. On the other hand there was clear evidence that in the short term, at least, the feeding profiles would differ with heavier feeding on control sites for at least some food types. Finally, the study provided evidence that the food resources on thin-layered sites tend to converge with those on adjacent unmodified areas over 6 to 14 months, or else come to exceed them.

7.6.3 Response of Fishes to Simulated Thin-Layer Deposition. The second research project examined the survival of larval and juvenile fishes experimentally exposed to laboratory simulated thin-layer deposition. The purpose was to determine if direct physical effects of the falling sediments might cause significant mortality.

A potential effect of thin-layer deposition on larval and early juvenile fishes might arise from direct contact with falling sediments in the discharge plume. Although larger and more mobile fishes would be expected to easily avoid the plume, the same is not necessarily true for smaller and more fragile fishes. We decided to attempt to simulate thin-layer deposition in the laboratory and compare its effects on small fishes in a factorial design in which, in addition to fish species, sediment grain size and sediment depth could be experimentally varied under controlled conditions. Although previously undetected structural problems at the Beaufort Laboratory required premature termination of the first phase of this work we were later able to continue the research albeit with a simpler design and testing apparatus..

These experiments were divided into two phases. In the first phase, a battery of 12 test columns was used to test treatment combinations of depth and sediment grain size in a factorial design, but replication of the experiments was less than desired. The six sediments employed in the full design were five grain-size categories of sand, and kaolin clay. The depths employed were 10, 20, and 40 cm. Later, in the second phase of experimentation, we used a single, re-designed test column to test fewer experimental treatments, but with more adequate replication. In this second phase of the experimentation clay, coarse sand, and sand obtained from a local beach were employed with a single depth of 20 cm

The cylindrical design of the test columns used in the first phase of these experiments restricted test fish from moving laterally to avoid the falling sediments, an option probably available to them when confronted with falling sediments during application of a thin-layer. In addition, the height of the test columns in some instances made it difficult to gently dip-net fish from the column at the termination of the trial, making it necessary to siphon the fish from the column into a dip-net. In those cases where fish were buried in the sediment, recovery entailed draining the water and sediments from the column into a container, a procedure that in all probability exposed the fish to abrasion and reduced their survival. Therefore, there is reason to believe that survival was reduced by factors other than the direct effects of the falling sediments; i.e. experimental artifacts associated with the recovery of the fish at the conclusion of a test.

The laboratory simulations of thin-layer application differed from the real thing in a number of ways. In both phases of the experimentation fish were presented with the sudden release of sediments, rather than the more or less continuous discharge of an actual thin-layer application. The sediments were dry when dropped onto the surface of the water at the top of a column instead of being discharged as a slurry; the clay treatment was an exception to this. The height of the test columns was far less than the 3-6 m. height of the water column over thin-layered sites in Mississippi Sound.

The appearance of the sand falling within a test column resembled the roiling appearance of the mushroom cloud following a nuclear explosion. On a number of occasions Spot were observed to instantly respond to the falling sediment by rapidly swimming upwards in the column. This implies that they were able to detect the shock wave generated as the sediments hit the surface of the water. This in turn suggests that if they were in close proximity to a thin-layer discharge, they would readily detect it and probably attempt to move away to reduce their exposure to the falling sediments.

The design of the test apparatus for the second phase of experimentation made at least limited provision for avoidance of falling sediments by lateral movement. However, because the fishes were not confined directly under the discharge column prior to sediment release, we have no measure of the fishes' tendency to move laterally following the release. In any case, there were no statistically significant differences in initial or 24 hour survival of a species between a sediment treatment and the corresponding control treatment.

One of the more remarkable results from the experiments was the very low numbers of fish that were buried by the falling sediments. The experiments revealed that even very fragile fish larvae were relatively robust to the simulated depositions and survivals were generally above 80 percent, frequently above 90 percent. A majority of the fish also fed successfully when offered brine shrimp after 24 hours, confirming that they were in relatively good health. This held even for fragile, relatively weak swimming Menhaden larvae. Larval Flounders often rest on the floor of an aquarium (or test column) and they would therefore seem especially vulnerable to burial, but that proved not to be the case. This suggests that they too responded to the initial shock wave of the falling sediment hitting the surface of the water by instantly swimming upward into the water column, thereby remaining above the sediment as it accumulated on the floor of the column or tank.

Our overall conclusion from the experiments is that the larval and post-larval species tested were remarkably robust to the falling sediments. Therefore it would seem unlikely that direct physical injury from thin-layer deposition would constitute a major source of mortality for larval and post larval fishes.

7.6.4 Fish Responses to Variations in Turbidity and Prey Density. The third research project investigated the relative feeding success of larval and juvenile fishes used a factorial experimental design in which turbidity and prey concentration were varied over four and three orders of magnitude respectively. In most of the experiments brine shrimp were used as prey, but experiments were also conducted using wild caught plankton as well. Logistic regression models were fit to the data for each species of fish tested and they provided a means of assessing the relative importance of the two factors in determining whether a fish had fed or not. Each species tested exhibited a different pattern of response, but a species' response to wild plankton tended to be similar to its response to brine shrimp. Some species such as Spot had a high probability of having fed over the entire range of turbidities. For others, such as Flounders, the probability dropped rapidly with increasing turbidity.

Turbidity is an environmental attribute of estuarine fishes that may influence their ability to meet their food requirements for metabolism and growth. It may, for example, decrease, or enhance, a larval fish' s ability to capture the plankton on which its survival and growth depend. On the other hand, that same turbidity may similarly decrease, or enhance, a piscivore's ability to capture that larval fish. And finally, because turbidity, by definition, determines the transmission of light through water, it can profoundly effect primary production of an aquatic ecosystem. Thus turbidity may, in somewhat complex ways, effect the productivity of fish stocks dependent upon estuaries for the completion of their life cycles.

Turbidity of an estuary of course varies as a consequence of the inherent composition of the soils of its watershed, land development, agricultural practices, weather, and a host of other factors. Increasing turbidity of estuaries and near shore zones of the world's oceans would seem a likely consequence of unprecedented global population growth and attendant over-exploitation and deterioration of terrestrial ecosystems. So, it is unlikely that turbidity will join those natural phenomena that disappear before they can adequately be studied and understood.

In what follows we have defined turbidity only in terms of the amount of a kaolin clay added to test chambers. The exact nature of the turbidity arising from addition of a suspension of this clay to the test chambers, is unclear. We have, as a result of attempting a more satisfactory definition, come to appreciate the complex nature of clay, the inconsistency of definitions of terms as used in the literature on clays, and the ineluctable fact that one would need to know the physical structure of the immersion of clay particles to really comprehend the nature of the turbidity produced and the way it influences a planktivorous fish.

One might conceptualize the ambient environment from the viewpoint of the fish. If the clay particles are plate like in physical structure, then the foraging larval fish is faced with attempting to detect an intermittently swimming copepod among all the continually moving, plate-like snow filling its visual field. Questions arise as to what is the 2 dimensional area of the copepod's silhouette with respect to the 2-dimensional area of the adjacent clay flakes? What is the visual contrast between the two?

Plankton in nature are notoriously "patchy" in their distribution with concentrations varying over orders of magnitude within a few meters. Turbidity in nature also varies over orders of magnitude, temporally over hours and spatially over kilometers or less. Because of the species comparative nature of our experiments, and the orders of magnitude variation encountered in nature, we elected to experimentally vary turbidity and prey concentration over orders of magnitude so as to maximize our opportunities to detect taxonomic differences in response to variation in the two factors.

The approach to examining the effect of turbidity on the ability of small fishes to capture food items had to deal with two problems. The first of these is the tendency of clay particles placed in sea water to agglomerate and settle out of suspension, making it difficult to maintain a specified level of turbidity over the duration of a test interval. The second problem arose from the fact that brine shrimp nauplii were used as prey and they are strongly phototactic. In a static system then, they would aggregate in the direction of the strongest light, thereby influencing the ability of the fish to feed upon them. To deal with these problems, a testing apparatus was designed that consisted of a clear acrylic "wheel" partitioned into six chambers to hold seawater, clay, fish and brine shrimp. A chamber held a mean volume of 2,733 mls and had two access ports with expandable plugs for convenient filling and draining. During a test, the wheel was slowly rotated on a motorized base so as to maintain the clay in suspension through gravity and to continuously alter the direction of light and thereby nullify any tendency of the brine shrimp to concentrate through phototaxis. In practice, two wheels were used so that 12 test chambers were available simultaneously for a given experimental trial.

The data from the first phase of these experiments are useful for examining the relative importance of turbidity and prey concentration in determining the likelihood that a larval or juvenile fish will feed. The differences in the patterns for the different taxa can only be explained by closer examination of how the different taxa detect and capture prey. That is, a clear understanding of the results must await a better understanding of differences in fish sensory physiology and behavior. Undoubtedly there are other, ontogenetic factors that come in to play as well.

Attempts to culture *Brachionas plicafilis* and *Acartia tonsa* (species of plankton) and use them in prey were largely unsuccessful, but use of wild caught plankton assemblages provided useful information for comparison with the results during the first phase. In general, the model parameter estimates were surprisingly consistent for the two prey types. The exception was the lesser importance of food concentration for Menhaden feeding on the wild plankton.

The artificial nature of the experiments becomes apparent when one attempts to relate them to the situation a larval or juvenile fish encounters in nature. The chambers of the testing apparatus were only a few centimeters in maximum extent and therefore the maximum distance a fish could be from a transparent surface exposed to ambient light was only several centimeters. Therefore, the foraging environment presented to the foraging test fish most closely resembles one the fish might encounter within a few centimeters of the sea's surface in waters carrying the specified concentration of clay particles.

If one were only considering the effect of clay on reduction of light for visual detection of prey, then one could of course conceptualize the system so that a specified weight of clay in a test chamber was equivalent to the reduction of light that would occur at some depth with an equivalent weight of clay dispersed in the water between the fish and the surface. However, all of that presupposes that the only effect of the clay is to reduce the level of light reaching the eye of the fish. That would seem unlikely. We instead see the clay as additionally acting as both a physical barrier in the visual path of the fish preventing it detecting the prey, as well as providing a contrasting visual background against which the prey may perhaps be more easily seen.

The impact of increased turbidity on the feeding of larval and post larval fish is very species specific. For example the probability of Menhaden feeding was inversely related to turbidity and directly related to food concentration, i.e. the probability of feeding dropped sharply as either the turbidity increased or the food concentration decreased. For Spot and Croaker, on the other hand, turbidity appeared to have little effect on the probability of feeding regardless of food concentration.

7.6.5 Behavior of Fishes Foraging on Experimental Substrates. The fourth research project was designed to determine if juvenile Spot could readily distinguish differences in foraging profitability of different experimental sediments. In the first phase of these experiments a factorial experimental design was followed. Sediment grain size category and length of time the sediment had been exposed for colonization by meiofauna were the two factors. Later, in the second phase, natural sediments from an intertidal flat were used along with medium sand. The fish displayed relatively high foraging efficiency throughout the experimental series, with many entirely avoiding sterile sediments that were offered. The fishes' ability to assess the foraging value of the different sediments suggests that they would probably not linger over sediments largely devoid of food items, but would instead move on to more profitable environments. This, in turn, would tend to minimize the impact of thin-layer deposition and any attendant, if temporary, reduction in benthic prey, on production of fishery organisms.

A central idea behind thin-layering of dredged materials is to spread the materials thinly over a relatively large area so as to keep the depth of the deposited materials within some specified depth; e.g.. six or twelve inches. That being the case, the impact of thin-layer disposal to a foraging fish is to some extent determined by how much effort it puts in to foraging over presumably unprofitable (i.e. thin-layered) substrate, rather than moving on to more profitable foraging sites. In other words, how much time would the foraging fish waste? We originally proposed attaching sonic tags to fish and tracking their movements after release either over thin-layered sites or adjacent sites that had not been modified. For a host of reasons, that was deemed impracticable and so we instead proposed a laboratory experimental approach that would examine a fish's ability to assess the profitability of substrates naturally colonized with meiofaunal prey versus those deliberately sterilized of prey. Such an approach would at least throw light on whether a foraging fish would, or would not, suffer from wasting effort where it was not profitable.

In the first phase of these experiments we incorporated grain size as a factor in the experiment because of the likelihood that different grain sizes would presumably influence what organisms colonized them. In the second phase of the experiments we additionally compared the tendency of a foraging fish to feed on undisturbed, disturbed and sterile substrates

One consequence of thin-layer disposal is the burial of organisms living in and on the surface of the sea floor. The effect of this burial on fishes that prey upon these organisms will depend in part upon their ability to detect reduced abundance of prey in and on the thin-layered deposits, and thus continue moving to feed elsewhere.

A second potential consequence of thin-layer disposal could arise from changes in the grain size composition of the surficial sediments, if the grain size composition of the dredged sediments differ markedly from those they bury. The grain size composition of sediments can influence which organisms colonize them and in what level of abundance, and therefore thin-layer disposal could change the overall quality of the sea floor affected as to its suitability for foraging fishes. The first series of foraging experiments deliberately compared sands of different grain size categories. The results indicated that they were all about equally attractive to the foraging Spot and presumably to colonizing prey as well. Instead, what was of major importance was the length of time the sand had been available for colonization.

The second series of experiments convincingly demonstrated that juvenile Spot can readily distinguish the suitability of a sediment surface for foraging and further indicated that they apparently can do this without actually sampling (biting) the sediment as part of their assessment.

The third series of experiments provided a third type of sediment, sediment that had been available for colonization, but that was presented to the fish after it had been mixed, so as to redistribute prey within the sediment and perhaps eliminate subtle visual cues as to their presence within the surficial sediments. To some degree, this sediment type might correspond to recently deposited thin-layer. In any case, for 20 of the 33 Spot the response to the undisturbed sediment was at least one order of magnitude higher than for the disturbed sediment. This implies that their ability to distinguish among the sediments was far more discriminating than merely on the basis of presence or absence of prey, as was also revealed in the results of the first series of foraging experiments.

7.6.6 Summary and Conclusions

The fishery research conducted during the National Demonstration Program has attempted to address certain potential consequences of thin-layer dredged material deposition on the production of fishery resources. Its direction was partly dictated by the fact that comparison of standing crops of fishes on thin-layered and adjacent sites was found wanting as a metric for addressing potential effects of the method, if for no other reason than that fishes tend to be highly mobile as juvenile and adults and are readily advected as planktonic larvae. Fish are also frequently aggregated either in response to hydrographic phenomena which concentrate foods or simply because they form schools. The aggregated nature of their spatial distributions tends to produce high levels of variation among samples, leading to low statistical power in detecting differences in density from one study site to another.

The first research project compared the feeding success of individual juvenile Spot placed in cages on the floor of Mississippi Sound, either on, or adjacent to, sites that had been thin-layered. The comparison of fish that had fed, or not fed, revealed evidence of differences only on the Beta site, and that implied that more fish that had been placed over the Beta site had fed than those place over the adjacent area of Mississippi Sound. On the basis of the feeding success criterion then, the evidence favored rapid recolonization of the thin-layered sites by meiofauna taking advantage of the available uncolonized substrate that was made available as a part of the process of thin-layer disposal. In that sense, the ecological process was similar to weeds invading newly exposed soil.

Comparisons of the food types found in the guts of the caged fishes revealed some differences that were not apparent in the comparisons of whether they had fed or not. Alpha was studied from immediately after it was thin-layered in August 1992 until 14 months later in October 1993 and thus provided the best data for examining for evidence of temporal convergence in foraging opportunities between thin-layered and control sites. Comparison of food profiles for copepods, diatoms and foraminifera revealed differences immediately following the thin-layer deposition. Subsequent sampling 11 months later in July 1993 however, indicated that there were higher proportions of heavy consumers of copepods and forams on Alpha than on the corresponding controls. By the following October the food type profiles were indistinguishable. The Zulu and Delta sites also revealed differences several months after thin-layer deposition, but these differences too were no longer detected during the October 1993 investigation. No differences in the food profiles between the thin-layered site and the control samples were detected for Beta and Foxtrot when sampled in October 1993, 12 to 13 months after they had been thin-layered.

The studies of feeding by Spot deployed in cages on the floor of Mississippi Sound thus revealed that the effects of thin-layering were manifested not in whether fish had fed, but rather, at least for several months, in terms of what they fed upon. The data also indicated that convergence in food resources for benthic feeding fishes like Spot probably is achieved within 8 - 14 months in a system like Mississippi Sound.

The investigation of direct physical effects of thin-layer deposition on larval and post larval fishes through laboratory-simulated, thin-layer deposition revealed that even the most fragile fish larvae are relatively robust to sediment falling through the water column. The relatively limited mortality observed may have been due, at least in part, to the process of recovering the fish at the termination of an experimental trial. Given that the experimental simulation restricted the fish in ways they would not be in an actual thin-layer deposition, and because we deliberately included relatively fragile larval stages of fishes in the tests, the results represent a "worst case" set of events. We therefore find it unlikely that thin-layer deposition will cause an important amount of fish mortality through direct physical effects of the falling sediments.

Increased turbidity is another consequence of thin-layer deposition, although its spatial extent and temporal duration may be quite limited, depending upon the sediments deposited, prevailing currents, and other factors. Our highly replicated studies compared the feeding response of 5 species of larval and juvenile fishes to differences in turbidity and prey concentration that extended over four and three orders of magnitude respectively. Each species exhibited a different pattern, with Spot showing little reduction in the probability of having fed if prey concentrations were high, regardless of the turbidity. Paralicthid Flounders on the other hand only had a high probability of feeding if the water was relatively clear and the prey concentration was high. Subsequent experimentation with wild-caught plankton assemblages, generally revealed that the fishes tested exhibited responses that tended to parallel their earlier responses when brine shrimp were the prey, and thus increased our confidence that the earlier results were not tied to the fact that brine shrimp, rather than their normal prey, were used.

If a foraging animal can not readily detect ambient densities of its food, then when confronted with an artificially created habitat (i.e. a thin-layered site, perhaps largely devoid of food) it may continue to expend energy foraging over unproductive environments and thereby suffer the consequences in terms of diminished growth and production. On the other hand, if it can readily detect unprofitable environments, it can continue to move on in search of other, more food-rich environments, and the overall effects of the artificially food-poor environments will be minimized. Our several studies of the foraging behavior of juvenile Spot were remarkably consistent in demonstrating the capability of that species to detect differences in the relative profitability of different substrates for foraging. We conclude that juvenile Spot are very capable of putting their foraging effort in to searching substrates that yield food and not wasting foraging effort over those of low prey concentration. Therefore, we would expect that the effects of temporarily diminished food resources on a thin-layered site, on production of benthic feeding fishes like Spot, would be less important than if they were unable to so effectively assess the food resources of their immediate environment.

7.7 WATER QUALITY

7.7.1 Introduction. The question posed by the Study Team to be answered by the water quality studies was:

- What changes in water quality occur as a result of the disposal operation and how long is the period of recovery to ambient conditions?

The water quality study plan included the thin-layer placement of dredged material at four areas, two sites located on the west side of the channel, which received maintenance material, and two sites located on the east side, which received new work material. This was done to analyze the differences between the two types of material when dispersed in a thin-layer over a vast area. To address possible temporal variability in thin-layer placement impacts to water quality, disposal was performed at two different times, the first during September/October 1992 on Beta and Foxtrot which were located closer to shore. Delta and Zulu were disposed on during March/May 1993.

The monitoring for each disposal area consisted of four phases: predisposal, during disposal, short-term post-disposal (2 - 4 days following disposal), and long-term post-disposal (monthly for six months). During the predisposal, during disposal, and short-term post disposal phases, the following parameters were measured at each station-by-depth combination: temperature, salinity, pH, dissolved oxygen (DO), turbidity, total suspended solids (TSS), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), ammonia, nitrate, nitrite, total phosphorus, orthophosphate, sulfate, and chlorophyll a. During the long-term surveys, temperature, salinity, pH, DO and TSS were measured at each station-be-depth combination.

In addition to the above parameters, total fecal coliform bacteria was measured in surface and bottom waters during disposal monitoring at Foxtrot. Of the 76 samples taken, 70 observations were below the detection limit (1 MPN/100 ml). Each of the remaining 6 observations was 1 MPN/100 ml and included both surface (1) and bottom (5) water samples. Since there was no indication that thin-layer disposal was releasing fecal coliform bacteria, additional bacteria samples were not collected.

Both temporal and spatial references were used to judge whether thin-layer disposal affects water quality. Temporal references involved comparing predisposal results to during and post-disposal results. Spatial comparisons consisted of establishing reference sites relative to the disposal sites. Each pair of disposal sites had 3 reference areas (East, West, and South). Separate reference sites were needed for each pair because of differences in distance from shore and water depth.

7.7.2 General Comments on Water Quality Not Related to Thin-Layer Disposal. Before detailed discussions of differences between the thin-layer placement and the reference areas, a few general comments should be made about the water quality of Mississippi Sound during the study. There was little stratification of the water column at Foxtrot, Beta, and their surrounding reference areas because the waters were shallow and easily mixed by waves and currents. TSS was the exception to this general rule. TSS concentrations in bottom waters were often twice the values in surface waters, particularly during the long-term post disposal phases. Natural stratification was stronger at Delta, Zulu, and the 3 corresponding reference sites, because the deeper waters provided a greater potential for stratification and required higher current and wave energies to mix the water column. Surface salinity were generally 2-5 ppt lower than bottom waters during spring and summer, while usually isohaline during the fall. TSS concentrations were generally 2-4 times greater in bottom waters compared with surface waters during the entire study. DO concentrations were stratified during the spring and summer with hypoxic and near hypoxic conditions common in bottom waters during the summer at Zulu and Delta and their east reference site.

Although primary production was not measured during this study, indirect evidence suggests it was low throughout the study relative to other estuaries. Chlorophyll a measurements were higher in and near Foxtrot and Beta sites (4-8 μg/l) than offshore at Zulu and Delta (1-2 μg/l). Median values of 8 μg/l have been reported from Florida estuaries with 90% of all observations greater than 2 μg/l (Freidemann and Hand, 1987). TKN values were similarly low, typically on the order 0.2 to 0.8 mg/l at N. The TOC concentrations in Mississippi Sound were exceptionally low, typically 1 - 3 mg/l; 90% of the observations from Florida estuaries exceed 3 mg/l. Concentrations of DO (2 - 9 mg/l), total phosphorus (0.03 - 0.40 mg/l at P) , TSS (10 - 40 mg/l), levels of pH (7.70 - 8.10) and turbidity (2 - 20 NTUs) were representative of those from other Gulf of Mexico estuaries.

Average current speed was 0.6 ft/s and ranged from 0.0 to 1.8 ft/s. Most of the time, mean current flow was to the northwest, west or southwest (51%), with eastward flow representing 14% of the cycles; however during 29% of the cycles, no clear mean direction existed.

7.7.3 Effects of Thin-Layer Disposal on Water Quality. Thin-layer disposal resulted in changes in pH, DO, turbidity, TSS, TKN, ammonia, nitrate, and perhaps chlorophyll a. Most of these effects occurred during or soon after disposal and the differences were more significant with maintenance material than with new work.

pH was the most frequently affected parameter, but results were contradictory. Disposal apparently decreased pH at Foxtrot and Beta, but it increased pH at Delta and Zulu. Initially, the small pH reductions at Foxtrot and Beta made sense because dredging often exposes reduced materials to the water column, and their oxidation would reduce pH. However, preliminary calculations indicate the magnitude of the effects observed at Foxtrot and Beta cannot be accounted for by the estimated disposal rate and redox potential of the dredged material. Although the cause of the pH differences was not identified, the magnitude observed was within the natural annual variation of pH and therefore poses no ecological consequences.

DO concentrations were effected by the fall disposal event (Beta and Foxtrot) more than the spring disposal. Bottom waters were affected by a 10-20% reduction in DO compared to surface and middepth waters (5-10%).

Turbidity was affected by the disposal of maintenance material and though it affected the entire water column, the greatest effects were seen in bottom waters. Compared to reference sites, increases were less than 6 NTU for surface and middepth waters of Foxtrot and Zulu, but 19-27 NTU in the bottom waters of Zulu and 60-64 NTU for the bottom waters of Foxtrot. Increased turbidity is the most commonly reported effect from disposal plumes though the magnitude of the increases here are consistent with those caused by frontal storms.

TSS was also elevated in the bottom waters of disposal areas. Its limitation to the bottom waters suggest rapid settling rates of the material or low wave and current energy unable to resuspend sediments. Consistently higher TSS numbers were found at Foxtrot throughout the 8 month sampling period suggesting the possibility of channel water invading the disposal area. Bottom and slope sediments of recently dredged channels may resuspended easily and thus may be advected by strong currents. Further, dredging occurred in the channel and turning basin throughout much of the long-term post-disposal phase for Foxtrot and Beta, and suspended material from this work may have been transported by the channel onto Foxtrot and Beta.

Thin-layer disposal appeared to have elevated TKN, ammonia, and nitrate on a few occasions, all during the fall dredging and mostly during the maintenance dredging. Fine grained nutrient rich sediments seem to cause increases in nutrient levels and although Foxtrot's sediments were not significantly enriched, they consisted of fine maintenance material from nearshore waters. Nutrient levels were also elevated for the short term survey suggesting nutrients can leach out of disposal sediments for at least a week after disposal.

Thin-layer disposal appeared to elevate chlorophyll a concentrations by 40% in the bottom waters of Beta after disposal ceased. It would be premature to link this result to increased nitrogen levels seen at Beta during the same period. Generation times of phytoplankton are longer than the time required for water to move through the disposal area, so it is unlikely the phytoplankton were responding to the increased nitrogen levels.

7.7.4 Conclusions. In summary, thin-layer disposal clearly affected pH, DO concentrations, turbidity and TSS levels during disposal, and these effects were stronger when maintenance material was disposed than new work material. In general, these effects were limited to times when disposal was actually occurring. Ammonia and other forms of nitrogen may have leached from disposed material after one of the four disposal events, but the increase in nitrogen concentrations were small. TSS concentrations were elevated at one disposal site throughout the long-term post-disposal monitoring, but these elevations could have been caused by factors other than thin-layer disposal. Other than this potential increase in TSS concentrations, effects from thin-layer disposal on water quality were limited to the areas of the disposal sites and the times when disposal was occurring or soon after disposal stopped.

8.0 SUMMARY OF NATIONAL DEMONSTRATION PROGRAM RESULTS

Throughout these studies an attempt has been made to not only detail the possible negative impacts associated with the thin-layer disposal of dredged material but also to investigate ways to mitigate those impacts that do occur, and if possible to glean benefits from the management of the placement operation. The results of the research conducted during the Thin-Layer National Demonstration Program indicate that the disposal of dredged material in a controlled thin lift can be managed without causing negative environmental impacts and in fact can be managed to effect beneficial impacts to the estuarine system. Short term impacts to water quality, primarily increases in turbidity and total suspended solids, are shown to be restricted to the immediate vicinity of the placement operation and to the time of disposal and immediately (2 - 4 days) thereafter. Thin-layer placement of dredged material has surprisingly few direct physical impact to the even the most fragile forms of larval and post larval fishes. In addition, the increases in turbidity and total suspended solids appear to have highly variable impacts on the feeding ability of these forms. Feeding of Paralithid Flounder had the greatest tendency to be negatively impacted by increases in turbidity but since the increase in turbidity is shown to be very short term, it is highly unlikely that this impact would result in significant impacts to the Flounder resource of the estuary. The possible total loss of the benthic community as a result of thin-layer disposal (i.e. the community becomes azoic) did not result in impacts to the fishery resource in terms of wasted feeding effort at least for Spot, the only species tested. Since there was no evidence of thin-layer placement causing total defaunation of any of the disposal areas, the possibility of additional impacts through feeding effort of other species is reduced. The response of the macrobenthic community to thin-layer disposal is dependent upon the initial sedimentary characteristics and thus the existing community type, the sedimentary characteristics of the dredged material, and the time of the placement operation. At no time, however, did the thin-layer placement result in the total defaunation of the disposal area. Evidence of migration upward through the thin layer of material was evident in all studies. In addition, the 'environment' of the newly placed dredged material was suitable for recolonization by organisms migrating inward from adjacent areas as well as recolonization through larval settlement and growth. Placement of dredged material with different sedimentary characteristics from that of the disposal area may cause a shift in the faunal composition and depending upon the time of placement, recovery may be slow initially mediated by upward and inward migration of adult forms. This was evident when placement was accomplished in the fall and total recovery was not noted until after the spring larval recruitment event. On the other hand, providing heterogeneity in the substrate, i.e. placing sandy dredged material on a fine grained environment, can be utilized to enhance the productivity of the macrobenthic community without any initial negative impact.

9.0 RECOMMENDATIONS

The removal or excavation, transport, and placement of dredged sediments are the primary components of the "dredging process". In design and implementation of any dredging project, each part of the dredging process must be closely coordinated to ensure a successful dredging operation. Once the dredged material has been collected and transported, the final step in the dredging process is placement in open-water, nearshore, or upland locations. The choice of management alternatives involves a variety of factors related to the dredging process including environmental acceptability, technical feasibility, and economic feasibility of the chosen alternative. In 1992, the U. S. EPA and USACE prepared a technical guide to evaluate the commonly important factors to be considered in managing dredged material in an environmentally acceptable manner. The framework consists of five broad steps:

- Evaluation of dredging project requirements.
- Identification of alternatives
- Initial screening of alternatives
- Detailed assessment of alternatives
- Alternative selection

The results of the Thin-Layer National Demonstration Program are an integral part of the detailed assessment of alternatives. Thin-layer placement of dredged material will not always be an acceptable means for managing open water disposal of dredged material, e.g. even the short term limited increases of total suspended solids and turbidity could result in a significant impact if the disposal area were in the immediate vicinity of a coral reef and the dredged material were fine-grained in nature. However, for the majority of estuarine areas, thin-layer placement may provide that environmental acceptable - economically feasible means of disposing of dredged material and in fact may be used to enhance the productivity of estuarine areas. Prior to selection of thin-layer placement as the alternative of choice, the guidance provided in the Technical Framework (U. S. EPA and USACE, 1992) should be applied with input sought from all stakeholders of the area.

In addition, the following specific recommendations are made concerning the application of thin-layer disposal of dredged material.

9.1 CONTRACTUAL

Contract specifications should be written to ensure that the maximum thickness of the dredged material during the initial placement is no greater than 12 inches. Preparation of a thin-layer disposal plan prior to the initiation of the dredging is a must. As part of this plan, there should be contingencies for dealing with instances when the thin-layer specifications are exceeded. To ensure proper application of thin-layer technology contracts should require continuous tracking during disposal with hard copy daily plots provided to the dredging inspector or the Contracting Officer. In addition, Global Positioning System (GPS). positioning or it's equivalent should be utilized for tracing the movement of the spill barge within the discharge area. Soundings should be taken throughout the disposal process to monitor depths, with cross sections taken immediately behind the spill barge as it advances. Preparation of a thin-layer disposal plan prior to the initiation of the dredging is a must. As part of this plan, there should be contingencies for dealing with instances when the thin-layer specifications are exceeded.

9.2 OPERATIONAL

Submerged discharge is recommended to reduce water-column impacts. The use of a submerged point of discharge reduces the area of exposure in the water column and the amount of material suspended in the water column susceptible to dispersion. In addition, the use of submerged diffusers also reduces the exit velocities for hydraulic placement, allowing more precise placement and reducing both resuspension and spread of the discharged material (Neal, Henry, and Green, 1978)..

9.3 ECOLOGICAL

The first step will be to determine whether the objective of the thin-layer placement is to reduce impacts from a currently practiced uncontrolled openwater disposal operation, to use thin-layer placement in lieu of a more costly alternative without incurring adverse impacts to the estuarine system, or to increase the macrobenthic production of an estuarine system by utilizing thin-layer placement. Secondly, information on the physical nature of the dredged material and the macrobenthic communities of the area are recommended so that predications of the recovery stream can be made. In all cases, it is recommended that disposal be timed to occur so that maximum advantage can be taken of larval recruitment events as the mediator of recovery. Management relative to the compatibility of the sedimentary texture of the dredged material and the disposal area will be specific to the objective(s) to be achieved, however it is recommended that a total change in sediment type, i.e. from fine-grained material to coarse grained sands, be avoided. The goal should be to increase the heterogeneity of the community without an initial total defaunation.

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APPENDIX 1

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