DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-23

HABITAT DEVELOPMENT FIELD INVESTIGATIONS WINDMILL POINT MARSH DEVELOPMENT SITE JAMES RIVER, VIRGINIA

SUMMARY REPORT

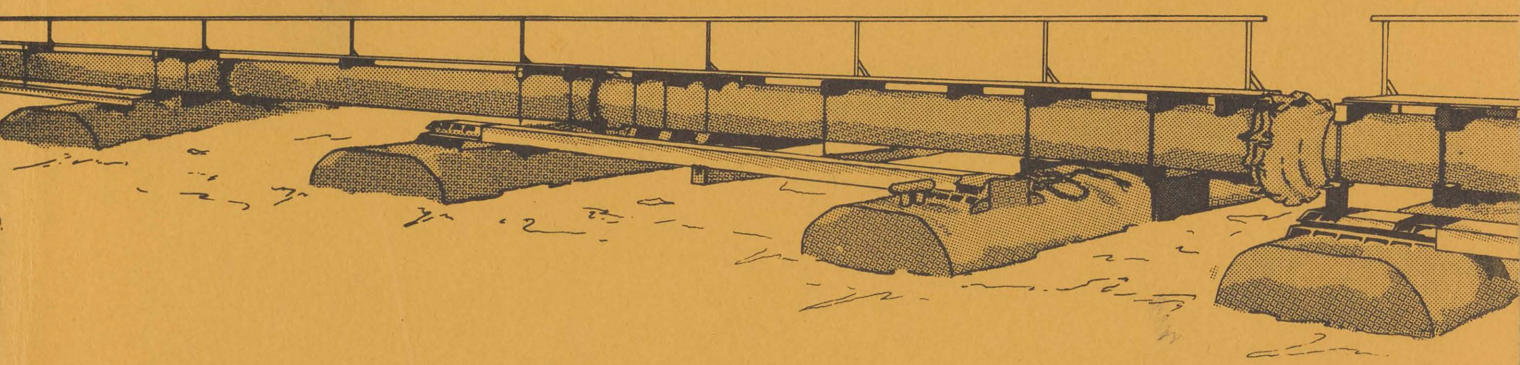
by

John D. Lunz, Timothy W. Zeigler, Robert T. Huffman, Robert J. Diaz
Ellis J. Clairain, and L. Jean Hunt

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

August 1978
Final Report

Approved For Public Release; Distribution Unlimited



Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under DMRP Work Unit No. 4A11M

HABITAT DEVELOPMENT FIELD INVESTIGATIONS, WINDMILL POINT
MARSH DEVELOPMENT SITE, JAMES RIVER, VIRGINIA

Appendix A: Assessment of Vegetation on Existing Dredged Material Island

Appendix B: Propagation of Vascular Plants

Appendix C: Environmental Impacts of Marsh Development with Dredged Material: Acute Impacts on the Macrobenthic Community

Appendix D: Environmental Impacts of Marsh Development with Dredged Material: Botany, Soils, Aquatic Biology, and Wildlife

Appendix E: Environmental Impacts of Marsh Development with Dredged Material: Metals and Chlorinated Hydrocarbon Compounds in Marsh Soils and Vascular Plant Tissues

Appendix F: Environmental Impacts of Marsh Development with Dredged Material: Sediment and Water Quality

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESER

13 October 1978

SUBJECT: Transmittal of Technical Report D-77-23

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of a series of research efforts (work units) undertaken as part of Task 4A (Marsh Development) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 4A was part of the Habitat Development Project (HDP) and had as its objective the development and testing of the environmental, economic, and engineering feasibility of using dredged material as a substrate for marsh development.

2. Marsh development using dredged material was investigated by the HDP under both laboratory and field conditions. This report, "Habitat Development Field Investigations, Windmill Point Marsh Development Site, James River, Virginia; Summary Report" (Work Unit 4A11M), summarizes the activities that occurred during marsh development studies in the James River, Virginia, between 1974 and 1977. A general discussion of the engineering and ecological aspects of the research is presented. The reader is referred to Appendices A through F to this report for more detailed discussions.

3. A total of nine marsh development sites were selected and designed by the HDP at various locations throughout the United States. Six sites were subsequently constructed. Those, in addition to Windmill Point, include: Buttermilk Sound, Atlantic Intracoastal Waterway, Georgia (4A12); Apalachicola Bay, Apalachicola, Florida (4A19); Bolivar Peninsula, Galveston Bay, Texas (4A13); Pond #3, San Francisco Bay, California (4A18); and Miller sands, Columbia River, Oregon (4B05). Detailed design for marsh restoration at Dyke Marsh on the Potomac River (4A17) was completed, but project construction was delayed in the coordination process. Marsh development at Branford Harbor, Connecticut (4A10) and Grays Harbor, Washington (4A14) was terminated because of local opposition and engineering infeasibility, respectively.

4. Evaluated together, the field site studies plus ancillary field and laboratory evaluations conducted in Task 4A establish and define the range of conditions under which marsh habitat development is feasible. Data presented in the research reports prepared under this task are synthesized

in the technical reports entitled "Upland and Wetland Habitat Development with Dredged Material: Ecological Considerations" (2A08) and "Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation" (4A24).

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report D-77-23	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HABITAT DEVELOPMENT FIELD INVESTIGATIONS, WINDMILL POINT MARSH DEVELOPMENT SITE, JAMES RIVER, VIRGINIA; SUMMARY REPORT		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John D. Lunz, Timothy W. Zeigler, Robert T. Huffman, Robert J. Diaz, Ellis J. Clairain, and L. Jean Hunt		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DMRP Work Unit No. 4A11M
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE August 1978 13. NUMBER OF PAGES 116
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Appendices C, D, E, and F to this report were published separately. Appendices A and B were reproduced on microfiche and are enclosed in an envelope attached inside the back cover of this report. See list of appendices on inside of front cover of this report.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dredged material	Habitats	Waste disposal sites
Dredged material disposal	James River	Windmill Point
Environmental effects	Marsh development	
Field investigations	Sediment	
Habitat development	Vegetation development	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A marsh habitat was developed using fine-textured inorganically and organically enriched sediments dredged from the James River navigation channel in the winter of 1974-75. During the period between the autumn of 1974 and September 1977, engineering and ecological activities were accomplished to document marsh construction operations and environmental alterations that accompanied the marsh habitat development. The hydraulic construction of a relatively inexpensive sand dike on a soft river bottom foundation and the

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

ability of the dike to contain fine-grained hydraulically dredged sediments were demonstrated. Ecological monitoring and experimental studies of plants, soils, sediment and water quality; fish, aquatic invertebrate, and wildlife communities; and metals and chlorinated hydrocarbon compound uptake by marsh plants were also conducted. The ecological studies contrasted preconstruction and postconstruction conditions and compared postconstruction conditions with those of a natural marsh habitat. The freshwater intertidal, semi-contained and upland dredged material substrate was nearly completely covered with over 75 types of naturally invaded plants within about 6 months following its construction. Intertidal plantings of smooth cordgrass (*Spartina alterniflora*), American bulrush (*Scirpus americanus*), and other species, and experimental plot studies using arrow arum (*Peltandra virginica*), common three-square (*Scirpus robustus*), big cordgrass (*Spartina cynosuroides*) and other species were nearly completely destroyed in the autumn of 1975 as a result of Canada goose predation, erosion, or native plant invasion and competition. Seeding the upland elevations with a mixture of plant species including American beachgrass (*Panicum spp.*), tall fescue (*Festuca elatior* var. *arundinacea*) and ladina white clover (*Trifolium repens*) was moderately successful and more resistant to conditions that destroyed intertidal plantings. Postpropagation fertilization did not appear to enhance plant development on the sandy dikes. The dredged material disposal mode permitted the retention of less than half of the channel sediments pumped into the dike. The dike effluent contained high suspended loads of organic and other high cation exchange capacity sediments and suggested conditions effecting the solubilization of nitrogen forms and metals. The channel sediments were slightly modified by the disposal operation. Natural reference marsh substrate characteristics more closely resembled those of the original channel sediments than the modified channel sediments forming the substrate of the experimental marsh. Within 2 years following its construction, an apparent chemical equilibrium had developed, and tidal chemical conditions at the natural and experimental marshes were similar. The marsh construction effected a displacement of the original shallow riverine aquatic habitat and produced a habitat of equal or greater value to the fish community. Habitat value judgements were based on observations of cover and trophic value considering macro- and meiobenthic standing crop, community structure, biomass, production and predation by the fish community during cage exclosure, fish food habit studies, and fish community censuses. The dredged material marsh also provided cover for a large variety of waterfowl, passarines, shore and wading birds, and birds of prey, which found cover and/or food on the site's vegetated and unvegetated substrates. In a study of marsh plant uptake of metals and chlorinated hydrocarbon compounds, nickel and possibly DDE were found in higher concentrations in the experimental marsh plants compared with two natural marshes. There was no apparent relationship between total sediment chemical composition and plant available metal and chlorinated hydrocarbon compounds. Soil characteristics occurrent in marshes including near neutral pH, high organic content, and reduced oxidation reduction conditions appeared to restrict chemical mobility and bioavailability and favored chlorinated hydrocarbon degradation. Kepone was present in the experimental marsh soils at concentrations of about 500 ppb, dry weight, which exceeded Kepone levels in the natural marshes studied. Differences in Kepone levels between marsh plant tissues from the different marshes were not indicated.

PREFACE

In the 1970 River and Harbor Act, Congress authorized the Corps of Engineers to initiate a comprehensive, nationwide study to provide more definitive information on the environmental impact of dredging and dredged material disposal and to develop new or improved dredged material disposal operations. The study was divided into four phases: problem identification and assessment, research plan development, research accomplishment, and field evaluation of new or improved disposal practices. The first three of these phases were assigned to the U. S. Army Engineer Waterways Experiment Station and designated the Dredged Material Research Program.

The planning and implementation of the Dredged Material Research Program was accomplished by an interdisciplinary team of scientists and engineers within the Environmental Laboratory at the Waterways Experiment Station. These scientists and engineers worked on one or more of four major research projects:

a. Environmental Impacts and Criteria Development
b. Habitat Development
c. Disposal Operations
d. Productive Uses

Each research project was divided into several research tasks. This report is one of a series documenting the field site investigations conducted by the Habitat Development Project, which was concerned with the following tasks:

a. Task 2A Effects of Marsh and Terrestrial Disposal
b. Task 4A Marsh Development
c. Task 4B Terrestrial Habitat Development
d. Task 4E Aquatic Habitat Development
e. Task 4F Island Habitat Development

Field research in habitat development was designed to test the feasibility of using dredged material to either: establish marsh lands or other aquatic habitats, enhance existing marsh lands, or enhance the biological value of upland areas. Feasibility is determined not only by the practical and logistical problems involved, but also by economic cost, social and political constraints, and environmental effects of such an endeavor relative to the same factors affecting other means of disposal (unconfined open-water, diked upland, etc.). The field site research can therefore be stated as addressing three basic goals:

a. Determine what mechanisms exist that cause the success or failure of habitat development.

b. Determine the environmental effects of dredged material disposal and habitat development.

c. Develop feasible alternatives for disposal of dredged material that will improve the biological characteristics of the disposal site.

The scope, results, conclusions, and recommendations based on the experience of the Habitat Development Project at one of these sites are presented herein.

This report acknowledges the efforts of many persons both within and outside of the Corps of Engineers.

Mr. John D. Lunz was the editor and principal author of the report. He was assisted in its preparation by the various authors of individual chapters. Mr. Lunz was responsible for the overall management and coordination of the Windmill Point marsh development site, the authorship of the introductory, site characterization, and overall conclusions and recommendations and technical sections entitled "Sediment and Water Quality" and "Metals and Chlorinated Hydrocarbon Compounds in Marsh Soils and Vascular Plant Tissues." Mr. Tim W. Zeigler wrote the Engineering and Construction Operations section. Dr. Robert Terry Huffman wrote the Botany section. Dr. Robert J. Diaz and Mr. Ellis J. Clairain prepared the section on Aquatic Biology and Ms. L. Jean Hunt wrote the section on Wildlife.

In addition to the above persons, numerous other past and current employees of the Environmental Laboratory share responsibility for the conduct and completion of studies at the Windmill Point site. In alphabetical order they are: Dr. Paul Becker, Dr. J. Scott Boyce, Mr. Jon Clark, Dr. Richard A. Cole, Dr. Walter Gallaher, LTC Bud Griffis, Dr. Raymond Jones, Dr. A. Dale Magoun, Mr. Thomas Patin, Mr. E. Paul Peloquin, Dr. Judith Unsicker, Dr. Thomas Wood, and Mr. David Wright.

Personnel of the U. S. Army Engineer District, Norfolk, provided technical, contract administration, and logistical support to the Windmill Point Project throughout the period between April 1974 and the preparation of this report.

Special assistance was provided by personnel in Norfolk District within the Engineering Division's Architect and Engineering Contracts Section, Survey Branch and Computer Mapping Section and the Construction-Operation Division's Navigation Branch and Dredging Section.

The cooperation of Mr. David Harrison, Owner, Windmill Point Island; Mrs. Bruce Crane Fisher, Owner, Herring Creek-Ducking Stool Point Marsh; and Mr. Harold Olson, Manager, U. S. Fish and Wildlife Service-Presquile National Wildlife Refuge, Turkey Island, allowed the field observations and collections summarized in this report.

The study was under the general supervision of Dr. Hanley K. Smith, Manager, Habitat Development Project; Dr. Conrad J. Kirby, Chief, Environmental Resources Division; Dr. Roger Saucier, Special Assistant for Dredged Material Research; and Dr. John Harrison, Chief, Environmental Laboratory. Directors of the Waterways Experiment Station during the conduct of this study were COL G. H. Hilt and COL J. L. Cannon. Technical Director was Mr. F. R. Brown.

CONTENTS

CONTENTS (Continued)

NOTE: Appendices C, D, E, and F to this report were published separately. Appendices A and B were reproduced on microfiche and are enclosed in an envelope attached inside the back cover of this report. See list of appendices on inside of front cover of this report.

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

HABITAT DEVELOPMENT FIELD INVESTIGATIONS, WINDMILL POINT MARSH DEVELOPMENT SITE, JAMES RIVER, VIRGINIA

SUMMARY REPORT

PART I: INTRODUCTION

1. The disposal of fine-textured dredged material is a common and often serious problem for the Corps of Engineers. Unlike coarser-grained sandier sediments, fine-textured silts and clays have limited value for fill, aggregate, or beach nourishment. Because of their physical and chemical properties, fine-textured sediments may contain high concentrations of chemical substances used or produced by agricultural, industrial, or domestic activities and discharged directly or indirectly into navigable waterways. Dredged material disposal alternatives for these materials are limited by their chemical properties, which have traditionally defined them as unacceptable for open-water disposal. The most serious disposal problems exist in urbanized, industrialized areas where, in addition to open-water disposal, upland disposal is restricted by land use competition affecting property values.

2. The Corps conducts its dredging activities within about 30,580 km of waterway and 500 harbors throughout the United States. Of the approximately 290 million cu m of material dredged annually, nearly one-third is comprised of silts and clays with particles less than 0.062 mm in diameter. If mixed materials comprised of clays, silts, and sands are considered, the proportion increases to over 80 percent (or 232 million cu m) (Boyd et al. 1972), a volume capable of filling an area of 2,590 sq km to a depth of about one metre. The dimensions of this problem led to the 1970 Congressional authorization of the Dredged Material Research Program conducted at the U. S. Army Engineers Waterways Experiment Station by the Environmental Laboratory. Part of this program was directed to demonstrate and evaluate the environmental effects of the use of dredged material to construct fish and wildlife habitats.

3. This report presents the scope and results of activities designed to develop a marsh habitat on fine-textured sediments dredged

from the freshwater tidal James River at Windmill Point, downstream from Hopewell and Richmond, Virginia.

4. Studies at the site were designed to satisfy the following information objectives:

a. Document the planning, design, construction, and subsequent physical changes in the substrate and engineered structure used for habitat development.

b. Document the planting of vegetation and cultural practices used to develop the habitat.

c. Relate the performance of selected plant species on dredged material to the varying chemical and physical properties of the site.

d. Relate patterns of animal use to the physical characteristics of the dredged material and the vascular plants.

e. Describe the changes in water quality, sediments, hydraulics, hydrography, and aquatic biota following the disposal of dredged material and the development of habitat.

f. Document the concentrations of selected metals and chlorinated hydrocarbons in the dredged material and associated plants and animals.

PART II: SITE CHARACTERIZATION

Site Selection

5. The selection of the Windmill Point location for marsh habitat development studies was made using a list of selection criteria that considered:

a. Regional representation.

b. Habitat type.

c. Sediment type.

d. Energy regime.

e. Association with an authorized Corps project.*

f. Compatibility with the time frame of the Dredged Material Research Program.*

g. Proximity to logistical support.*

6. Under this scheme, the Windmill Point site was classified as a fine-grained, nutrient enriched, polluted freshwater marsh - riverine area in the mid-Atlantic, Chesapeake Bay region. The energy regime was preliminarily classified as low to moderate. The location was associated with the authorized operation and maintenance dredging of the James River navigation channel, could be studied within the time schedule of the DMRP, and was assessible using locally available logistical support.

Site Description

Geographic setting

7. The Windmill Point marsh development site, hereafter referred to as the site, is located at longitude 77°06', latitude 37°18', in the James River 0.4 km west of Windmill Point, Prince George County, Virginia (Figure 1). The largest of Virginia's estuaries, the James River, drains

---

*Note: Practical considerations made these criteria the most important; if any of these three criteria were not satisfied, a particular site could not be seriously considered for selection.

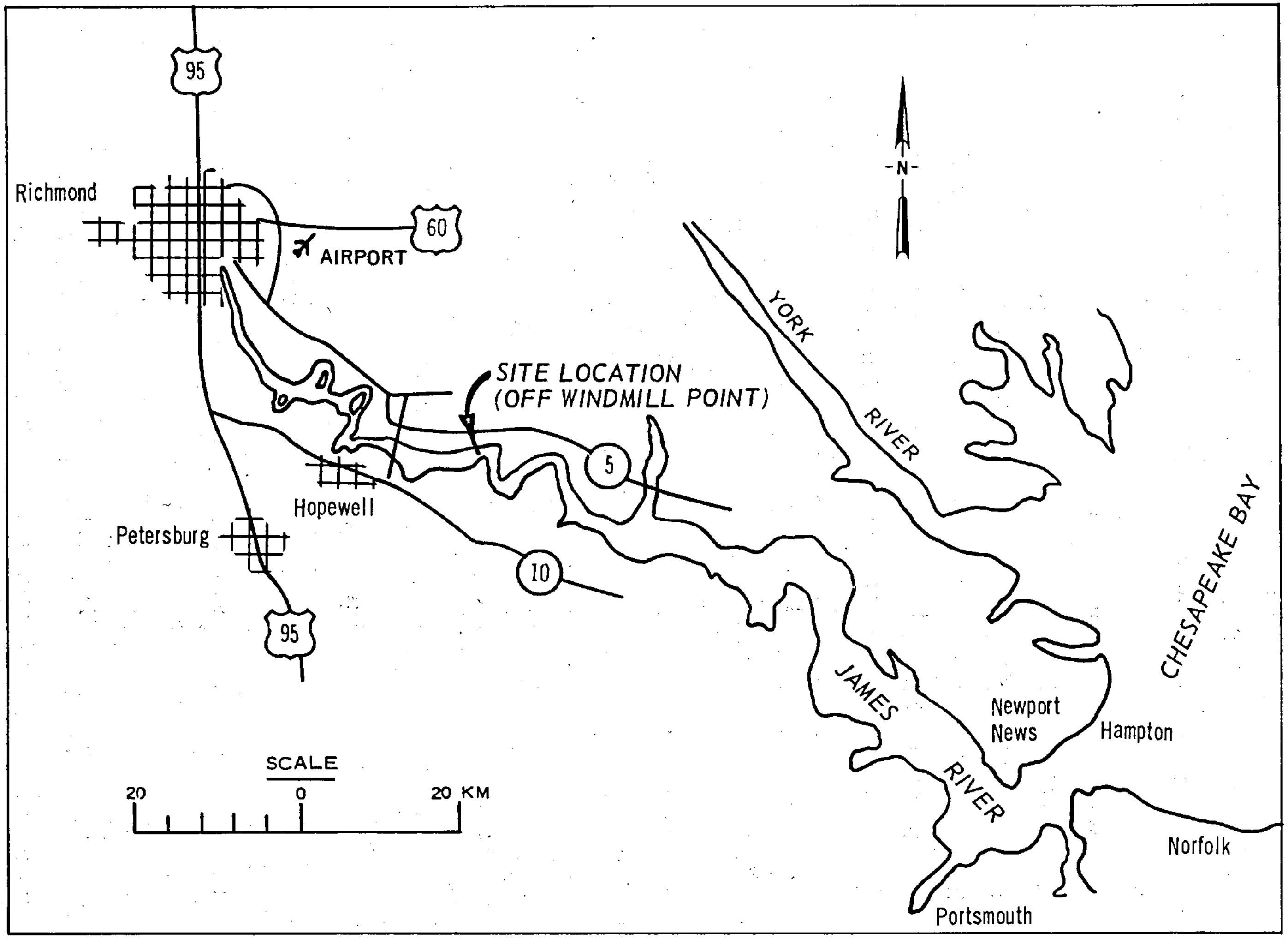


Figure 1. Vicinity map, James River marsh development site, James River, Virginia

a basin of 16,100 sq km in both Virginia and West Virginia and is nearly 550 km long.

8. Land use in the river basin is characterized by intensive farming of the floodplain, centers of primary industry at Richmond and Hopewell, Virginia, cement production, sand and gravel mining operations along the river above Richmond, and rapidly expanding urban and industrial development of the lower portions of the estuary.

Climate

9. Average precipitation for Byrd International Airport (Richmond) weather station (29.0 km northwest of the study area) is 112.29 cm per year with an average of 11.79 cm per month during the period from June through September. Mean annual temperature for the airport station is 14.5° C. A record low temperature of -24.4° C was recorded 29 January 1940 and a record high of 41.7° C was recorded 6 August 1917 (Parker 1975). The direction of prevailing winds is south-southwest. Average number of frost free days is 216 per year. Records of mean monthly climate conditions for periods of at least 10 years are provided in Bryson and Hare 1974.

Hydrology

10. The James River is tidally influenced from its mouth all the way to the city of Richmond at River Mile 90 (km 145) with mean ranges of tides being 0.79 m at Newport News and 0.97 m at Richard. The mean annual discharge at Richmond is approximately 212 cu m/sec (Brehmer 1972). The water at the Windmill Point site is essentially fresh; however, during periods of low flow with the upstream movement of saline waters, salinity at Windmill Point may reach 2 to 3 ppt. This has occurred at least once during the last 78 years.

Sediment and water quality

11. The river is characterized by high sediment loadings and high turbidity. Sediments dredged from the navigation channel and used to develop the marsh site were fine-grained (fine sand and clayey silt), inorganically enriched by natural detritus from freshwater swamps and marshes, and modified by agricultural, industrial, and domestic wastes. Discharges that contribute to sediment characteristics also contribute

to localized water chemistry conditions along the river. Sediment and water quality conditions in the river and at the site are summarized in Part V of this report.

Biological setting

11. The biological components of the James River Basin are diverse and reflect the variety of habitats along gradients of elevation and soil type, tidal amplitude, salinity, and energy regimes. Climax vegetation in the area is classified as oak-hickory-pine floodplain forest. Bald cypress (Taxodium distichum) borders the freshwater marshes. The shoreline of the river near the site is characterized by coarse-grained sandy beaches sparsely vegetated by bulrushes (Scirpus spp), the exposed margins of cypress - tupelo gum swamps, and eroding bluffs undercut by high water associated with spring flows and periodic storm flooding in the basin. Freshwater marshes exist in protected pockets along the shoreline and along the river's tributary creeks. The marshes exist on fine-textured sedimentary substrates vegetated by a large variety of plant species whose persistence is strongly dependent on conditions of elevation related to periodic flooding. Lower marsh elevations are dominated by non-woody broad-leaved plant types such as arrow arum (Peltandra virginica), arrowhead (Sagittaria spp.), and pickeral weed (Pontederia spp.) with isolated patches of wild rice (Zizania aquatica) and smartweed (Polygonum punctatum). The low marsh zone edges against a diverse higher marsh zone containing species such as jewel-weed (Impatiens capensis), tearthumb (Polygonum arifolum), dense stands of beggar ticks (Bidens laevis) and patches of cattails (Typha spp.). The marshes of the area are often broken by small higher elevation pieces of terrain serving as islands in the marsh, or marshes are fringed, sometimes nearly surrounded by upland areas.

12. The James riverine habitats support a large variety of animals with direct or indirect social importance due to their commercial value, recreational value, threatened or endangered status, or their role in the life support of any of these animals. The river and its tributaries in the area of the site support both estuarine and freshwater fish species. Anadromous species, including American shad (Alosa americanus),

blueback herring (Alosa aestivalis), and alewife (Alosa pseudoharengus), use the area for spawning or as a migratory corridor; striped bass (Morone saxatilis) and white perch (Morone americanus) use the area for spawning or as a nursery. Commercially or recreationally important freshwater fish species in the area of the site include channel catfish (Ictalurus catus), carp (Cyprinus carpio), sunfishes (Lepomis spp.), crappie (Pomoxis spp.), and black bass (Micropeterus salmoides).

13. The site is situated in an area of complex natural landscapes characterized by segmented open-water, wetland, and upland habitats, and an abundance of natural plant and animal food supplemented by man-made habitats associated with agriculture. The area attracts and in various ways supports a large variety of birds including numerous song-birds, shorebirds (like gulls and sandpipers), wading birds (like egrets and herons), waterfowl (including black duck, mallard, pintail, blue-winged teal, wood duck, snow goose and Canada goose), and birds of prey (including the osprey and bald eagle). Detailed information about the aquatic biological and wildlife resources of the site area is presented in Part VII and Part VIII of this report respectively.

Corps of Engineers setting

14. The site is located within the jurisdiction of the Norfolk District, U. S. Army Corps of Engineers. Dredging and disposal activities near the site are periodically conducted under authorization of the River and Harbor Act of 1970 and numerous modifications to the act made as recently as 1962. Navigation channel dimensions near the site are authorized at a depth of 10.8 m and a width of 92.3 m; the project is currently maintained for a 7.7-m deep by 92.3-m wide channel from the river's mouth at Hampton Roads to Hopewell, Virginia.

15. The Jordan Point-Harrison Bar-Windmill Point channel section associated with the Habitat Development site has required maintenance dredging every 1.8 years since it was initially dredged in 1932. Every dredging operation has removed nearly 340,000 cu m of channel sediment, which was traditionally placed overboard using hydraulic pipeline disposal techniques.

16. The marsh development site location south of the navigation channel and 0.4 km west of Windmill Point, has routinely been used for the open-water disposal of portions of the dredged material, usually about 220,000 cu m of sediment from the Harrison Bar and Windmill Point Shoals. At the time of site selection in 1974, an 0.63-ha island that was the result of traditional disposal operations existed at the site location. A description of the island is presented in Parts III and IV.

17. Concern about potential environmental impacts related to the unconfined open-water disposal of the chemically enriched dredged material from the James River navigation channel led to a mutual agreement between the U. S. Army Engineer District at Norfolk and the Waterways Experiment Station in 1974 (U. S. Army Engineer District, Norfolk 1977). The agreement was sanctioned by representatives of the U. S. Environmental Protection Agency, Region III Philadelphia; the U. S. Fish and Wildlife Service, Annapolis Field Office; and the National Marine Fisheries Service, Oxford, Maryland. In substance, this agreement stated that the Norfolk District and the Waterways Experiment Station would cooperatively construct a marsh habitat at the Windmill Point location using dredged material from the Jordan Point - Windmill Point shoals, scheduled to be dredged during December 1974 to January 1975. With logistical and technical support from the District, the Waterways Experiment Station would conduct studies to document the physical, chemical, and biological alterations at the site associated with the habitat development activity.

Site Development and Research

Schedule overview

18. The planned maintenance dredging of the Jordan Point and Windmill Point navigation channels during the 1974 to 1975 winter season launched the habitat development project at this site. The Dredged Material Research Program's scientific and engineering studies and the construction and physical development of the Windmill Point marsh site

occurred over a period of nearly 3.5 years from April 1974, when the site was first visited by Environmental Laboratory personnel, to September 1977, when the last field observations presented by this report were made.

Construction and physical developments

19. Construction and disposal operations from November 1974 through February 1975 followed procedures designed to retain most of the fine-grained channel sediments and to develop a substrate that could be colonized and would maintain a variety of plants and animals.

20. In order to retain most of the fine-grained channel sediments in and around the disposal site, two engineering techniques were employed in the disposal operation:

- a. Dikes were constructed to contain the dredged material.
- b. Silt curtains were used during active disposal to help contain the plume of suspended materials leaving the diked inclosure.

Dike construction

21. A two-stage dike construction technique was used. In the first stage, sand was dredged from a submerged borrow area located approximately 2,743 m west of the original Windmill Point Island and pumped to form a 1,097-m perimeter. During the second stage of construction, a dragline derrick advanced along the dike and transferred sand from the interior of the perimeter to the top of the dike thereby increasing the dike's elevation and slurry retention capabilities.

Disposal operations

22. Channel dredging and disposal operations commenced upon the completion of the dike construction and following some necessary dike repairs. A discussion of dike foundation problems, their cause, course, and subsequent repairs is presented in the engineering and construction operations portion of this report (Part III).

Engineering and scientific activities

23. Activity conducted at Windmill Point can conveniently be divided among three time periods with reference to the active dike construction and dredging and disposal operation. Those scientific and engineering activities that occurred before, during, and after

active dike construction dredging and disposal are referred to in the following text as preoperational, operational, and postoperational, respectively. The engineering aspects of site development including dike construction and the filling of the dike with the dredged material to achieve an intertidal substrate for marsh vegetation were demonstrations. These demonstrations used the best guesses and on-site decisions of engineering and operations personnel from both the District and the Waterways Experiment Station. An evolving methodology for marsh habitat construction evolved during the Dredged Material Research Program from experience gained in areas like Windmill Point. The state-of-the-art methodology is presented in a Dredged Material Research Program synthesis report entitled "Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation."

24. Research activities at the site underlined the importance of habitat characteristics having the greatest potential for altering the "quality" of the area for animal use. Three types of studies were emphasized. First, emphasis was placed on vegetation both as a stabilizing influence affecting the persistence of the area in the river over time as a source of cover and nourishment for animal populations. Second, emphasis was placed on the benthic component of the aquatic biota as a natural resource providing nourishment to the finfish community. The deemphasis on direct observations of the fish community should not be interpreted as any indication of their lesser importance as an aquatic biological resource; this simply reflects the extreme difficulties of obtaining accurate fish community information. Third, emphasis was placed on documenting the movement of chemical substances from the dredged material used as the substrate for marsh habitat development. This was because of the concern with the chemically enriched ("polluted") nature of the James River channel sediments.

Pre-operational studies

25. From the engineer's viewpoint, studies conducted during this phase can be considered site planning activities. Planning began after site selection had already taken place, creating a situation that although undesirable, was considered as the only way the technical

feasibility of marsh development in conjunction with Corps of Engineers maintenance dredging programs could be tested in the field. From the natural scientist's viewpoint, pre-operational studies can be considered environmental inventories. Physical, chemical, and biological observations conducted during this phase represented an effort to document the environmental characteristics of the site before the site development program began. These studies served as exploratory investigations or pilot studies that permitted the more effective planning of monitoring activities and provided "baseline" data for documenting certain types of short-term changes associated with site development.

Operational and post-operational studies

26. The intention of these activities was to provide data that would complement other field studies, laboratory studies, technical literature reviews, and position papers prepared under the Dredged Material Research Program. The experience from the Windmill Point site best serves those thinking about developing a freshwater tidal marsh with fine-textured dredged material. The total experience of the Habitat Development Project with marsh development provides engineering and scientific information along a gradient of conditions that are regularly encountered during routine Corps of Engineers operations.

PART III: ENGINEERING AND CONSTRUCTION OPERATIONS

Dike Design

27. The dike for containment of the fine-grained navigation channel sediments that would provide substrate for the marsh vegetation was aligned to follow the natural upstream-downstream orientation of the shallow bottom (Figure 2). Bottom elevations across the site ranged from 18.3 to -15.2 cm CELW* except along the east dike alignment, which traversed a small L-shaped island (elevation from 97.5 to 106.7 cm CELW) as shown on Figure 2. Dredged material was to be placed within the dike to an initial elevation of 106.7 to 137.2 cm CELW so that estimated consolidation of dredged material and foundation would yield a final intertidal (between mlw and mhw)** substrate surface elevation suitable for marsh habitat development. The retaining dike was designed to provide both initial retention of dredged material during disposal operations and later protection against substrate erosion during a 4- to 5-month period of dredged material consolidation and marsh establishment. The dike was not designed to provide long-term protection for the planned marsh island.

28. The following diking methods were considered during initial project planning:

- a. Sandbag structure.
- b. Shell-filled gabion structure.
- c. Sand-filled embankment (fill barged in place).

These diking methods were rejected, based largely on a preliminary knowledge of soft, weak foundation soils at the disposal site, which were not likely to support the concentrated loads produced by these diking methods. In addition, construction materials would have to be barged

---

* Elevations are referred to Corps of Engineers Low Water Datum (CELW); see tide-datum chart, Figure 2.

** mlw = mean low water = EL. 0.3-m CELW.
mhw = mean high water = EL. 1.0-m CELW.
See tide-datum chart, Figure 2.

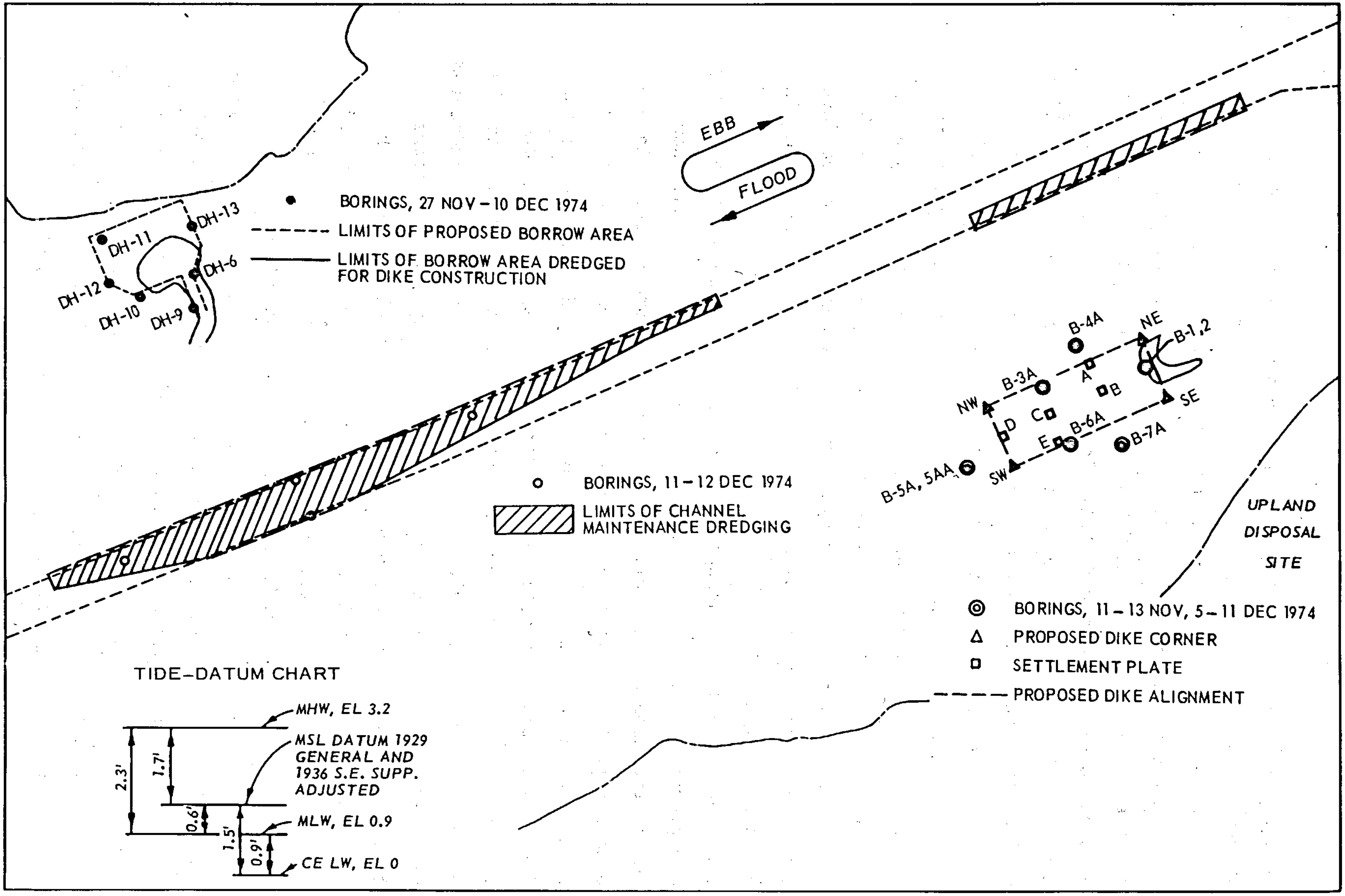


Figure 2. Dredging and habitat development project plan. Planimetric features were developed from aerial photographs flown in January 1956 and December 1966. Base map and depth soundings provided by Norfolk District, CE. (See overlay in envelope at back of report.)

to the site, which would require dredging of access channels prior to dike construction.

29. A two-stage dike construction method was proposed as shown in Figure 3. In the first stage, a wide hydraulic fill (sand) section would be constructed to elevation 1.4-m CELW. In the second stage, a dragline would be used to place additional fill along the dike centerline to reach elevation 1.8-m CELW. In dragline fill construction, sand would be borrowed from the interior slope of the hydraulic fill section. The dike design was selected because stability on soft foundation soils would be improved by the wide hydraulic fill section and construction would be economical. The decision was made to use the two-stage design assuming that a riverine sand deposit could be located in the project area. Dike foundation characteristics and strength parameters were also to be determined for conducting theoretical stability analyses of the proposed dike section shown in Figure 3.

30. During November through December 1974, a comprehensive subsurface exploration and sampling program was conducted to locate sand for dike construction and determine dike foundation properties. An extensive sand deposit suitable for dike construction was located in a shallow water area near Bucklers Point approximately 2.4 km west of the marsh development site. Locations of split spoon sample borings and the proposed sand borrow area are shown on Figure 2. Bottom elevation in the area ranged from approximately 0.2 to -0.9 m CELW. Boring logs indicated that borrow area sediments consisted largely of silty sand to depths of -1.5 to -2.4 m CELW, underlain by fine to medium clean sand with gravel to depths of -6.1 to 12.2-m CELW where borings were terminated.

31. Sample borings at the marsh development site were located along or near the proposed dike alignment as shown on Figure 2. Disturbed (split spoon) and undisturbed (Shelby tube) samples were obtained and in situ vane sheer tests were conducted. Borings ranged in depth from 12 to 18 m below river bottom (except boring 5-AA, which consisted only of an undisturbed sample taken from 0.3 to 1.5 m below river bottom). Undisturbed sampling and vane shear tests were conducted in borings B-2, B-3A, B-4A, and B-5AA and were limited to depths of less than 3.4 m

below river bottom (except boring B-2 in which undisturbed sampling and vane shear testing were continued to a depth of 13.1 m below river bottom).

32. Foundation soils consisted of an approximately 9.1-m thick layer of loose clayey silt (with organic material) underlain by a loose silty fine sand. Properties of the clayey silt, as determined from laboratory tests of disturbed samples and field vane shear tests, are summarized in Table 1. Grain-size analyses indicated an average of 96 percent (by weight) passing the No. 200 sieve. Organic content averaged 4.5 percent. Average natural moisture and Atterberg Limits were determined as:

Moisture content = 79 percent;
Liquid limit = 49 percent;
Plantic limit = 33 percent;
Plasticity index = 16 percent.

Shear strength (cohesion, c) in the upper 3.0 m of the clayey silt ranged from 450 to 1215.7 kg/sq m as measured in unconsolidated-undrained triaxial tests and from 620 to 1699 kg/sq m as measured in field vane tests. Consolidation parameters were determined from one-dimensional consolidation stress. Compression index and coefficient of consolidation averaged 0.06 and 0.02 sq m per day, respectively, in the upper 3.0 m of the clayey silt.

33. Slope stability of the proposed dike section (Figure 3) was analyzed for assumed circular-arc failure surfaces passing through both the dike and foundation soils. Computer analyses were conducted using the Modified Swedish Method of Slices presented in Corps of Engineers manual "Stability Earth and Rock-Fill Dams," EM1110-2-1902 dated 1 April 1970. Soil properties used in the stability analyses were:

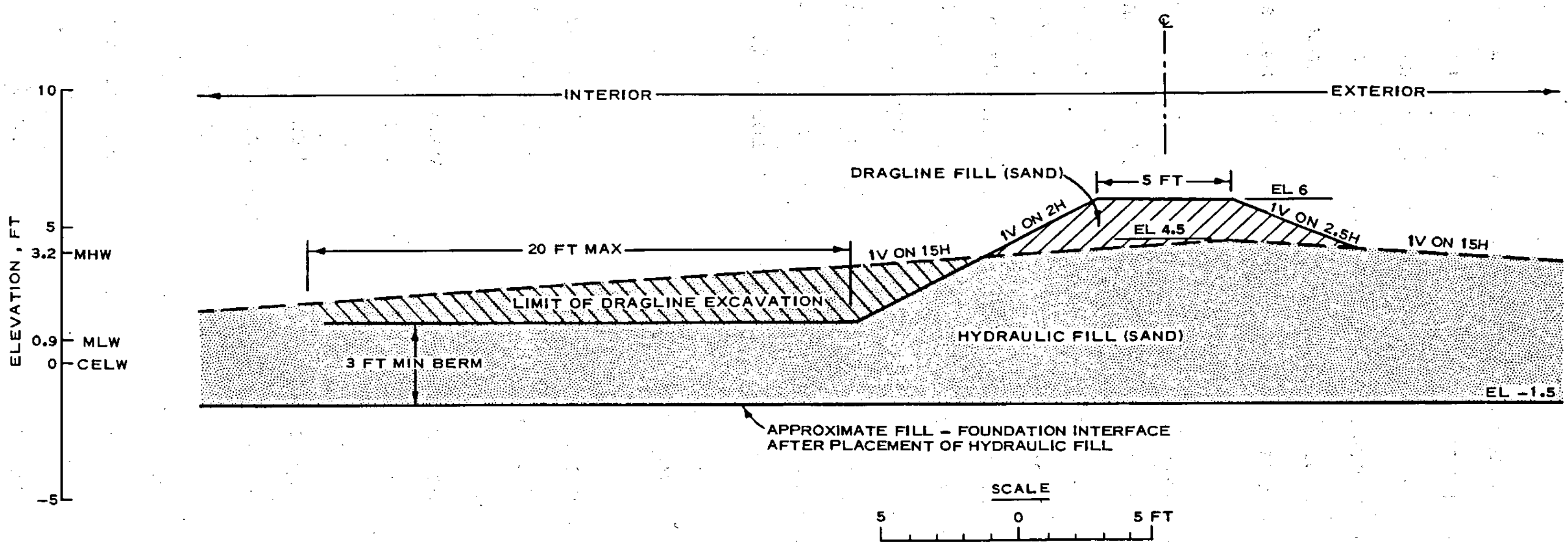
Soil Property	Dike (sand)	Foundation (clayey silt)
Wet Unit Weight	2050 kg/cu m	---
Submerged Unit Weight	1065 kg/cu m	480 kg/cu m
Angle of Shearing Resistance, ϕ	26 deg	---
Cohesion, c	---	1201 kg/cu m

Table 1

Foundation Soil Properties - Habitat Development Site*

Boring**	Depth†, ft	Soil Description	Organic Content, %	Natural Moisture Content, %	Wet Unit Weight, kg/cu m	Wet Unit Weight, kg/cu m	Percent Finer 200 Sieve	Spec. Gravity	Void Ratio	Liquid Limit	Plastic Limit	Plasticity Index	Compression Index, Cc	Shear Strength, Cohesion, c, psf: Triaxial Test ††	Shear Strength, Cohesion, c, psf: Field Vane Test
B-2	9.0-13.0	Brown very clayey silt with silty fine sand seams	4.2	66.8	1638.7	981.9	97.6	2.71	1.76	53.8	35.4	18.4	-	250	-
		Gray clayey silt with organic matter	-	73.7	1566.6	901.8	-	-	2.09	-	-	-	0.42	-	-
	16	-	-	-	-	-	-	-	-	-	-	-	-	-	276
B-2	24.0-26.0	Gray slightly fine sandy clayey silt	5.1	89.5	1451.3	765.7	95.1	2.60	2.52	51.4	34.0	17.4	0.93	-	-
	26	-	-	-	-	-	-	-	-	-	-	-	-	-	508
B-3A	0.0-3.5	Gray brown very clayey silt with slight organic material	3.4	94.8	1563.4	802.5	99.2	2.70	2.48	53.8	31.9	12.8	0.66	92, 78 ‡	-
	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	127
B-3A	6.0-9.5	Gray slightly clayey silt	6.0	60.8	1638.7	1010.8	88.9	2.64	1.64	42.2	29.9	12.3	-	200,160 ‡‡	-
			-	70.8	1645.1	962.7	-	2.64	1.99	-	-	-	0.63	-	-
	10.0	-	-	-	-	-	-	-	-	-	-	-	-	-	164
B-3A	16.0-19.0'	Gray clayey silt with organic matter	4.6	97.3	1430.4	732.0	94.9	2.59	2.59	47.1	36.6	10.5	0.85	-	-
B-4A	0.0-3.5	Gray brown clayey silt with organic matter	5.3	78.8	1489.7	833.0	98.6	2.67	2.21	48.6	32.5	16.1	-	249	-
	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	348
B-5AA	1.0-5.0	Gray brown clayey silt	3.2	76.7	1669.1	945.1	99.6	2.68	1.83	46.4	28.4	18.0	-	194,165 ‡	-

* Soil sampling and testing conducted by Soils and Materials Engineers, Inc., Raleigh, North Carolina.
** Boring locations shown on Plate 1.
† Depth below river bottom.
†† Q-test, unconsolidated-undrained.
‡ Creep test.
‡‡ R-test, consolidated-undrained.



NOTE: ELEVATIONS ARE IN FEET REFERRED TO
CORPS OF ENGINEERS LOW WATER DATUM (CELW)
MHW= MEAN HIGH WATER ; MLW= MEAN LOW WATER

Figure 3. Proposed dike cross-section and construction scheme

Properties of the dike sand were assumed based on experience within the Norfolk District. Foundation properties were also assumed since the laboratory testing program was not completed in time to meet project scheduling. Laboratory tests indicated that the assumed foundation soil properties were conservative. Stability analyses resulted in a theoretical factor of safety of 2.1 provided that a minimum 0.9-m thick berm was maintained following dragline excavation on the hydraulic fill interior slope (Figure 3).

34. Consolidation parameters were used to estimate dike settlement of approximately 0.3 m due to foundation consolidation under the dike loading. Foundation consolidation under dredged material loading within the disposal site was expected to be negligible. Prior to dike construction, settlement plates were installed along the dike alignment and within the disposal site for monitoring foundation consolidation. Settlement plates at locations A, D, and E (shown on Figure 2) were for monitoring foundation consolidation under dike loading. Settlement places at locations C and B (shown on Figure 2) were for monitoring foundation consolidation under the dredged material loading.

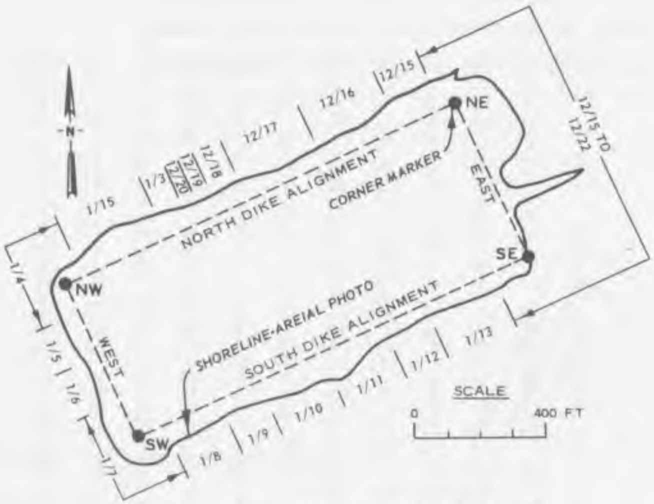
Dike Construction

35. Retaining dike construction was the responsibility of the channel dredging contractor (Merritt Dredging Co.) and was supervised by Norfolk District personnel. Construction of the hydraulic fill (sand) section was initiated on 15 December 1974. A hydraulic pipeline dredge (45.7-cm diam pipe) was used to pump material from the borrow area (near Bucklers Point) to the marsh development site (Figure 2). Fine-grained material, initially dredged from the borrow area entrance channel was discharged east of the disposal site. Dike construction was then initiated at the northeast corner of the habitat site and proceeded, simultaneously (using a 90-deg wye discharge outlet) along the north and east dike alignments. Progress of hydraulic fill placement is given in Figure 4a. Initial hydraulic fill discharge along the north dike alignment is shown in Figure 4b. It was originally planned to extend the discharge

pipe continuously along the dike alignment with closure near the southeast corner. However, dredge production along the north dike alignment dropped significantly on 18 December as shown in Figure 4a. The dredge pipeline length had reached approximately 2,500 m and pump capacity was inadequate. A suitable booster pump could not be located; consequently, discharge was moved on 4 January 1975 to the northwest corner to reduce overall pipeline length by approximately 610 m.

36. Hydraulic fill placement progressed uniformly along the west, then south dike alignments from 4 January through 13 January 1975. Fill placement along the west dike alignment was completed by 7 January 1975 as shown in Figure 4a and the aerial photograph, Figure 4c. An elevation survey of the partially completed hydraulic fill section was made on 8 through 10 January 1975 and results are shown on Figure 5. Elevations along the dike centerline averaged approximately 1.2-m CELW except in the northeast corner where the average elevation was approximately 1.5-m CELW. The hydraulic fill slope angle varied from approximately IV (vertical) on 15H (horizontal) to IV on 25H. When discharging during low tide stages, the sand slurry tended to run greater distances resulting in flatter slope angles. Fill placement along the south dike alignment was completed on 13 January 1975. The gap along the north dike alignment (Figure 4c) was closed on 15 January 1975 to complete the hydraulic fill dike section as indicated in Figure 4a. The completed hydraulic fill is shown in the aerial photograph, Figure 4d. A final hydrographic survey of the borrow area indicated that approximately 62,322 cu m of material was used in hydraulic fill construction. The borrow area was dredged to depths of -3.0 to -4.6-m CELW within the limits shown on Figure 2.

37. Elevation readings of foundation settlement plates A, D, and E (Figure 2) taken during and immediately following hydraulic fill construction indicated an initial foundation consolidation (or displacement) of approximately 0.2 m. Dike foundation settlement plates were again surveyed on 23 July 1975. Readings indicated an additional 0.2-m foundation consolidation during the 6-month period following dike construction.



a. HYDRAULIC FILL CONSTRUCTION SCHEDULE

c. HYDRAULIC FILL CONSTRUCTION, 7 JAN 1975

b. HYDRAULIC FILL CONSTRUCTION, 15 DEC 1974

d. COMPLETED HYDRAULIC FILL, 17 JAN 1975

Figure 4. Construction of hydraulic fill dike section during the period 15 December 1974 to 15 January 1975

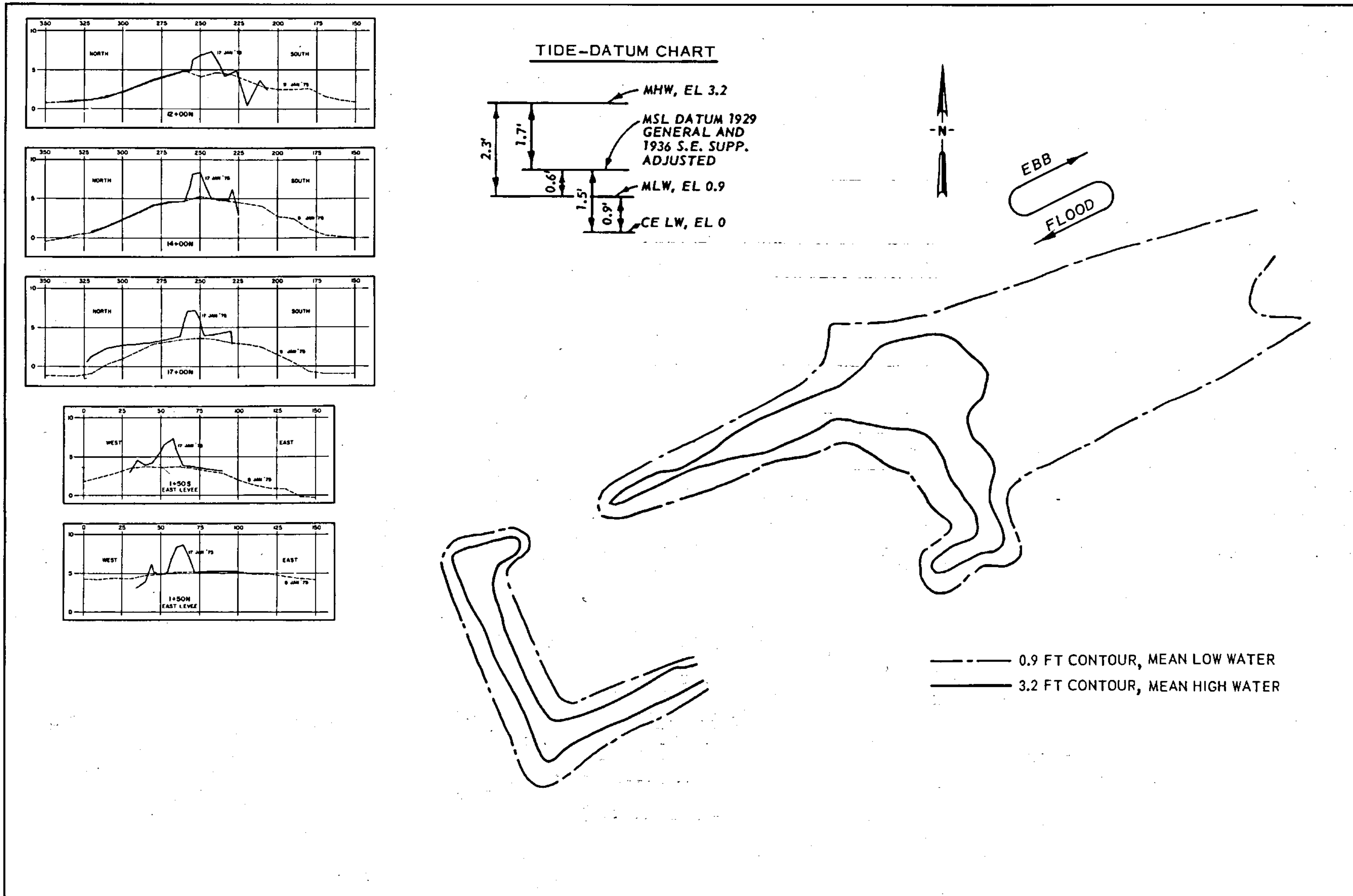
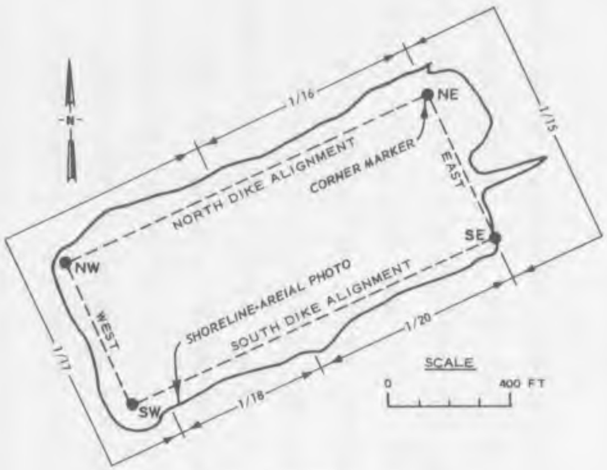


Figure 5. Elevation survey of the Windmill Point marsh development site during dike construction. Base map and elevation data provided by the Norfolk District, CE. (See overlay in envelope at back of report.)

38. Construction of the dragline fill section (Figure 6) was done by Higgerson-Buchanan, Inc. under subcontract to Merritt Dredging Company. Dragline fill placement was initiated on 15 January 1975 on the east dike alignment and progressed continuously along the hydraulic fill section to completion at the southeast corner on 20 January 1975. In Figure 6 are shown the construction schedule (Figure 6a), photographs of dragline fill placement operations (Figure 6b), and a completed dragline fill section (Figure 6c). Fill was placed to elevations from 1.8- to 2.4-m CELW. Dragline fill cross-sections surveyed on 17 January 1975 are shown on Figure 5 as superimposed on hydraulic fill cross-sections surveyed on 8 to 9 January 1975. Dike settlement problems were experienced during dragline fill construction. On several occasions, vibration during dragline movement caused recently placed fill to settle excessively. Settled sections were immediately repaired by placing additional fill. Repaired sections tended to remain stable during additional dragline movement. However, dike settlements continued at certain locations requiring treatment as discussed in the following section.

Dike Performance

39. Dike erosion and settlement problems became evident during construction of the dragline fill section (15 to 20 January 1975). Channel dredging and disposal into the habitat site actually began on 21 January 1975 but was halted that same day to facilitate dike repair during the period 22 to 26 January 1975. Exterior slopes along the north and west dike alignments were subject to significant wave and current action. The north dike exterior slope was particularly vulnerable to wave action generated by barge traffic along the ship channel paralleling the north alignment (Figure 2). Erosion protection along the flat hydraulic fill slopes was not considered necessary; however, immediate protection of the steep dragline fill slopes was required. A cover of polyethylene sheeting was chosen to provide temporary erosion protection. More substantial (or permanent) protection such as riprap or sand bag layers was not economically justified since the dragline



a. DRAGLINE FILL CONSTRUCTION SCHEDULE

b. DRAGLINE FILL CONSTRUCTION

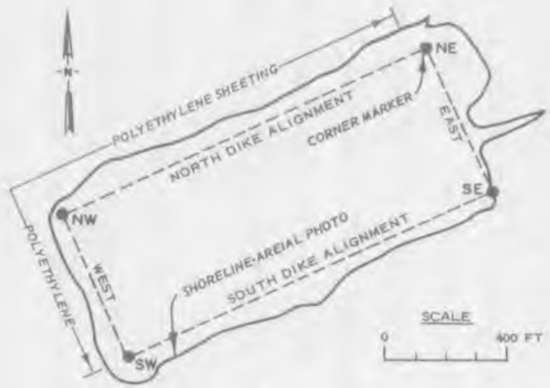
c. COMPLETED DRAGLINE FILL ALONG NORTH DIKE ALIGNMENT

Figure 6. Construction of dragline fill dike section during the period 15 to 20 January 1975

fill section was to be graded after a 4- to 5-month period of dredged material consolidation and marsh establishment. The polyethylene sheeting was installed on 21 through 22 January 1975 along the north and west dike alignments as indicated in Figures 7a and 7b. However, sand bags used to anchor the polyethylene sheets provided to be inadequate. Wind and water forces displaced the polyethylene sheets at many locations as shown in Figure 7c. Erosion of the dragline fill slopes was a continual problem during and after the dredging operations.

40. Excessive dike settlement resulted in breaches along the north and south dike alignments as shown in Figure 8a. The breached section along the north dike alignment was approximately 76.2-m long and was reported to have settled 0.9 m in one day. The rapid subsidence indicated that an embankment-foundation shear failure had occurred. Personnel directly involved in the project and engineers consulted from the Savannah District examined the failed section. Detailed field investigations and analyses of the failure were not conducted; however, site observations and review of dike construction procedures indicated that failure was likely caused by development and entrapment of foundation mud waves during hydraulic fill construction. Hydraulic fill placement normally causes mud waves to form as soft foundation soils are displaced. Mud wave material is generally weakened in its remolded or disturbed condition and may not provide adequate support when trapped beneath the hydraulic fill. Entrapment of mud waves is a common problem at hydraulic fill tie-in or closure locations. The breach in the north dike alignment corresponds closely to the 91.4-m gap near the northwest corner, which was closed on 15 January 1975 (Figures 4a and 4c). Earlier hydraulic fill placement at both ends of the gap could have generated mud waves that were later covered with hydraulic fill during final closure on 15 January 1975.

41. The breached dike sections on the north and south dike alignments (Figure 8a) were repaired by placement of additional hydraulic fill (sand) obtained from the borrow area near Bucklers Point (Figure 2). In dike repair, the dredge discharge pipe was supported on elevated cribbing along the centerline of the breached sections. Fill material was discharged from the end of the pipe and from bleeder holes in the

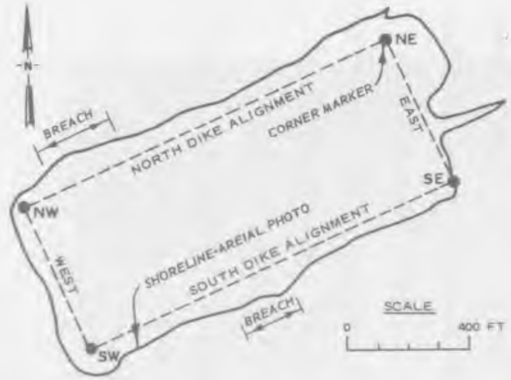


a. DIKE LENGTHS COVERED WITH POLYETHYLENE SHEETING ON 21-22 JAN 1975

b. POLYETHYLENE SHEETING - NORTH DIKE ALIGNMENT, 23 JAN 1975

c. DAMAGED POLYETHYLENE SHEETING - WEST DIKE ALIGNMENT 28 JAN 1975

Figure 7. Polethylene sheeting used for erosion protection



a. BREACH LOCATIONS

c. BREACH ON SOUTH DIKE ALIGNMENT, 24 JAN 1975

b. REPAIRED BREACH ON NORTH DIKE ALIGNMENT, 24 JAN 1975

d. REPAIR OF BREACH ON SOUTH DIKE ALIGNMENT, 26 JAN 1975

Figure 8. Dike breaches repaired during 22 through 26 January 1975

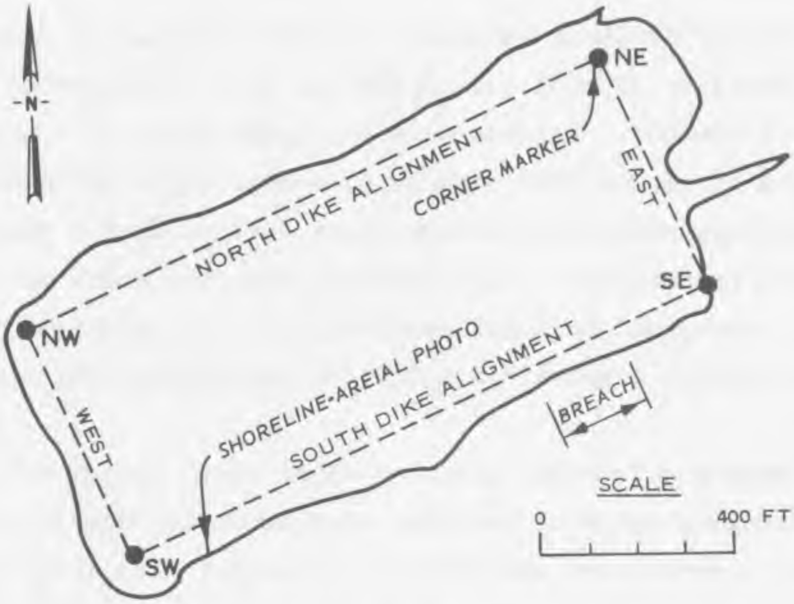
underside of the pipe. Hydraulic fill was placed to design elevation (5.7-m CELW) without additional working by dragline. The repaired breach on the north dike alignment is shown in Figure 8b. The breached section on the south dike alignment and subsequent hydraulic fill repair work are shown in Figures 8c and 8d, respectively. Dike repair was completed on 26 January 1975. Channel dredging and disposal into the habitat site was continued on 27 January 1975.

42. Dike erosion and settlement continued during disposal operations. The poorly installed (and subsequently damaged) polyethylene sheeting was largely ineffective in preventing erosion of the dragline fill slopes. Erosion of exterior slopes was predominant during high tide periods. Interior turbulence flow velocities generated by the dredged material (slurry) discharge caused significant erosion of interior slopes during disposal operations. Erosion of the dragline fill section continued after dredging and disposal operations were completed.

43. Dike settlement was concentrated along the eastern half of the south dike alignment. An approximately 61-m long breach developed near the southeast corner as shown in Figure 9a. Dike repair was accomplished by placing dredge pipe sections, polyethylene sheeting, and sand bags across the settled zone as shown in Figure 9b. Seepage through the dike was observed along the repaired section and several other locations along the south dike alignment. Seepage was predominant during low tide periods when interior-exterior head differential was a maximum (approximately 0.6 to 0.8 m). Dike sand was very soft at seepage exit locations, however, seepage water was clear with no indication of subsurface erosion or piping within the dike. Localized minor settlement along the south dike alignment continued to develop throughout the disposal operations. Settled areas were filled with sand (or sand bags) as needed until disposal within the habitat site was completed on 4 February 1975. Dredging and disposal operations are discussed in the next section.

Dredging and Disposal Operations

44. Two channel shoals were located near the site as shown on Figure 2. Predredging surveys conducted November 1974 and January 1975



a. LOCATION OF BREACH

b. REPAIRED BREACH, 29 JAN 1975

Figure 9. Dike breach repaired during the disposal operations, 27 Jan-4 Feb 1975

indicated required dredging volumes of 18,885 cu m in the downstream shoal (Sta 356+00 to 378+00) and 222,790 cu m in the upstream shoal (Sta 282+00 to 336+00). Volumes were estimated based on required dredging to a depth of -8.2-m CELW plus an allowable 0.3-m overdredge. A portion of the upstream shoal material was designated for disposal in the marsh development site. The remaining upstream shoal material and entire downstream shoal material was designated for disposal in a separate upland confined disposal site located on Windmill Point as shown on Figure 2.

45. Sediments from the upstream shoal were sampled prior to dredging. Dredging material was also sampled at the discharge pipe during disposal operations and within the habitat site after disposal operations were completed. Properties of the dredged material as determined from laboratory tests are summarized in Table 2. Dredged material consisted of clayey silt (90-95 percent passing the No. 200 sieve) with organic content ranging from 5 to 15 percent. Liquid limits ranged from 59 to 98 percent and plastic limits ranged from 35 to 40. Natural water content of channel sediments prior to dredging ranged from 83 to 112 percent. Natural water content of fine-grained dredged material contained within the habitat site after dredging averaged 110 percent.

46. Dredging and disposal operations using a hydraulic pipeline dredge (45.7-cm diam pipe) were conducted by Merritt Dredging Company under supervision of Norfolk District personnel. The downstream shoal was dredged during 16 through 19 January 1975 with all material deposited in the upland site on Windmill Point. Dredging of the upstream shoal with disposal in the habitat site was initiated on 21 January 1975. However, dredging was stopped that same day to facilitate dike repair during the period 22 through 26 January 1975. Dredging of the upstream shoal with disposal in the habitat site was continued on 27 January 1975. Discharge into the habitat site was located near the northwest corner as shown in Figures 10a and 10b. Slurry effluent was returned to the James River through two 45.7-cm diameter pipes extending through the dike near the southeast corner as shown in Figures 10a and 10c. Dredged material slurry was pumped into the habitat site at a volume flow rate

Table 2

Dredged Material Properties - Before, During, and After Dredging

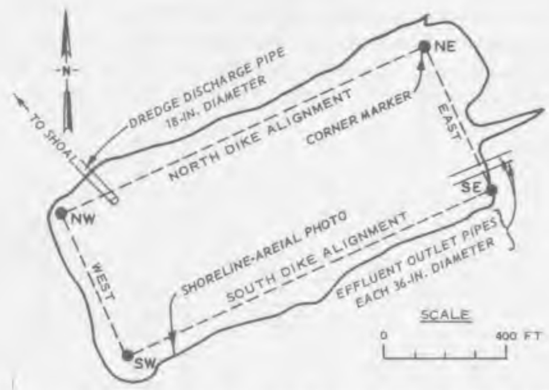
Material	Percent Solids, %	Water Content, %	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Organic Content, %	Specific Gravity of Solids	Percent Finer No. 200 Sieve,	Sampling Dates and Methods
Channel sediment* (upstream shoal) ††	-	83	59	40	19	5.4	2.62	-	11-12 Dec 1974, Borings 10-12, Figure 2 fixed piston tube sampler, 7.62-cm diam., max depth of 2.4 m, tube pushed by drill rig
Channel sediment ** (upstream shoal)	-	-	90	35	55	-	2.62	95	11 Dec 1974, Boring 9, Figure 2 (see above)
Channel sediment † (upstream shoal)	-	112	-	-	-	14.8	-	95	9 Jan 1975, 10 cores, 7.1 cm OD, max depth of 1 m, weighted benthos plastic core liner, gravity penetration
Dredged slurry at discharge pipe**	20	-	98	40	58	-	2.61	-	27 Jan-4 Feb 1975, 4 1.3-litre samples
Effluent at outlet pipe†	14 15	- -	- -	- -	- -	- -	- -	- -	31 Jan 1975, 2-hand collected samples 3 Feb 1975, 2-hand collected samples
Dredged material contained within habitat site†	-	110	68	39	29	4.7	-	91	17-18 July 1975, 11 cores, 7.1 cm OD, max depth of 1.2 m, benthos plastic core liner pushed by hand

* Tests conducted by Soils and Materials Engineers, Inc., Raleigh, North Carolina.

** Tests conducted by Massachusetts Institute of Technology, Cambridge, Massachusetts.

† Tests conducted by Old Dominion Research Foundation, Norfolk, Virginia.

†† The upstream shoal extends from Sta 282+00 to 336+00 (See Plate 1).



a. LOCATION OF DREDGE DISCHARGE AND EFFLUENT OUTLET PIPES

b. DREDGED MATERIAL DISCHARGE

c. EFFLUENT OUTLET PIPES

Figure 10. Dredged material discharge in habitat development disposal site during the period 27 January to 4 February 1975

of approximately 0.68 cu m/sec (i.e., 40,504 cu dm/min). Effluent flowed freely through the outlet pipes at rates controlled largely by tidal fluctuations. At low tide, effluent flow rate was a maximum and associated with high interior flow velocities, channelization, and turbulence. A depression eroded beneath the discharge pipe outlet and channelization towards the effluent outlet pipes remain evident in the aerial photograph (Figure 11) taken 5 months after completing disposal operations. Rapid flow of dredged material slurry through the disposal site prevented adequate settling of suspended solids. Comparison of discharge and effluent solids contents measured during disposal operations (values in Table 2) indicate that at times, only 25 percent of the incoming dredged material solids were being contained in the habitat site. Dredging was stopped intermittently during critical low tide periods, but with minimal overall improvement in containment efficiency.

47. Channel dredging from Sta 282+00 to 304+00 had been completed when discharge into the habitat site was stopped on 4 February 1975. The remaining channel dredging from Sta 304+00 to 336+00 was completed during the period 4 through 12 February 1975 with disposal in the upland site on Windmill Point. Post dredging channel surveys indicated that approximately 207,278 cu m of sediments were discharged into the habitat site. An estimated 61,164 cu m of dredged material was contained in the habitat site. The contained volume was computed based on an average interior surface elevation of 1.0-m CELW as determined from results of the July 1975 site survey shown on Figure 12.

Postdredging Maintenance and Behavior

48. Dike maintenance was most important during a 4- to 5-month period of dredged material consolidation and marsh establishment following completion of dredging operations. Erosion of the dragline fill section was significant with most damage occurring during extreme high river stages, which completely inundated the habitat site in late March 1975. Floating debris was deposited within the site and the dragline fill section was washed out at six separate locations. However, only

Figure 11. Marsh development site, 2 July 1975

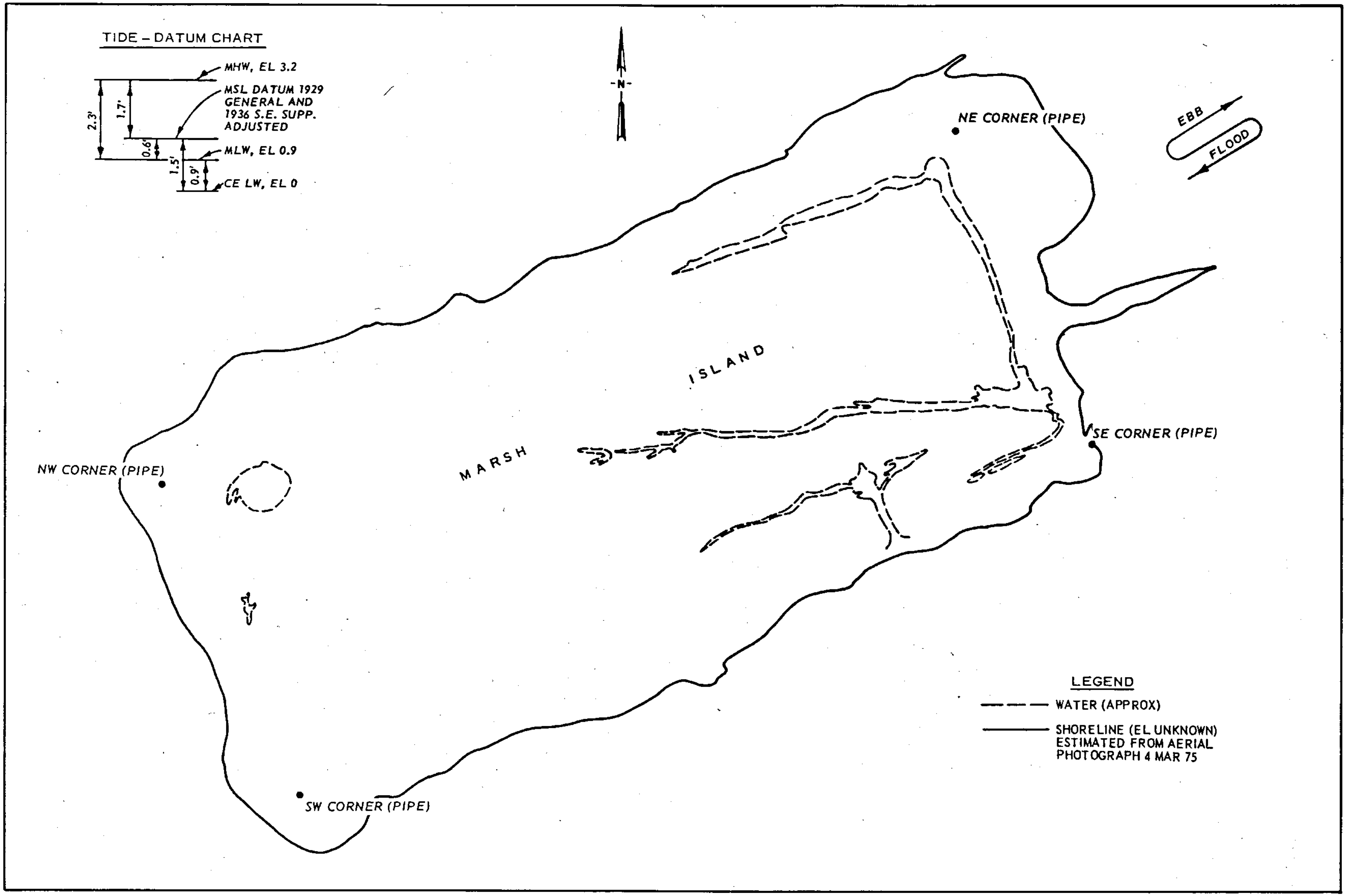


Figure 12. Windmill Point marsh development site after grading, July 1975. Base map and depth soundings provided by the Norfolk District, CE. (See overlay in envelope at back of report.)

two breaches developed that required repair. The breaches, shown in Figure 13, were 3.0 to 4.6-m wide and were located along the south dike alignment in an area that had previously settled and been repaired during dredging operations (Figure 8). Plywood sheets and sand bags were placed to repair the breached sections. This section breached again 1 to 2 months later, but was left unrepaired to facilitate intertidal water circulation within the site.

49. In July 1975, a small tractor was used to grade the remaining dragline fill section and portions of the hydraulic fill. Dredged material within the habitat site was not graded. After grading, marsh vegetation was propagated along the exterior (hydraulic fill) slopes to provide long-term erosion protection. Smooth cordgrass (_Spartina alterniflora_) plants were sprigged along the slopes in July 1975 and developed quite rapidly as shown in Figure 14a. However, these plants were ultimately destroyed by wave action and animal depredation. In September 1975 portions of the dike's exterior slopes did not support any vegetation as shown in Figure 14b.

50. Long-term dike erosion has been indicated by periodic site visits and comparison of site elevation surveys conducted in July 1975 (Figure 12), April 1976 (Figure 15), and April 1977 (Figure 16). Erosion has been predominant along the north and west dike alignments, which are exposed to significant wave and current action. Dike sand has been eroded along the exterior slopes exposing coarse gravel and cobbles (max 20.3-cu diam). Erosion and deposition of sand around the southwest corner is evidenced by development of sand spit (or berm) as shown on the 1976 survey (Figure 15) and 1977 survey (Figure 16). Dredged material has been eroded and dike sand carried into the habitat vegetation along the west dike alignment. Interior sand deposits have also formed near tidal inlets (or breaches) cutting across the dike crest. The first tidal inlet was formed prior to July 1975 and was located along the south dike alignment within a length of dike that had previously breached both during and after disposal operations as shown in Figures 8 and 13, respectively. The inlet was approximately 20-m wide when surveyed in April 1977 (Figure 16). Two additional tidal inlets (or

Figure 13. Breached section along south dike,
25 Mar 1975

a. EXTERIOR SLOPE, OCT 1975

b. EXTERIOR SLOPES, SEP 1976

Figure 14. Plantings for exterior slope stabilization on the west dike

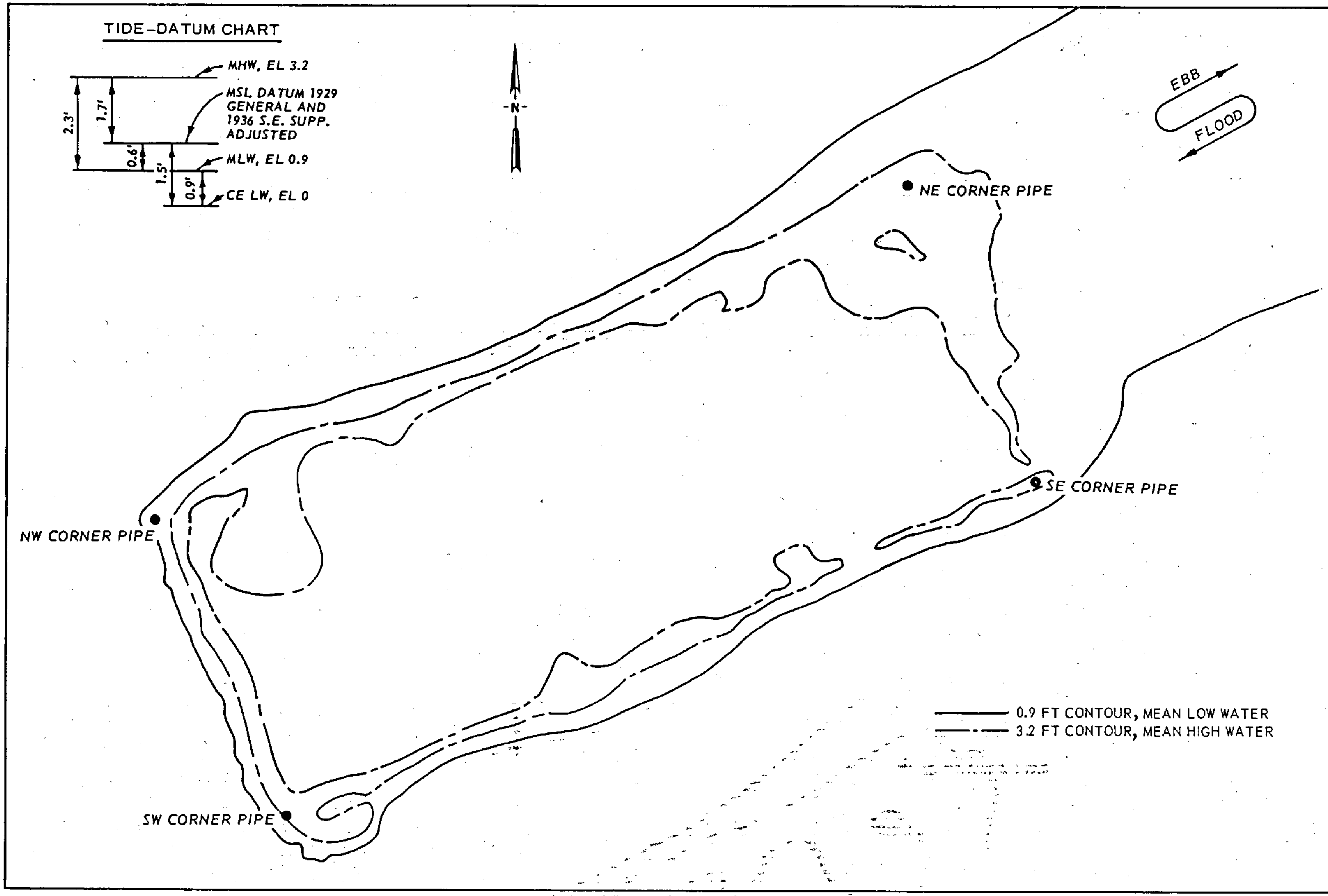


Figure 15. Marsh development site, survey of April 1976. Base map and elevation data provided by the Norfolk District, CE. (See overlay in envelope at back of report.)

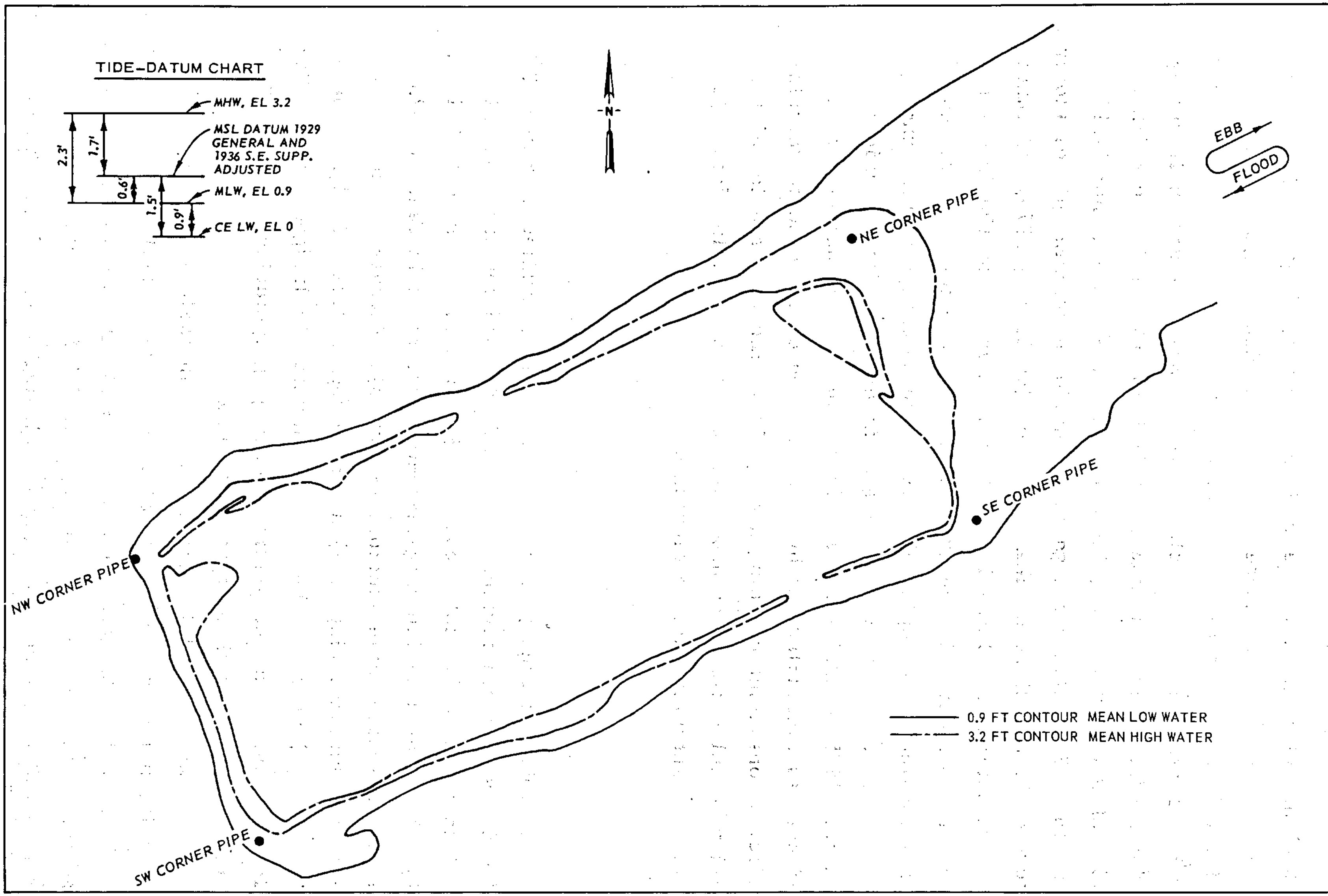


Figure 16. Marsh development site, survey of March and April 1977. Base map and elevation data provided by the Norfolk District, CE. (See overlay in envelope at back of report.)

breaches) are also shown on the April 1977 survey (Figure 16): a 24-m wide inlet located in the center of the north dike alignment and a 6.1-m wide inlet located near the northwest corner.

51. Comparison of elevation surveys shows a reduction in average interior surfave elevation from 1.0-m CELW in July 1975 (Figure 12), to 0.8-m CELW in April 1976 (Figure 15), to 0.7-m CELW in April 1977 (Figure 16). Elevation readings of foundation settlement plates (located as shown on Figure 2) were taken only once (on 23 July 1975) following dike construction and disposal operations. Readings of the interior plates B and C indicated foundation consolidation under the dredged material loading to be negligible during the 6-month (February through July 1975) period. The reduced rate of interior surface subsidence (0.2 m from 1975 to 1976 and 0.1 m from 1976 to 1977) suggests that subsidence was caused largely by consolidation of the dredged material (foundation consolidation being negligible). However, erosion of the dredged material surface may also have been a contributing factor in lowering the interior surface elevation.

Costs

52. Costs of engineering operations are summarized in Tables 3 and 4. Costs of marsh development site design and construction are summarized in Table 3: total cost was $202,693.30. This cost includes additional borrow area dredging conducted 22 through 26 January 1975 in repair of settled dike sections (Figure 8). However, placement of polyethylene sheeting (Figure 7) and dike repair during dredging operations (Figure 9) were absorbed in the contractor's dredging costs. Dike sections breached after completion of dredging operations (Figure 13) were repaired by Norfolk District personnel.

53. Costs of dredging are summarized in Table 4: total cost was $264,778.19, which includes disposal in both the habitat and upland sites. Cost of disposal in the habitat site was $114,829.89 plus one-half the dredge mobilization-demobilization cost of $12,500. Total cost of habitat site design, construction, and filling with dredged material

Table 3

Cost of Marsh Habitat Site Design and Construction

Service	Contractor	Cost
Dike foundation exploration and laboratory testing	Soil and Material Engineers, Inc.	$20,932.00
Dike sand borrow area exploration	Soil and Material Engineers, Inc.	9,399.00
Dike design and analyses	Dr. Robert Y. K. Cheng	4,820.00
Dike construction		
Hydraulic fill section	Merritt Dredging Co.	117,816.80
Dragline fill section	Higgerson-Buchanan (Subcontractor)	8,500.00
Dike repair	Merritt Dredging Co.	40,000.00
Settlement plates	Machine Services	1,225.50
	TOTAL	$202,693.30

Table 4

Cost of Dredging

Channel Station - Station	Dredged Volume, cu m	Paid Volume, cu m	Disposal Site	Cost Per cu m	Total Cost
282+00 to 304+00	166,489	123,473	Habitat Site	$0.93	$114,829.89
304+00 to 336+00	166,543	97,483	Upland Site	1.05	102,357.15
356+00 to 378+00	40,735	18,055	Upland Site	0.93	16,791.15
		Dredge Mobilization - Demobilization			25,000.00
			Dragline Work - Upland Site		5,800.00
				TOTAL	$264,778.19

becomes \$330,023.19. The marsh development project added \$220,693.30 to the operation and maintenance dredging costs for the Windmill Point - Harrison Bar - Jordan Point shoal.

PART IV: BOTANY

Methods and Materials

54. Botanical studies at the Windmill Point marsh development site consisted of (a) floristic surveys before and after marsh site construction during the 1974 to 1975 dredging season, (b) plant establishment activities during June to August 1975, and (c) botanical monitoring during the 1975, 1976, and 1977 growing seasons. Monitoring studies in 1976 and 1977 contrasted botanical conditions at the experimental marsh with a natural marsh at Herring Creek, located 3.2 km upriver from the Windmill Point project.

Preconstruction floristic survey

55. A 0.6-ha island, which existed at the experimental site prior to the 1975 disposal operation, was surveyed during June and December 1974. This island was the product of unconfined dredged material disposal as far back as the 1890's and afforded planners of the habitat development project with information about the types of plant that grow within freshwater tidal and supratidal dredged material habitats on the James River. Plants found growing on the site were collected, identified, and mapped according to elevation (Silberhorn and Barnard 1977).

Postconstruction floristic survey

56. During the period following dredged material disposal and site construction from February 1975 to July 1975, non-destructive observations of developing vegetation were made. In July 1975, personnel from the Waterways Experiment Station, Environmental Laboratory conducted a floristic survey of the marsh island. Plant species were collected, identified, and mapped according to their elevational locations.

Planting operation

57. During July of 1975, portions of the recently constructed dredged material substrates were planted. Fine-grained, confined and unconfined dredged materials and unconfined coarse-grained sandy

dredged material were planted. The sandy material was the dredged material used for dike construction.

58. Plant species and planting methods varied with substrate quality, elevation, and protection. The purposes of the plantings, other than to test the feasibility of such an operation on various types of dredged material, was to provide food and habitat for wildlife and for bank stabilization against riverine erosion. Most of the plant species were selected because they occurred naturally in similar freshwater habitats. However, smooth cordgrass, not usually found in tidal freshwater areas, was selected for its ready establishment on moderate energy shorelines, rapid lateral spread, sediment stabilization characteristics, and consequent potential for protecting invading species that might otherwise not become established. A generalized account of the planting operation follows; for a more detailed description of these activities see Garbisch (1978).

59. Plantings on unconsolidated confined dredged materials. By mid-July 1975, most of the confined dredged material had naturally vegetated (Figure 17). The only portion of the confined dredged material substrate available for planting studies was a small supratidal area located in the northeast corner of the confined area. The area was fertilized and seeded with a mixture of tall fescue (*Festuca elatior*), orchard grass (*Dactylis glomerata*), ladina white clover (*Trifolium repens*), switch grass (*Panicum virgatum*) and coastal panic grass (*Panicum amarulum*) (Figure 18).

60. Plantings on unconfined dredged material. A total of eight block replicates consisting of sixteen 3 by 3-m plots were established on unconfined dredged material located at the eastern end of the containment dike (Figure 19). The planting design consisted of either seeding or sprigging smooth cordgrass, big cordgrass (*Spartina cynosuroides*), arrow arum, and saltmarsh bulrush (*Scirpus robustus*) on 0.38-m centers within each plot. Each plot was either unfertilized or fertilized prior to planting. A total of 49 propagules were planted in each plot. A spacing interval of 0.9-m between each plot was used as experimental control plots.

Figure 17. Natural vegetation invasion of the confined dredged material, July 1975

Figure 18. Northeast corner of the dike looking west along the north side on 31 July 1975 just following seeding (after Garbisch 1978).

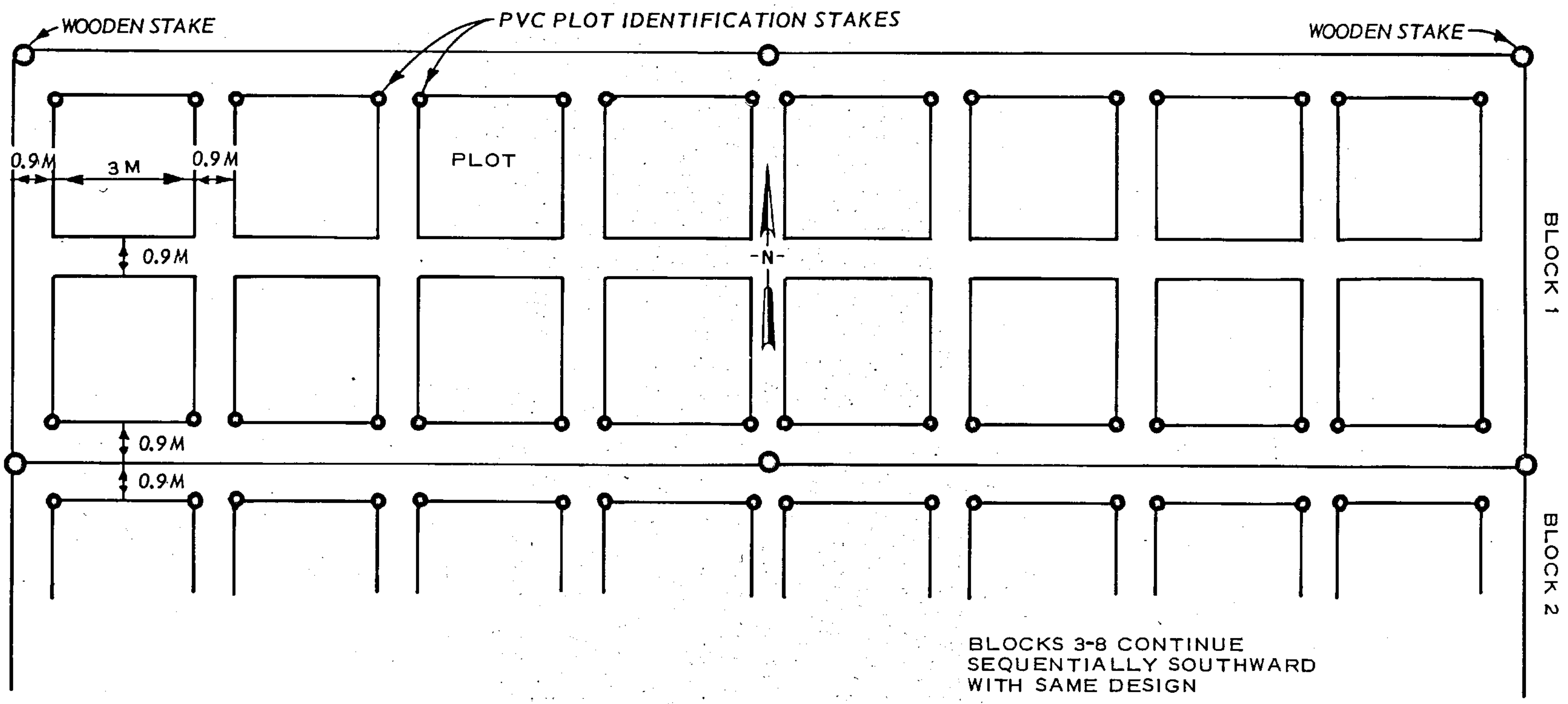


Figure 19. A schematic representation of the physical design of the blocks of plots (after Garbish 1978).

61. Plantings on the dike. Areas without vegetation in the upper half of the intertidal zone of the exterior portions of the sand dike were planted with sprigs of common three-square (*Scirpus americanus*) and smooth cordgrass. The sprigs of each species were planted in alternating rows (8 total) on 45-cm centers. The width of the transplanted area varied from 3.0 to 4.6 m, while its length was 1,097 linear m (the entire dike). At supratidal elevations on the containment dike, alternating fertilized 46 by 15-m and unfertilized 15 by 15-m sections were seeded with the same seed mix used for the northwest corner of the confined dredged material (Figure 20).

Aerial photography studies

62. Anticipating that the dredged material island would undergo many large-scale changes following its construction, aerial photography was used to document the nature and rate of plant development on the island as well as changes in site morphology, such as dike shape and condition, internal drainage patterns, and distribution of major soil types. Newly acquired and older aerial photographs dating back to the 1950's were used. New aerial photographs were taken at bimonthly intervals during the 1976 and 1977 growing season by the Georgia Air National Guard. Photointerpretations conducted at WES using a scanning stereoscope allowed the development of vegetation maps used to document changes in cover class (Doumlele and Silberhorn 1978).

On-site botanical monitoring

63. In order to monitor the planting studies several plant growth and development variables were to be studied at the end of the 1975 growing season. These variables included survival, density, height, cover, and primary production. However, animal depredation, primarily Canada goose grazing damage, destroyed the majority of the planted vegetation in the fall of 1975. Thus, detailed monitoring of the plantings was not initiated. During the 1976 and 1977 growing seasons, ground truth observations were made coincidental with aerial photography operations. A more intensive botanical study consisting primarily of ground truth cover estimates, was conducted at the site during the 1977 growing season (Doumlele and Silberhorn 1978).

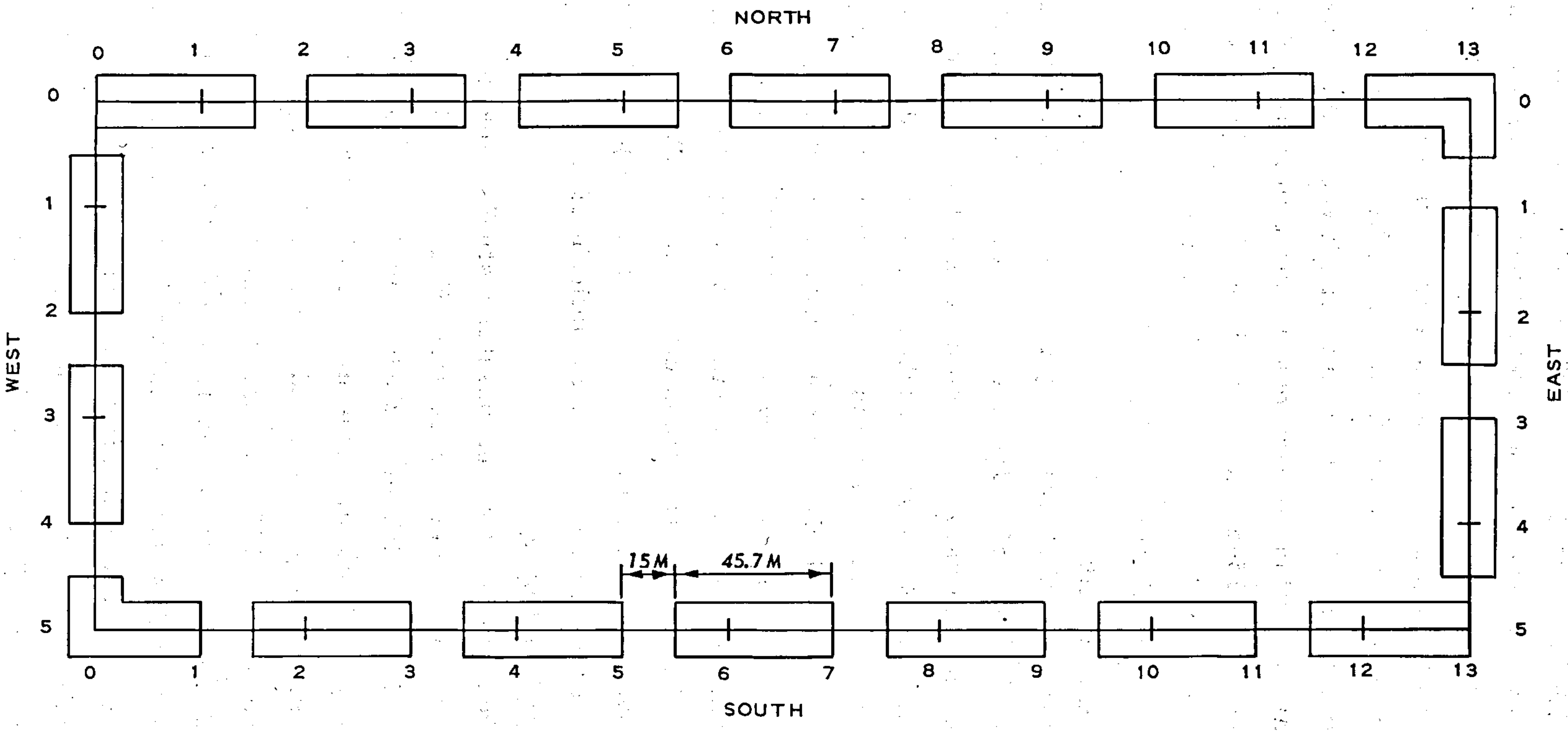


Figure 20. A schematic representation of the dike showing alternate 45.7-m and 15-m sections (after Garbisch 1978).

64. Ground cover estimates were obtained from each plant zone or community at the experimental and reference marshes. Preliminary identification of these areas was based on previous aerial photography and resulting cover maps. Plant cover within each plant zone was estimated visually at bimonthly intervals for each species using a scale for guided estimation similar to that of Phillips (1959).

Results and Discussion

Vegetation of the original island

65. The 0.6-ha island was occupied by 58 plant species. Three distinct plant communities were present: a marsh community dominated by pickerelweed (*Pontederia cordata*) associated with arrow arum; a marsh/fastland pioneer community represented by wool grass (*Scirpus cyperinus*), tag alder (*Alnus serrulata*), and eight other species; and a fastland pioneer community dominated by dog-fennel (*Eupatorium capillifolium*) associated with species of aster. A detailed vegetation map of the original island is presented in Silberhorn and Barnard (1977).

Vegetation development immediately following site construction

66. The natural invasion of the vegetation following the February 1975 disposal operations was unexpectedly rapid and extensive. By mid-April 1975, propagules were visible, and by mid-June the intertidal elevations of the dredged material substrate were largely covered with a diversity of endemic plant species (Figure 21). At that time plant growth was also apparent at the higher elevations. By mid-July, the confined dredged material was thickly vegetated (Figure 17) with exception of a few small and discrete upland areas on the sand dike and at various elevations within the confinement. More than 75 plant species were documented at the site, the greatest species diversity occurring in the high intertidal area. An incomplete listing of plant species collected in July 1975 is presented in Table 5. Based on the field observations and collections made by WES personnel in July 1975, initial plant development was described (Dredged Material Research Program 1975). Three vegetative communities were well established on

Figure 21. Looking northwest across the contained dredged materials at the site on 18 June 1975.

Table 5

James River Site, Incomplete Plant List Based Upon Field Observations and Collections, July 1975

Scientific Name	Common Name
Acalpa rhomboides	Three -seeded mercury
Acer rubrum	Red maple
Alisma subcordatum	Water plantain
Alopecurus carolinianus	Foxtail grass
Amaranthus cannabinus	Pigweed
Amaranthus hydridus	Pigweed
Amaranthus spinosus	Pigweed
Artemisia annua	Sage
Bidens aristosa	Beggar's tick
Bidens frondosa	Beggar's tick
Boehmeria cylindrica	False nettle
Cassia sp.	Sensitive plant
Celtis sp.	Hackberry
Chenopodium ambrosioides	Mexican-tea
Cyperus strigosus	Flat-sedge
Datura stramonium	Jimson weed
Digitaria sanguinalis	Crabgrass
Echinochloa crusgalli	Barnyard grass
Echinochola crus-pavonis	Barnyard grass
Eclipta alba	Yerba-de-Tago
Eleocharis obtusa	Spike-rush
Eleusine indica	Goose grass
Eragrostis hypnoides	Lovegrass
Erianthus sp.	Plume grass
Eupatorium capillifolium	Dog-fennel
Fimbristylis sp.	Fimbristylis
Galium trifolium	Bedstraw
Gratiola virginiana	Hedge hyssop
Hibiscus moscheutos	Mallow
Hypericum sp.	St. John's-wort
Impatiens capemsis	Jewel-weed
Juncus tenuis	Pathrush
Leersia oryzoides	Rice cut-grass
Lindernia dubia	False pimpernel
Liriodendron tulipifera	Tulip tree
Lolium sp.	Rye grass
Ludwigia decurrens	Seedbox
Ludwigia uruguayensis	--
Mikania scandens	Climbing hempweed
Mollugo verticillata	Carpet-weed
Oenothera sp.	Evening primrose
Oxalis sp.	Wood sorrel

(continued)

Table 5 (Concluded)

Scientific Name	Common Name
Panicum dichotomiflorum	Panic grass
Paspalum fluitans	--
Peltandra virginica	Arrow arum
Penthorum sedoides	Ditch stonecrop
Phytolacca americana	Pokeweed
Pilea pumila	Clearweed
Platanus occidentalis	Sycamore
Polygonum lapathifolium	Smartweed
Polgonum punctatum	Smartweed
Polygonum sagittatum	Tearthumb
Pontederia cordata	Rice cut-grass
Populus deltoides	Cottonwood
Potentilla norvegica	Cinquefoil
Ranunculus sp.	Buttercup
Rorippa islandica	Yellow cress
Rotala ramosior	Tooth-cup
Rumex sp.	Dock
Rumex conglomeratus	Dock
Sagittaria latifolia	Arrowhead
Salix nigra	Black willow
Solanum americanum	Nightshade
Taxodium distichum	Bald cypress
Typha latifolia	Cattail
Veronica amagallis-aquatica	Speedwell
Viola sp.	Violet
Xanthium strumarium	Cocklebur
Zea mays	Corn

the dredged material. An intertidal community dominated by pickerel-weed and arrowhead (Sagittaria latifolia) covered most of the confined area along with the frequent occurrence of false pimpernel (Lindernia dubia) and false loosestrife (Ludwigia palustris). A more mesic community of grasses and forbs existed on a narrow contour band just inside the sand dike. Flat-sedge (Cyperus strigosus), rice cut-grass (Leersia oryzoides), barnyard grass (Echinochloa crus-parvonis), love-grass (Eragrostis hypnoides), panic grass (Panicum dichotomiflorum), Yerba-de-Tago (Eclipta alba), and beggar's tick (Bidens frondosa) were dominant plants in that community. The highest elevations within the dike contained robust specimens of smartweed (Polygonum lapathifolium), some of which reached 2.1 m in height.

Planting studies

67. Initially, growth response appeared good throughout the intertidal plantings of smooth cordgrass, big cordgrass, arrow arum, and common three-square. The only exception to this was the lack of seed germination in saltmarsh bulrush and smooth cordgrass.

68. The successful trend changed abruptly, though, during August 1975 when many of the intertidal plantings were lost primarily to Canada goose grazing (Figure 22). Plants also were washed out by wave action that resulted from continual ship and barge traffic on the James River and by high current energies during periods of high water on the river. By 30 September 1976 only two out of 128 intertidal monotypic study plots remained with transplants growing on them. One of the remaining plots was sprigged with smooth cordgrass and the other with big cordgrass. These plantings continued to grow during the 1977 growing season but replacement of them by the invasion of willows (Salix nigra) appears quite possible by the next growing season.

69. Intertidal plantings of common three-square and smooth cordgrass on the exterior intertidal portions of the dike suffered the same general fate. Only sparse patches of these plantings remain on the low energy side of the experimental site although initial response was good as is evidenced by Figure 23. It is anticipated that these remaining plantings will develop significantly during the 1978 growing

Figure 22. Animal excavations at the base of S. cynosuroides in sprigged plots as seen on 29 August 1975.

Figure 23. Looking east at the fringe marsh along the exterior southern side of the dike from the southwest corner on 16 October 1975.

season since their density appears to have increased and their underground portions probably have become well established in the dredged material substrate. The former condition should help dissipate wave energies created by river traffic and high winds, while the latter should aid greatly in preventing washing out such as was observed previously. It is doubtful if any significant increase in stand size will be observed, however, if goose grazing once more becomes prevalent.

70. Contrary to these poor planting results, the areas planted above mhw with a mixture of tall fescue, orchard grass, ladina white clover, switchgrass, and coastal panic grass seed were generally successful. By October 1975, the areas planted with these propagules were dominated by switchgrass, coastal panic grass, and occasional dense patches of clover. At the close of the 1977 growing season, both panic grasses dominated the interrupted band of vegetation that surrounded the island. The occurrence of tall fescue and orchard grass was sparse throughout the period of study. The less successful development of tall fescue, orchard grass, and ladina white clover compared to the panic grasses could have been due to plant competition.

71. Response to nitrogen fertilization treatments during July and September 1975 was demonstrated by plants that appeared greener shortly after treatment when compared with plants in unfertilized plots. No other visible physical differences were observed. The green response was not evident during the 1976 growing season nor was any physical difference observed between the fertilized and unfertilized supratidal plots during the 1977 growing season.

Natural invasion and succession

72. Aerial photographs and on-site botanical observations identified vegetation patterns at the experimental site that were similar to those reported during pre-operational floristic studies in June and August 1974 (Silberhorn and Barnard 1977) and in the reference area (Doumlele and Silberhorn 1978).

73. Many of the naturally invading plant species found within the various plant zone communities that developed at the study area are typically freshwater marsh habitats described in "Preliminary Guide to

Wetlands of the South Atlantic States" (Environmental Laboratory 1978). The number of species present increased as periodic flooding decreased. A possible explanation is that a larger number of plant species within the area were genetically adapted to habitats characterized by less frequent inundation. The trend of increased diversity with less frequent inundation is common in marshes of the United States.

74. Plant distribution was governed to a large extent by the magnitude, frequency, and duration of flooding. Plant zones or communities at the experimental site could be related to the site's topographic relief. Physical and chemical soil parameters, such as soil structure and fertility, probably were of secondary importance in governing plant distribution (Wetzel and Powers 1978). The impact of soil conditions may change with time, but the effects of periodic inundation will remain as a major environmental influence.

Conclusions and Recommendations

75. The results of the propagation experiments conducted on the unconfined, fine- and coarse-grained dredged materials subjected to freshwater tidal activity showed initial promise, but remain inconclusive due to extensive goose grazing and washing out by wave and current action. The plantings that remained following natural perturbations increased in density. Future planting activities conducted in environments similar to this study should include plans for the protection of plantings against goose grazing and erosion from wave and current action.

76. Planting activities on coarse-grained dredged material at supratidal elevations were generally successful. The use of fertilizer at the rate and time intervals applied in this project appeared to have little effect on the success or failure of the supratidal plantings in the coarse-grained dredged materials. Rapid leaching through the coarse sand substrate during periods of high rainfall or flooding may have minimized the plant response to fertilizer.

77. Plant invasion of confined, intertidal, fine-grained dredged material was rapid. Protection from wave and current energies probably was a key role in effecting the rate of plant invasion. Personal observations by the author support the common occurrence of rapid invasion on fine-grained substrates throughout the southeastern United States.

78. Future loss of the experimental substrate is probable unless further erosion of the containment dike is prevented. If the physical structure of the experimental site remains intact, plant communities will probably become more similar to those at the reference marsh. The marsh may stabilize, and arrow arum might replace the pickerelweed and arrowhead species. The upland portions of the marsh island can be expected to support more woody vegetation, which could improve the resistence of the dike against riverine erosional energies.

PART V: SEDIMENT AND WATER QUALITY

Materials and Methods

79. Sediment and water quality studies at the Windmill Point marsh development site began during the period before navigation channel dredging in January 1975 and continued through January 1977. These studies were designed to characterize the navigation channel sediments before dredging operations commenced and to compare the physical and chemical properties of those sediments with the properties of the intertidal marsh substrate constructed from the channel dredged material. Changes in the marsh substrate quality through time were compared with observations of a natural reference marsh located 3.2-km upriver near Herring Creek.

80. Water quality studies at the habitat development site began with the monitoring of the effluent from the sand dike designed to retain the fine-grained dredged material slurry during the hydraulic dredging operation. These studies continued into the dredged material dewatering period after dredging operations were completed, and were repeated at periodic intervals during the following 2 years. Water quality studies conducted in 1976 and 1977 compared the movement of chemical substances through the dredged material marsh with observed movements through the Herring Creek marsh. The sequence and schedule of field sediment and water quality operations and the parameters studied by these operations are presented in Table 6. The source of the table, Adams et al. (1978), should be referred to for detailed methods and materials and discussion of data summarily presented in this Part.

Results and Discussion

81. Sediment chemical studies were conducted to provide information about sediments as reservoirs for soluble or easily solubilized biostimulatory or potentially toxic chemical substances. The physical characterization of the sediments was conducted to document the behavior

Table 6

Sampling Program at the James River Artificial Habitat Development Site and a Reference Marsh

Before and After Dredging

PERIODS	TIME/LOCATION	FIELD OPERATIONS	ANALYSES
Predredging	Jan 9, 1975 James River	10 channel cores (Figure 5)	Field sediment pH, Eh, temperature, pS, subsample for total H_2S for lab analyses, description Laboratory: 1. IW and bulk Ca, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Zn 2. IW PO_4, TDP, NH_4, NO_3, NO_2, TDN and bulk P, N 3. Water content, volatile solids, sediment size, mineralogy of clay, silt and sand, CEC
Dredging	Jan 31-Feb 1 Artificial Habitat	Six-hr. effluent water sampling at site AP (Figure 2)	Laboratory: 1. Suspended solids, dissolved and particulate Ca, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Zn 2. Dissolved PO_4, NO_3, NO_2, NH_4, and unfiltered TP, TKN 3. Suspended sediment size, CEC
POSTDREDGING PERIODS			
Dewatering (2-4 days)	Feb 6 - 8 Artificial Habitat	Six-hr. water sampling at site AP (Figure 2)	Laboratory: 1. Suspended solids, dissolved and particulate Ca, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Zn 2. Dissolved PO_4, NO_3, NO_2, NH_4, and unfiltered TP, TKN 3. No particulate metals
2.5 Months	April 18-20 Artificial Habitat	Data not useful due to high winds and negligible flood tide	————
3.5 Months	May 13 - 15 Artificial Habitat	Six-hr. water sampling at site AP (Figure 2)	Field: Water pH, Eh, temperature, alkalinity, dissolved oxygen Laboratory: 1. Suspended solids, dissolved and particulate metals same as dredging period 2. Dissolved PO_4, TDP, NO_3, NO_2, NH_4, TDN, and unfiltered TP, TKN 3. Suspended sediment size, CEC
6 Months	July 1975 Artificial Habitat	6 cores for chemistry, 11 cores for geology, 14 additional cores for probe analyses, % H_2O, IW - NH_4, and total H_2S. Vane shear at 22 locations (Figure 7)	Field: Sediment program same as predredging channel cores (except temperature during coring at top and bottom) Laboratory: 1. Same as predredging channel cores (except deleted dissolved Hg and obtained water content and volatile solids from separate samples collected during coring), added IW Cr and DOC, bulk Cr and total organic carbon, for sediments 2. Added Atterberg limits and photography of sediments after splitting cores

(continued)

Table 6 (Concluded)

POSTDREDGING PERIODS			
17 Months	July 1976 Artificial Habitat	19 surface grab samples (Figure 8)	Laboratory: sediment CEC
18 Months	August 5-7 (Summer Season) Artificial Habitat Reference Marsh	18 cores for chemistry and geology (9 at Artificial Habitat, 9 at reference marsh) Vane shear at coring sites Hourly water samples at 4 sites in duplicate (α and β) (2 sites at Artificial Habitats - AP + AB, and 2 sites at reference marsh--RL + RS) Most hourly water samples composited according to tidal stages (see Figures 2 and 3)	Field: sediment program same as July 1975 cores; water pH, temperature, dissolved oxygen, turbidity, alkalinity data was too poor to report Laboratory: 1. Same as 6 months' sediment program (except measured dissolved Hg and deleted Atterberg limits and photography) 2. Added description of one core from reference marsh site RS 3. Same as 3.5 months' water program (except dissolved Ca, Fe, Mn, Zn analyzed hourly in duplicate, DOC and VOC analyzed hourly), added current velocity at 3 channels, conductivity, chlorophyll, phaeophytin, Fo/Fa ratio on hourly basis 4. Dissolved parameters composited according to tidal stages: PO_4, TDP, NO_3 + NO_2, NH_4, TDN 5. Particulate parameters composited according to tidal stages: Unfiltered P and TKN, metals except Hg, silt/clay ratio, CEC
24 Months	January 8-10 (Winter Season) Artificial Habitat Reference Marsh	Same as during August 5-7 period Hourly water samples at 4 locations* (see Figures 2 and 3)	Field: Sediment program same as July 1975 cores (except total sulfides deleted) water program same as August 1976 Laboratory: 1. Same as August 1976 sediment program 2. Same as August 1976 water program, added filtered TOC for composited tidal stages
28 Months	June 1977 Artificial Habitat	4 cores	Laboratory: Special study of IW for dissolved metals at different centrifugation speeds for core from site AI and AS

Abbreviations: IW = Interstitial water, Eh = redox potential, pS = sulfide activity electrode, TDP = total dissolved phosphorus TDN = total dissolved nitrogen, CEC = cation exchange capacity, DOC and VOC = dissolved ~~total~~ organic carbon and volatile organic carbon Fo/Fa ratio = chlorophyll measurement before and after acidification

*A discussion of the hourly water sampling program is presented in Volume II of this appendix.

of solid sediment particles believed to have lesser water quality importance than soluble sediment phases. The questions addressed by sediment quality studies concerned the relationships between the dredging and disposal activities for habitat development and alterations of the fine-grained dredged material that could affect chemical mobilization.

82. Both sediment and water quality parameters can be classified into two categories. The first category includes the physical and chemical parameters believed to have direct importance because of their ability to stimulate, or effect a toxic response in a plant or animal or otherwise influence the usability of water for a purpose important to man. The second category includes parameters that by themselves may not be important when defining water quality,but that exert a controlling influence or are strongly correlated with determinents of water quality. The first category includes dissolved concentrations of chemical substances including nitrate, nitrite, ammonium, phosphate, and various metals. The second category includes particle size, organic content reflected by volatile solid values, organic or analytically defined composite forms of nutrients (such as total Kjeldahl nitrogen or total phosphorus) and total sediment metals and physical or chemical conditions, including pH, redox potential (Eh), cation exchange capacity, and sediment minerology.

83. Tables 7 through 10 summarize the results of sediment quality studies conducted during the Windmill Point marsh development project. The sediments that composed the substrate of the Windmill Point experimental marsh were modified by the dredging and disposal operation relative to channel sediment characteristics before dredging. The marsh sediments were more oxidized and contained less water and considerably less organic material than the channel sediments. By comparison with the sediments of the natural Herring Creek marsh, the Windmill Point marsh sediments contained less water and organic material (Table 7). If water content and volatile solids content are considered by themselves, the original James River navigation channel sediments were more like the Herring Creek marsh sediments than the experimental marsh

Table 7

Summary Statistics for Field Observations (Temperature, pH, and Eh), Percent Water, and Volatile Solids for Sediments from the Artificial Habitat Development Site and a Reference Marsh, James River, from July 1975 to January 1977. Channel Data are Provided as a Comparison

		James River Channel	Artificial Marsh			Reference Marsh	
Parameter	Statistic	January 1975	July 1975	August 1976	January 1977	August 1976	January 1977
Temperature (°C)	Mean	13.6	21.8	23.1	- 1.2	24.3	0.5
	Std. Dev.	2.9	3.7	1.5	3.9	2.0	1.3
	Number	22	13	18	18	18	18
pH	Mean	6.70	6.78	6.61	6.73	6.19	6.24
	Std. Dev.	0.22	0.40	0.35	0.31	0.49	0.55
	Number	21	13	26	23	24	26
Eh* (mV)	Mean	-25	+72	+ 105	+ 124	+ 128	+ 173
	Std. Dev.	54	110	100	117	53	43
	Number	22	13	25	23	26	26
Water (%)	Mean	50.8	38.7	47.0	44.2	66.1	67.9
	Std. Dev.	6.4	15.5	14.9	11.8	12.8	10.7
	Number	21	12	17	18	18	18
Water (%) (0-5 cm)	Mean	54.8	50.6	56.1	49.3	70.3	75.9
	Std. Dev.	5.4	9.6	7.9	11.1	13.7	6.0
	Number	10	26	9	9	9	9
Volatile Solids (%)	Mean	14.5	--**	7.2	7.8	15.1	16.6
	Std. Dev.	1.9	--	3.4	3.1	6.3	6.3
	Number	20	--	17	18	18	18
Volatile Solids (%) (0-5 cm)	Mean	13.8	4.9	10.9	8.9	17.4	19.2
	Std. Dev.	1.4	1.0	1.5	2.3	7.7	7.7
	Number	10	26	9	9	9	9

* Corrected for the potential of the saturated calomel electrode

** Not measured over entire depth of cores collected in July 1975

Table 8

Summary Statistics for Interstitial and Total Nutrients and Organic Carbon for Sediments from the Artificial Habitat Development Site and a Reference Marsh, James River, from July 1975 to January 1977. Channel Data are Provided as a Comparison

Parameter	Units	Statistic	James River Channel	Artificial Marsh July 1975	Artificial Marsh August 1976	Artificial Marsh January 1977	Reference Marsh August 1976	Reference Marsh January 1977
INTERSTITIAL								
TDP	mg/l	Mean	0.456	0.222	0.136	0.139	0.180	0.164
		Std. Dev.	0.153	0.081	0.047	0.024	0.084	0.027
		Number	20	12	18	17	21	22
ortho-PO_4	mg/l	Mean	0.252	0.054	0.100	0.076	0.059	0.082
		Std. Dev.	0.152	0.010	0.020	0.012	0.010	0.013
		Number	20	12	18	19	19	24
TDN	mg/l	Mean	69.66	34.22	12.66	5.56	10.16	3.52
		Std. Dev.	14.92	14.12	8.14	2.41	9.65	1.21
		Number	20	12	18	17	21	22
NH_4	mg/l	Mean	63.49	31.46	2.65	2.96	1.59	1.79
		Std. Dev.	12.50	8.40	1.89	1.25	1.21	0.52
		Number	43	10	18	19	20	24
$NO_3 + NO_2$	mg/l	Mean	0.064	0.024	0.100	0.106	0.119	0.104
		Std. Dev.	0.018**	0.009	0.020	0.049	0.047	0.052
		Number	20	12	18	19	19	24
DOC	mg/l	Mean	*	60.6	36.3	19.9	28.4	16.2
		Std. Dev.		16.0	15.6	7.1	14.1	4.6
		Number		11	26	24	25	25
TOTAL								
TP	μg/g	Mean	662	814	746	690	666	648
		Std. Dev.	110	58	311	528	407	416
		Number	39	16	27	24	25	25
TKN	μg/g	Mean	4,577	3,376	765	531	1,540	1,010
		Std. Dev.	684	707	360	285	823	398
		Number	39	16	27	24	25	25
TOC	μg/g	Mean	*	17,140	10,400	12,170	12,000	12,750
		Std. Dev.		1,590	2,050	1,950	2,460	2,176
		Number		11	27	24	25	25

* Not measured in channel sediments

** Standard deviation calculated for dissolved nitrate only

Table 9

Summary Statistics for Total Metals (μg/g) for Sediments from the Artificial Habitat Development Site and a Reference Marsh, James River, from July 1975 to January 1977. Channel Data Are Provided as a Comparison

Parameter	Statistic	James River Channel	Artificial Marsh July 1975	Artificial Marsh August 1976	Artificial Marsh January 1977	Reference Marsh August 1976	Reference Marsh January 1977
Fe	Mean	40,780	38,710	33,630	36,170	38,530	35,340
	Std. Dev.	8,100	11,870	10,380	8,184	11,950	6,870
	Number	25	16	27	24	25	25
Ca	Mean	4,100	3,030	2,830	3,140	3,310	2,100
	Std. Dev.	674	973	1,440	660	1,250	800
	Number	20	16	7	24	24	24
Mn	Mean	1,100	902	914	887	318	340
	Std. Dev.	204	263	280	180	109	207
	Number	25	16	27	24	25	24
Zn	Mean	240	188	182	190	224	186
	Std. Dev.	55	70	60	50	142	72
	Number	24	16	27	24	25	25
Pb	Mean	62.2	58.2	51.1	57.7	55.3	55.2
	Std. Dev.	14.3	21.9	17.8	17.7	17.5	17.0
	Number	25	16	27	24	25	24
Cr	Mean	*	71.3**	62	40	64	40
	Std. Dev.		0.0	14	9	10	7
	Number		1	20	24	25	25
Cu	Mean	49.0	41.4	40.2	40.9	45.4	41.1
	Std. Dev.	13.8	15.8	13.5	12.7	14.8	10.5
	Number	25	16	27	24	25	24
Ni	Mean	33.5	35.1	29.6	32.4	36.4	42.8
	Std. Dev.	7.5	12.9	9.5	9.1	5.3	3.2
	Number	25	16	27	24	25	24
Cd	Mean	1.32	1.54	1.33	1.46	1.16	1.24
	Std. Dev.	0.56	0.56	0.47	0.43	0.39	0.32
	Number	25	16	27	24	25	25
Hg	Mean	0.52	0.21	0.23	0.23	0.21	0.23
	Std. Dev.	0.17	0.10	0.08	0.08	0.12	0.25
	Number	19	15	27	24	25	25

* Cr was not measured in the James River channel sediments

** One sample from the middle of a core at site AI (Artificial Habitat intertidal location)

Table 10

Summary Statistics for Interstitial Metals (mg/l)* for Sediments from the Artificial Habitat Development Site and a Reference Marsh, James River, from July 1975 to January 1977. Channel Data are Provided as a Comparison

Parameter	Statistic	James River Channel	Artificial Marsh July 1975	Artificial Marsh August 1976	Artificial Marsh January 1977	Reference Marsh August 1976	Reference Marsh January 1977
Ca	Mean	215.9	60.6	81.5	65.2	26.5	13.4
	Std. Dev.	59.3	25.8	28.7	33.0	18.6	9.0
	Number	44	30	20	18	21	25
Fe	Mean	57.3	23.9	30.7	20.8	33.7	12.3
	Std. Dev.	26.7	12.6	16.6	14.4	26.1	10.9
	Number	44	30	20	18	21	25
Mn	Mean	6.94	2.68	3.82	2.84	1.44	1.27
	Std. Dev.	3.88	1.22	1.37	1.22	1.12	1.28
	Number	44	29	20	18	21	25
Zn	Mean	0.120**	0.322	0.063	0.056	0.075	0.053
	Std. Dev.	0.190	0.286	0.069	0.040	0.045	0.028
	Number	31	29	20	18	21	25
Cu	Mean	0.012	†	0.029	††	0.045	††
	Std. Dev.	0.014		0.029		0.049	
	Number	36		17		5	
Cr	Mean	‡	††	0.034	††	0.035	††
	Std. Dev.			0.009		0.014	
	Number			6		9	
Hg*	Mean	3.2	‡‡	5.6	0.8	4.0	0.6
	Std. Dev.	2.0		5.5	0.6	2.7	0.2
	Number	24		18	17	20	25

* Mercury concentrations are listed as μg/l

** Three (3) data greater than 1 mg/l were rejected as being nonrepresentative

† Quantity of water sample was not sufficient for the analysis of this metal

†† Below detection for specific metal

‡ Chromium was not measured in the channel sediments

‡‡ Not measured because of sample storage time

sediments. The loss of organic material in suspension by flotation during the dredging and disposal operation, and the mixing of sandy dike material with the muddier dredged material during the following substrate development is probably the cause of these differences. Both the volatile solids and water content of the experimental marsh substrate would have remained higher, and closer to the original channel and the natural marsh conditions if suspended material containment during marsh development had been more efficient. Among the total sediment parameters measured, there was a decrease in sediment concentrations of total Kjeldahl nitrogen, calcium, and mercury, and an apparent increase in total phosphorus (Tables 8 and 9). A decrease suggests the loss of the chemical substance from the sediments in either dissolved or solid form during or following the dredged and disposal operation. An increase suggests the selective retention of the chemical substance under circumstances occurring during or following marsh habitat development. Documenting a change in the chemistry of the sediments by itself said very little about the effects that marsh development had on water quality in the James River. To understand the reasons for these total sediment chemical changes, it was necessary to examine changes in the dissolved components of the total sediment concentrations and effluent quality during the following dredging and disposal operations (Table 11 through 14).

<u>Total phosphorus</u>

84. The increase in sediment total phosphorus concentrations was accompanied by a decrease in the total dissolved phosphorus and phosphate in the interstitial water. Evidence suggests that dissolved phosphorus forms were insolubilized during the dredged material disposal activities and that the insoluble fraction was selectively retained within the dike. Information on dissolved phosphorus concentrations in the dike effluent was considered in a computational model that compared observed phosphorus levels and computed levels (Table 15). The retention of phosphorus by the diked sediments was reinforced by this model.

Table 11

Statistics for Dissolved and Total Nutrients (mg/l) at the Effluent Pipe of the Intertidal Diked Containment Area on the James River near Windmill Point During the Periods of Active Dredging and Dewatering. Data Are Listed with Respect to the Nearest Tidal Period

		Active Dredging Period (Jan 31 - Feb 1, 1975)				Settling and Dewatering Period* (Feb 6 - Feb 8, 1975)			
Parameter	Tidal Period	Mean (mg/l)	Standard Deviation (mg/l)	Range (mg/l)	n	Mean (mg/l)	Standard Deviation (mg/l)	Range (mg/l)	n
				DISSOLVED NUTRIENTS**					
ortho-PO_4	low	0.030	0.010	0.020 – 0.040	4	0.026	0.004	0.021 – 0.030	4
	high	0.041	0.011	0.033 – 0.048	2	0.027	0.007	0.017 – 0.040	9
NH_4	low	18.43	--†	--	1	0.250	0.287	0.052 – 0.579	3
	high	18.00	5.65	14.88 - 26.46	4	--†	--	--	--
NO_3†	low	0.029	0.016	0.013 – 0.043	4	0.356	0.106	0.217 – 0.475	4
	high	0.031	0.012	0.022 – 0.039	2	0.320	0.132	0.120 – 0.515	9
NO_2†	low	0.015	0.008	0.007 – 0.024	4	0.027	0.008	0.016 – 0.035	4
	high	0.012	0.002	0.010 – 0.013	2	0.024	0.013	0.009 – 0.050	9
				TOTAL NUTRIENTS††					
TP	low	0.120	0.055	0.075 – 0.200	4	0.031	0.005	0.025 – 0.035	4
	high	0.073	0.004	0.070 – 0.075	2	0.058	0.046	0.035 – 0.180	9
TKN	low	24.03	1.16	23.0 – 25.5	4	14.50	10.99	4.60 – 30.2	4
	high	18.45	2.76	16.5 – 20.4	2	10.44	4.31	4.20 – 16.7	9

* Incoming flood tides crossed a delta consisting of fine suspended material before entering the effluent pipe of the diked containment area

** Water samples were collected with an ISCO Automatic sampler and stored individually (500 ml polyethylene bottles) in an insulated box. Bottles were recovered every 24 hours, stored on ice during transit, and processed immediately upon return to the laboratory (dissolved and filtered samples)

† Periodic interference in the measurement

†† Total nutrients measured on unfiltered acid-digested water samples

Table 12

Statistics for Dissolved and Total Nutrients (mg/1) at the Effluent Pipe of the Artificial Habitat on the James River near Windmill Point During a Tidal Period in May 1975 (3.5 Months After Dredging) with Respect to the Nearest Tidal Period

Parameter	Tidal Period	Mean (mg/ℓ)	Standard Deviation (mg/ℓ)	Range (mg ℓ)	n
		DISSOLVED NUTRIENTS			
TDP	low	0.102	0.046	0.046-0.147	4
	high	0.097	0.050	0.028-0.142	4
ortho-PO_4	low	0.048	0.020	0.038-0.078	4
	high	0.032	0.005	0.029-0.040	4
TDN	low	3.87	0.87	2.768-4.784	4
	high	0.95	0.27	0.587-1.168	4
NH_4	low	1.98	0.51	1.350-2.492	4
	high	0.26	0.05	0.201-0.296	4
NO_3	low	0.238	0.201	0.091-0.532	4
	high	0.231	0.019	0.207-0.249	4
NO_2	low	0.023	0.004	0.018-0.027	4
	high	0.021	0.001	0.019-0.022	4
		TOTAL NUTRIENTS*			
TP	low	0.899	0.330	0.538-1.334	4
	high	0.160	0.056	0.090-0.216	4
TKN	low	5.23	1.00	4.18 -6.55	4
	high	1.28	0.41	0.93 -1.83	4

* Total nutrients measured on unfiltered acid-digested water samples

Table 13

Statistics for Dissolved Metals (mg/1) at the Effluent Pipe of the Intertidal Diked Containment Area on the James River near Windmill Point During the Periods of Active Dredging and Dewatering. Data Are Listed with Respect to the Nearest Tidal Period and in Order of Greatest Abundance During the Dredging Period

		Active Dredging Period* (Jan 31 - Feb 1, 1975)				Settling and Dewatering Period*,** (Feb 6 - Feb 8, 1975)			
Parameter	Tidal Period	Mean (mg/ℓ)	Standard Deviation (mg/ℓ)	Range (mg/ℓ)	n†	Mean (mg/ℓ)	Standard Deviation (mg/ℓ)	Range (mg/ℓ)	n†
Ca	low	62.55	24.11	38.30 -95.86	4	37.73	24.33	16.45 -64.26	3
	high	48.58	6.40	44.05 -53.10	2	27.53	12.37	8.62 -42.89	6
Fe	low	6.010	6.637	0.250 -15.01	4	0.119	0.058	0.054 - 0.166	3
	high	0.532	0.357	0.279 - 0.784	2	1.056	2.327	0.025 - 5.803	6
Zn	low	5.304	4.608	1.144 - 9.487	4	0.103	0.070	0.037 - 0.176	3
	high	2.495	0.824	1.912 - 3.077	2	0.039	0.019	0.023 - 0.069	5
Mn	low	1.187	0.658	0.428 - 1.924	4	0.198	0.157	0.066 - 0.372	3
	high	0.202	0.016	0.190 - 0.213	2	0.286	0.433	0.032 - 1.161	6
Pb	low††	0.142	0.012	0.133 - 0.150	2	---	---	---	--
	high††	0.323	---	---	1	---	---	---	--
Cu	low	0.051	0.045	0.008 - 0.100	4	0.006	0.000	0.006 - 0.006	2
	high	0.035	0.021	0.020 - 0.050	2	0.020	0.022	0.006 – 0.045	3
Ni	low	0.035	0.022	0.017 - 0.059	3	0.027	0.010	0.016 – 0.034	3
	high††	0.020	---	---	1	---	---	---	--
Cd	low	0.019	0.016	0.005 - 0.037	4	0.018	0.010	0.011 - 0.029	3
	high††	0.005	---	---	1	0.013	0.007	0.006 - 0.026	6
Hg	low	0.0021	0.0008	0.0012 – 0.0032	4	0.0007	0.0001	0.0006 – 0.0007	2
	high††	0.0034	---	---	1	0.0009	0.0002	0.0006 – 0.0012	6

* Water samples were collected with an ISCO automatic sampler and stored individually (500-ml polyethylene bottles) in an insulated box. Bottles were recovered every 24 hours, stored on ice during transit, and processed immediately upon return to the laboratory (for dissolved and particulate samples)

** Incoming flood tide crossed a delta, which consisted of fine suspended materials, before entering the diked containment area. Therefore, the tidal variations might not be apparent.

† Numbers below the analytical detection limit for each particular parameter are not included

†† Below detection limit for dissolved metals during the Feb 6-8, 1975 sampling period

Table 14

Statistics for Dissolved Metals (mg/l) at the Effluent Pipe of the Intertidal Diked Containment Area on the James River near Windmill Point During a Tidal Period in May 1975 (3.5 Months After Dredging). Data Are Listed with Respect to the Nearest Tidal Period and in Order of Greatest Low Tide Abundance

Parameter	Tidal Period	Mean (mg/ℓ)	Standard Deviation (mg/ℓ)	Range (mg/ℓ)	n*
Ca	low	16.23	5.97	8.45 -21.40	4
	high	13.70	0.45	13.08 -14.11	4
Fe	low	0.518	0.226	0.351 - 0.837	4
	high	0.225	0.113	0.114 - 0.329	4
Mn	low	0.384	0.133	0.269 - 0.504	4
	high	0.026	0.011	0.018 - 0.042	4
Zn	low	0.034	0.015	0.015 - 0.048	4
	high	0.011	0.003	0.008 - 0.014	4
Ni	low	0.024	0.003	0.022 - 0.026	2
	high**	---	---	---	--
Cd	low *	0.003	---	---	1
	high**	---	---	---	--
Hg	low	0.0012	0.0012	0.0003- 0.0024	3
	high	0.0002	0.0000	0.0002- 0.0002	3
Cu	low†	0.006	---	---	1
	high**	---	---	---	--
Pb	low**	---	---	---	--
	high**	---	---	---	--

* Numbers below the analytical detection limit for each particular parameter are not included

** Below detection limit for each water sample during the sampling period

† Only one value, therefore listed along with level in order of abundance

Total Kjeldahl nitrogen

85. Nitrogen forms were discharged from the marsh development site during and following dredged material disposal activities. A decrease in the sediment total Kjeldahl nitrogen occurred during disposal and continued through the 2-year period of observation. Sediment interstitial water concentrations of total dissolved nitrogen and ammonium were decreased in the marsh substrate compared with channel sediment concentrations. A decrease in the total sediment and interstitial water levels suggested effluent discharge. When the computational model was applied (Table 15), measured dissolved ammonium levels in the effluent dredging exceeded computed levels by about 40 percent, suggesting the desorption and solubilization of ammonium during the dredging and disposal operations for marsh development. Kjeldahl nitrogen concentrations in the Herring Creek marsh sediments tended to be higher. The decrease in sediment Kjeldahl nitrogen at the Windmill Point marsh with time after dredging indicates an increased oxidation of the sediments leading to organic decomposition. The differences between the Windmill Point and Herring Creek marshes reflect differences in plant growth. Higher sediment Kjeldahl nitrogen in the natural marsh probably resulted from a long established equilibrium between plant growth and decay. The condition of organically bound and more refractory nitrogen was supported by higher cation exchange capacity and volatile solids levels in the natural marsh.

Metals

86. Total sediment concentrations of both calcium and mercury were decreased by marsh substrate construction. Sediment interstitial water levels of these metals did not follow the same patterns. Dissolved calcium in the pore water of the experimental marsh did not change following substrate construction. Concentrations throughout the 2-year period of observation were higher than occurred at the natural marsh. Dissolved mercury levels in the sediment pore waters of the experimental marsh were increased compared with levels in the navigation channel and appeared slightly higher than natural marsh levels. Application of the computation model (Table 15) suggested

Table 15

Budget for Dissolved Metals and Nutrients During Dredging at the Diked Containment Area on the James River Near Windmill Point

Parameter	Concentration (mg/l) Interstitial Water	James River Water		Calculated (mg/l)		Measured (mg/l)	Change* (%)
Ca	216	12	(13.7)**	52.8	(54.2)	63	+18
Cd	0.009	0.001†		0.0026		0.019	+631
Cu	0.011	0.003†		0.0046		0.051	+1,009
Fe	57.3	0.31	(0.255)**	11.71	(11.66)	6.01	-49
Hg††	3.0	0.24	(0.3)**	0.79	(0.84)	2.0	+146
Mn	6.85	0.028	(0.036)**	1.39	(1.40)	1.19	-15
Ni	0.05	0.008†		0.016		0.04	+150
Pb	0.08	0.03†		0.04		0.14	+250
Zn	0.12‡	0.050	(0.063)**	0.064	(0.074)	5.31	+7,700
TDN	69.66	2.20	(2.40)**	15.69	(15.85)	---‡‡	---
NH_4	63.49	0.44	(0.455)**	13.05	(13.06)	18.43	+41
$NO_3 + NO_2$	0.065	1.55	(1.76)**	1.25	(1.42)	0.044§	---
TDP	0.456	0.097	(0.125)**	0.169	(0.191)	---‡‡	---
PO_4	0.252	0.033	(0.042)**	0.076	(0.084)	0.030	-64

* Relative change between the calculated and measured concentration at the effluent pipe during dredging

** Concentration in the James River water (January 1977) during flood tide at the reference marsh (at Habitat breach)

† Half the detection limit in Table 5

†† Concentrations of mercury (Hg) are expressed in μg/l

‡ Three measurements over 1 mg/l (n = 31) were rejected as nonrepresentative (with these included the mean would equal 0.32 mg/l)

‡‡ Not measured during the dredging period

§ This number is doubtful because of analytical problems in measuring $NO_3 + NO_2$ in the interstitial water during dredging

SAMPLE CALCULATION

Effluent consisted of 16% solids, 16% channel sediment interstitial water, and 68% James River overlying water. Therefore, if sediments are ignored, the water consisted of 20% interstitial water and 80% James River water.

$$Ca = (0.2)(216) + (0.8)(12) = 52.8 \text{ mg/l}$$
$$= (0.2)(216) + (0.8)(13.7) = 54.2 \text{ mg/l}$$

solubilization of both calcium and mercury by dredged material disposal operations for marsh substrate construction.

87. The computational model identified other metals in the effluent at concentrations suggesting the occurrence of a solubilization mechanism. These included copper, nickel, lead, and zinc.

88. The construction of the Windmill Point marsh represents what was probably a worst-case dredging and disposal condition. The high chemical concentrations of metals and nutrients in fine-textured, organically enriched channel sediments, together with the flow through qualities of the dike containment led to poor sediment retention and apparent chemical solubilization and discharge of metals and nitrogen forms. This should not be interpreted as an impact statement because effluent sampling at the dike was akin to sampling the end of a dredged material discharge pipe. There was no attempt to monitor the dilution or transport or biological effects of materials discharged beyond the boundaries of the marsh development project.

89. Within the period of the 2 years between marsh site construction and January 1977, an equilibrium condition seemed to occur within the experimental marsh sediments (Table 16). By August 1976, approximately 18 months following substrate development, dissolved and total sediment chemical concentrations were comparable between the experimental and natural marshes. The emphasis of 1976 and 1977 studies was on chemical concentration relationships between the two marshes. These studies were important in considering the role of dredged material marshes in nutrient budgeting within the estuary. The reader is encouraged to refer to Adams et al. (1978) for more detailed information.

Table 16

Comparisons of Water Quality Parameter Values for the James River Artificial Habitat Development Site and the Reference Marsh During August 1976 (Summer) and January 1977 (Winter)

Parameter	Units	Summer: Development Site		Summer: Reference Marsh	Winter: Development Site		Winter: Reference Marsh
Conductivity*	mmho/cm	0.175	≥	0.165	0.179	>	0.106
Water temperature	°C	26.0	=	26.7	1.1*	≥	0.7*
pH*		7.18	≤	7.32	7.40	<	8.00
Dissolved oxygen*	mg/ℓ	5.71	<	6.94	11.44	<	12.29
Oxygen saturation*	°/o	53	<	86	82	≤	87
Alkalinity	meq/ℓ	--		--	0.49*	>	0.39*
Suspended solids	mg/ℓ	86*	>	25*	54	>	27
Turbidity*	FTU	35	>	16	22	>	11
Dissolved orthophosphate *	mg/ℓ	0.282	>	0.041	0.045	≥	0.033
Dissolved total phosphorus	mg/ℓ	0.092	≥	0.084	0.114*	≥	0.099*
Total phosphorus*	mg/ℓ	0.235	>	0.155	0.234	>	0.181
Dissolved ammonium	mg/ℓ	0.47	=	0.47	0.47	=	0.46
Dissolved $NO_3 + NO_2$*	mg/ℓ	0.619	>	0.524	1.95	>	1.61
Dissolved total nitrogen	mg/ℓ	3.48*	>	1.76*	2.60	=	2.53
Total Kjeldahl nitrogen	mg/ℓ	5.25	≥	4.23	3.07	=	3.29
Fo/Fa ratio		1.71	=	1.75	1.44*	<	1.52*
Chlorophyll	μg/ℓ	10.24*	<	13.88*	1.09	≥	0.81
Phaeophytin*	μg/ℓ	4.36	<	5.23	1.67	>	0.78
Dissolved volatile organic C*	mg/ℓ	2.6	>	1.4	2.1	>	1.3
Dissolved total organic C	mg/ℓ	9.8	≥	8.8	9.2	=	9.1
Particulate organic carbon	mg/ℓ	--		--	2.79	≥	1.47
Dissolved calcium*	mg/ℓ	16.3	>	13.7	13.5	>	11.6
Dissolved iron*	mg/ℓ	0.489	>	0.269	0.281	=	0.299
Dissolved manganese*	mg/ℓ	0.184	>	0.046	0.061	>	0.029
Dissolved mercury	μg/ℓ	0.61	=	0.61	0.31	=	0.28
Dissolved zinc	mg/ℓ	0.088	≥	0.078	0.067*	≥	0.048*

Note: > indicates greater than; = indicates equal to; < indicates less than. Differences are not necessarily statistically significant.

* Parameter values were significantly different when comparing flood tide values and ebb tide values. Slack tidal values were not tested.

PART VI: METALS AND CHLORINATED HYDROCARBON COMPOUNDS IN MARSH SOILS AND VASCULAR PLANT TISSUES

Materials and Methods

90. Marsh soils and vascular plant tissues were collected from the Windmill Point marsh development site and two natural marshes in October 1976. One of these natural marshes was located near the marsh development project at Windmill Point. The other was located upstream from Hopewell, Virginia, on Turkey Island (Figure 24).

91. Plant tissues were selected because of their occurrence in the three marshes and their wildlife food value. They were: (a) barnyard grass seeds and stem, leaf, and root tissues; (b) cattail stem, leaf, and tuber tissues; and (c) arrow arum seeds. Portions of all stem and leaf tissue samples were treated to remove surface layer metallic and chlorinated hydrocarbon contaminants. Soil and plant tissue samples were analyzed for the metals and chlorinated hydrocarbons listed in Table 17. Laboratory data was subjected to statistical or subjective analysis to describe marsh-soil-plant tissue chemical concentration relationships.

92. Details of the experimental design, field sampling, and laboratory processing and analytical methodologies are represented in Lunz (1978).

Results and Discussion

Metals

93. Mean concentrations of soils metals from both the marsh development site and the natural marsh were higher than metal concentrations in soils from unpolluted coastal marshes of the South Atlantic U. S. (Table 18). Among the five metals studied, there was more nickel and zinc in the natural marsh soils than in the soils of the dredged material marsh. The opposite was true of chromium, cadmium, and lead. There was no concentration relationship between marsh plant metal levels

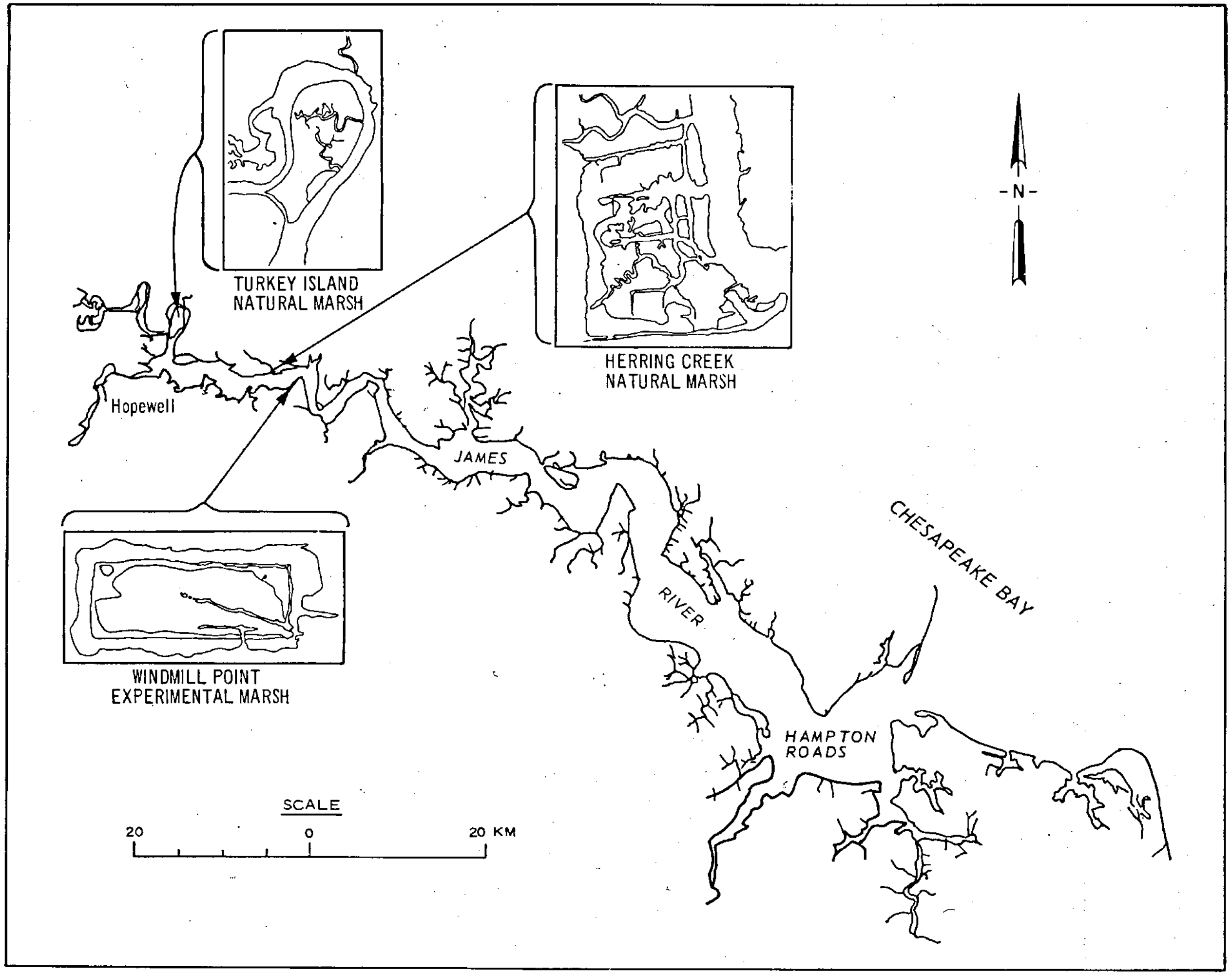


Figure 24. Location of the Windmill Point marsh and natural marshes at Ducking Stool Point and Turkey Island, James River, Virginia

Table 17

Metals and Chlorinated Hydrocarbon Compounds Analyzed in Marsh Soils and Plant Samples Collected from the Windmill Point Marsh Development Site and Natural Marshes

Metals	Chlorinated Hydrocarbon Compounds
Cadmium	Aldrin
Chromium	Dieldrin
Lead	Endrin
Nickel	Chlordane
Zinc	Heptachlor
	Heptachlor epoxide
	DDT
	DDD
	DDE
	Kelthane
	Lindane
	Methoxychlor
	Kepone
	Polychlorinated biphenyls

Table 18

Mean Metals Concentrations in Marsh Soils

(Concentrations are in ppm, dry weight)

Metal	Windmill Point Marsh Development Site	Natural Marsh Ducking Stool Point	Unpolluted South Atlantic Coastal Salt Marshes*
Cadmium	13	8.6	1.4
Chromium	165	80	
Lead	64	38	17
Nickel	16	30	
Zinc	78	150	49

* From Windom (1976).

and marsh plant soil levels. Generally, there were no statistical differences between plant tissue metal values when the same plant tissue types collected from different marshes were compared. There was one exception: dredged material marsh cattail stem and leaf tissue, which had not been treated to remove surface nickel contamination, contained more nickel than similarly treated tissue collected from a natural marsh.

Availability of metals to plant tissues

94. Factors influencing the solubility and mobility of metals in marsh soil-water systems and the uptake of metals by plants are presented by Lunz (1978) in a discussion about bioavailability.

95. Generally, the higher the soluble or easily solubilized concentration of a metal in a soil water mixture, the more available that metal will be for plant uptake. Conditions in marshes that effect the insolubility of metals have paramount importance in restricting soil to plant transfer. Information developed by agricultural researchers was reviewed and expanded by Gambrell et al. (1977) and Lee et al. (1978) to consider marsh soil conditions and marsh vegetation. Soil conditions typical of marshes, including moisture saturation, high organic content, near neutral pH, and low or no oxygen, appear to favor the formation of insoluble metal forms and restrict the transfer of metals and marsh plant tissues.

96. Using information developed by Adams et al. (1978), Lunz (1978) explained how the partitioning of metals among the soils collected from the dredged material and natural marshes might be used to interpret the plant metal uptake observations. Despite the differences in total soil metal values between marshes, there were generally only small differences in the soluble or easily solubilized soil metal fraction. In the case of nickel, the higher easily reducible nickel levels in the dredged material sediments and the lower organic content of the dredged material marsh were used to explain the difference in cattail nickel values between the marsh development site and the natural marsh.

Plant tissue metal concentration differences

97. Metal levels differences between different types of plants or different tissues of the same type of plant generally exceeded (with

the exception previously noted) differences between the same plant tissues from different marshes. Plants from the dredged material marsh generally contained higher levels of nickel. Plants from the natural marsh generally contained higher levels of lead, but at a level of significance ($\alpha = 0.13$) that raised questions about whether the difference was real. Root tissues from barnyard grass contained the highest metal levels of all metals studied. This observation was at least partially explainable by adherent soil metal contamination. The relative tissue metal levels in a particular plant provided some basis for describing the importance of soil metal transfer versus water or air metal to plant uptake routes. The effectiveness of stem and leaf washing in reducing nickel levels and the relatively low levels of this metal in seed tissues suggested plant uptake by air or water. The high relative seed tissue levels of zinc and the ineffectiveness of tissue washing of this metal suggested an absorption and internal plant translocation uptake route.

Forecasting metal uptake by plants

98. A nitric acid digestion procedure similar to ones traditionally used to describe the metals composition and pollution status of sediments was useless for explaining the metal contents of plants from the habitat development and natural marshes. Except for the availability of detailed sediment information contained in Adams et al. (1978) and summarized in Part V of this report, very little interpretation of the plant soil metals levels would have been possible. The use of chemical extractants, successfully used by agricultural chemists to describe soil fertility and being explored by Lee et al. (1978), may provide an efficient tool for predicting plant metal uptake.

Chlorinated hydrocarbons

99. The dredged material marsh development site generally contained more detectable concentrations of a variety of chlorinated hydrocarbon compounds than either of the natural marshes studied. The higher frequency of detectable concentrations, in marsh soils was not reflected in the plant tissues of the marsh development site. For details of the results and a complete discussion of the chlorinated

hydrocarbon study the reader is directed to Lunz (1978); a few compounds have been selected for discussion in this summary report.

Bioavailability of chlorinated hydrocarbon compounds to plants

100. Chlorinated hydrocarbon compounds are characterized by their persistence, low water solubility, high fat solubility, and bioaccumulative potential. As was the case with metals, the bioavailability of these compounds is related to their solubility, which affects the ease with which they can be transported into a plant or animal. Solubility considerations have equal importance when describing the transport from the soil to a root tissue and from an animal's gut into its bloodstream. The availability of chlorinated hydrocarbons to plants is affected by three major considerations: (a) the characteristics of the plant, (b) the characteristics of the soil effecting the solubility of the compound, and (c) the characteristics of the soil effecting the persistence of the compound and its existence as a reservoir for potential biological uptake. The scientific literature provided very little information about chlorinated hydrocarbons in marsh plants. Marshes have not been subjected to deliberate chlorinated hydrocarbon application. From the Windmill Point study, it seems that many of the observations of field crop experiments are also applicable to marsh plants.

101. DDE. DDE, a primary biological breakdown product of DDT was found in numerous plant tissues, and is believed transferred to plants by volatilization. Conditions of the soil substrate that increased the vapor pressure and potential volatilization of DDE would be expected to increase the potential for plant uptake of this compound. DDE volatilization is favored by low organic material, near neutral pH, and moving air and high temperature gradients. These conditions are not characteristic of navigation channel bottoms, but with exception (an important exception) to the organic material conditions, are characteristics of marshes. The new dredged material marsh at Windmill Point contained less organic material and had a slightly higher pH than the natural marshes. More of its plant tissues contained DDE than were collected from the natural marshes. The tissue treatment applied to stem and leaf tissues supported a surface contamination uptake mode that would be the result of volatilization.

102. Kepone. Kepone was detected in all marsh soils collected during this study and the data clearly identified the dredged material marsh as containing more of this compound than either of the natural marshes. Reports of Kepone's apparent availability and toxicity to estuarine animals (Hansen et al. 1976) and its possible high water solubility relative to other chlorinated hydrocarbon compounds (Saleh et al. 1978) caused concern about its biological mobility in the marsh. The root plant tissues of both barnyard grass and cattail collected from the dredged material and downstream natural marshes contained Kepone but there were no differences in the root tissue concentrations between the marshes. No other plant tissues contained detectable Kepone levels.

Summary and Conclusions

103. Dredged material conditions effecting the availability of soil metals and chlorinated hydrocarbon compounds need to be considered when forecasting plant uptake in a marsh development project. Soil conditions with primary importance when evaluating the metals uptake potential, appear to be Eh, pH, and organic content. Organic content and to a lesser extent pH, are important considerations in assessing chlorinated hydrocarbon availability to plants. Conditions of near neutral pH, low redox potential, and high soil organic content characterize many marsh soils and limit the bioavailability of soil associated metals and to some extent chlorinated hydrocarbon compounds. While marshes serve as a sink for metals by limiting bioavailability, they may also provide a substrate for the accelerated loss of certain chlorinated hydrocarbon compounds from aquatic systems. One mechanism for this loss may be the increased volatilization of DDT and its breakdown compounds, DDD and DDE. The observation of DDE uptake by plant surfaces on a dredged material marsh probably from a volatilization uptake route suggest the importance of maintaining conditions during and following habitat development, which would limit volatilization losses. Minimizing the loss of organic solids during disposal operations

for marsh site development would be a site construction recommendation directed by considering both metal and chlorinated hydrocarbon uptake data.

104. Kepone was present in all soils collected during this study but did occur in highest concentrations at the marsh development site. Kepone was only present in root tissues and was not translocated in detectable concentrations to any plant stems, leaves, or seeds studied.

PART VII: AQUATIC BIOLOGY

Materials and Methods

105. A baseline survey of benthos was conducted in November 1974 to assess conditions prior to marsh habitat construction. During the second growing season after construction, studies contrasted the use of the experimental site by fish and benthic invertebrates with a "natural" marsh 3.2-km upriver from the habitat development site, at the mouth of Herring Creek. This marsh provided the most reasonable natural reference for the experimental area given all of the possible choices, but it differed in many respects including size, mean depth, and dominant plant species composition. For the baseline study, macrobenthos were collected from and around the area of proposed marsh development using a 0.05 m^2 Ponar grab. Two samples were taken at each sampling location and washed through 500-μ sieve (see Diaz and Boesch (1977) for further details). Benthic sample collections for the study within the marsh habitat was accomplished by stratifying the Windmill Point and Herring Creek marshes on elevation and vegetation. A total of six strata were recognized (Figure 25). Samples were taken to a depth of 10 cm at randomized points within strata using a 160-cm sq by 10-cm deep can core and sieved using a 500-μ sieve. Macrobenthos was sampled seasonally from the summer of 1976 through the summer of 1977. Mieobenthos was sampled only in the summer of 1977 after it was discovered that they were important fish food components. A 3.8-sq cm by 5-cm core washed through a 125-μ sieve was used to collect mieofauna. Further details of methods and sampling design are presented in Diaz et al. (1978).

106. Fish sampling was conducted seasonally from the fall of 1976 through the summer of 1977. Collections were made during the day and night at both the habitat and reference sites. A variety of sampling gear was employed to catch the fish because no single gear would effectively sample both the interior of the marshes and the habitats surrounding the marshes in the James River. Outside of the

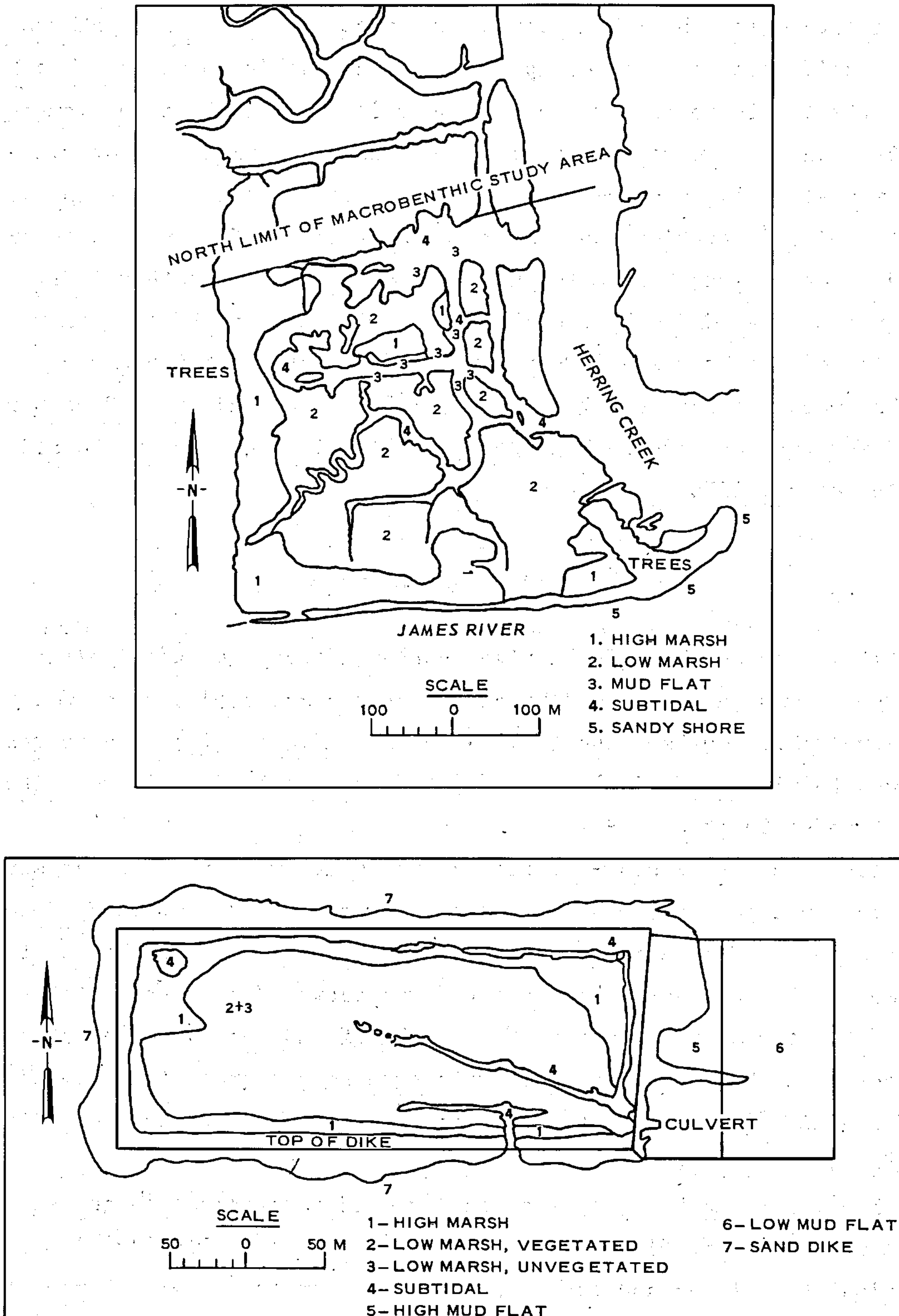


Figure 25. Habitat stratification at the Windmill Point experimental site for benthic invertebrate studies

marsh a 19.8-m long by 1.8-m deep beach seine with 6-mm bar mesh was used. Inside the marsh it was physically impossible to use the beach seine effectively so minnow traps 42.5-cm long and 22.2 cm in diameter with 6-mm bar mesh were set in groups of six. A similar set of six traps was also placed outside the marsh for comparison. The traps were set at similar elevations and water depths. Winged fyke nets were also placed in areas leaving the two marshes to catch fish as they left. Each fyke net was 2.9 m long with a 0.9-m diameter mouth. Interior mesh size of the body was 1.9-cm bar mesh and outer webbing was of 6-mm bar mesh. Wings were 7.5 m long, 1.5 m deep, and had 3.2-cm bar mesh. For further information on fish collection methods and locations see Dias et al. 1978.

Results and Discussion

107. The benthos of the river bottom affected by the habitat development was characterized by the Asiatic clam, tubificid worms, and larval chironomids (insects). Although sediments in the area varied from mud to fine sand, dominant benthos were broadly distributed with respect to sediment type.

108. Acute effects were felt by the benthos at the habitat site, where bottom topography was altered and organisms were buried by deposition of dredged material, and at the site excavated for dike construction material. However, when the area was surveyed 6 months after site development the only changes in the benthos found were in areas where sediment types had been drastically changed by construction activities. This is believed to be due to the resilience of the benthic communities in the tidal freshwater James River.

109. The benthos colonized the dredged material marsh quickly and by the middle of the first growing season (6 months following site construction) tubificids and larval chironomids were abundant. During this first season the benthos had a greater similarity to those found in the river bottom than to marsh fauna. As time progressed, more species characteristic of marshes invaded the area. Although the dominant groups

were still tubificid worms and larval chironomids, the species were different with respect to those in the river, particularly for the chironomids.

110. As the habitat marsh developed, sediments tended to become sandier than those in the reference marsh at Herring Creek. Portions of the fine-grained dredged material substrate of the experimental marsh became mixed with sand from the dike and were transported into the marsh by wind and wave action on the rising tide. The reference marsh was more protected from waves with muddier sediments containing more organic material.

111. Density and biomass of benthos varied seasonally with highest values in the summer and lowest in the winter. This is attributable to more stressful winter conditions of lower temperatures, tidal heights, and frequencies of marsh substrate inundation. The presence of plant cover and life cycle patterns contributed to the high summer densities and biomass observed.

112. The total density and biomass of benthos was highest in the low marsh and subtidal channels of the experimental site. Intermediate density and biomass were found in the higher marsh at both experimental and reference sites and in the low marsh of the reference site. Lower values were found outside the marshes on adjacent tidal flats and on subtidal bottoms claimed by the marsh development project. Between habitat differences were mainly due to differences in populations of tubificid worms.

113. Species diversity of benthos was higher at the reference site than in comparable habitats at the experimental site. This was due both to the greater richness (number of species) and greater evenness (less dominance by a few species) at the reference site habitats.

114. The experimental and reference marsh habitats were also separable on the basis of the species composition of the benthos. The reference marsh had more unique species, but several widely distributed species were more common in the experimental marsh.

115. Protection of tidal flat benthos from predation by means of an exclosure cage resulted in a three-fold increase in density and a 44-fold increase in biomass over the surrounding area. Although

local changes in sediment and hydraulics may have been partly responsible, this suggests that predation by fishes and birds plays an important role in structuring the benthic community and that the production and resource value of the benthos is underestimated by standing crop estimates.

116. The permanent meiobenthos was comprised principally of nematodes and small crustaceans (cladocerans, ostracods, and copepods). The density of meiobenthos was greatest in the low marsh, subtidal channel, and tidal flat at the experimental site. Estimated biomass was greater in reference site habitats that in comparable experimental site habitats. This was due to the greater densities of crustaceans at the reference site. The crustaceans were much larger than the nematodes, which were more abundant at the experimental site.

117. Production estimates showed that in the reference marsh habitats, meiobenthic and macrobenthic production were nearly equal, while macrobenthos production (principally by oligochaetes) was overwhelming in experimental marsh habitats. Although total production of benthos was much higher in experimental marsh habitats than in the reference marsh or on the open tidal flat, meiobenthos production was greater in reference marsh habitats than any of the other habitats.

118. The feeding habits of the five most abundant fish found in the marshes indicated benthic animals were important dietary components, particularly the meiobenthos and chironomid larvae. Larger macrobenthos such as tubificids and the Asiatic clam were not numerically important in fish stomachs, but their importance may have been underestimated. Tubificids are soft bodied and disintegrate rapidly making their detection in stomachs difficult. The Asiatic clam (<10 mm) tended to be eaten by larger fish, which were not adequately sampled for feeding habits. Another important source of food to the fish were terrestrial insects and spiders, which had fallen into or ventured onto the surface of the water.

119. The distribution of fish species was similar between the two marshes but over 65 percent of the fish collected and 72 percent of the biomass were obtained from the experimental marsh. The greatest number of fish were caught in the summer. Biomass was similar for all

seasons except winter when biomass, species, and numbers were lowest. There was little overall difference between day and night catches indicating a constant level of use of both marshes with regard to photoperiod.

120. A comparison of similar habitats between the experimental and reference marshes indicated that for each habitat and collection gear, more fish and greater biomass were caught at the experimental site than at the reference site (Table 19). Minnow trap data at the experimental site suggests that abundance and biomass inside and outside the marsh were similar. At the reference with minnow trap, catch was greater in abundance and biomass outside of the marsh.

121. In addition to examining and contrasting total catch at each site, individual fish species were ranked according to several criteria (see Dias et al. 1978 for details) and assigned a relative importance value. Of the top five "most important" species, the spottail shiner (Notropis hudsonius) (ranked first), white perch (second), and mummichog (Fundulus heteroclitus) (fifth), were analyzed for sexual maturity, length-frequency distribution, and age composition.

122. Results indicated that most gravid adults were collected in the spring at the experimental marsh. A decline in the mean size of these species was observed during summer collections at both locations as a result of the influx of immature fish.

123. These data suggest that the experimental marsh may provide attractive spawning and nursery areas.

Summary and Conclusions

124. The quickness with which the benthos colonized the habitat marsh is not suprising considering the opportunistic and eurytopic nature of the fauna that inhabit the tidal freshwater James River (Diaz 1977, Diaz and Boesch, 1977, Diaz et al. 1978). The second growing season after the construction of the marsh, and most likely during the first growing season as well, production by the benthos in the experimental marsh was 2 times greater than the reference marsh and about 1.5 times greater than the production of the shallow shoal area on which the

Table 19

Total Abundance and Biomass (gm) of Fish Collected from the Windmill Point and Herring Creek Marshes

Location and Gear	Windmill Point			Herring Creek		
	Day	Night	Day	Night	Day	Night
a. Nekton abundance						
Marsh Exterior:						
Beach Seine	665	2,693	3,358	1,038	920	1,958
Minnor Traps	161	20	181	24	26	50
Subtotal	826	2,713	3,539	1,062	946	2,008
Marsh Interior:						
Minnow Traps	151	11	162	0	3	3
Gut Fyke Net	323	72	395	36	135	171
Culvert Fyke Net	9	32	41			
Subtotal	483	115	598	36	138	174
Total	1,309	2,828	4,137	1,098	1,084	2,182
b. Total biomass						
Marsh Exterior:						
Beach Seine	7,047.7	22,099.3	30,047.0	5,819.4	9,731.5	15,550.9
Minnow Traps	852.6	190.9	1,043.5	237.4	202.7	440.1
Subtotal	8,800.3	22,290.2	31,090.5	6,056.8	9,934.2	15,991.0
Marsh Interior:						
Minnor Traps	586.3	97.2	683.5	0.0	14.5	14.5
Gut Fyke Net	41,782.9	26,869.0	68,651.9	7,366.0	17,643.3	25,009.3
Culvert Fyke Net	299.2	2,354.1	2,653.3			
Subtotal	42,668.4	29,320.3	71,988.7	7,366.0	17,657.8	25,023.8
Total	51,468.7	51,610.5	103,079.2	13,422.8	27,592.0	41,014.8

marsh was placed (excluding the contribution of large, >10 mm, Asiatic clams that appear not to be fed upon by fish). The experimental marsh, therefore, has the potential of having a much greater resource value to fish and wildlife that feed upon benthos than the preexisting shoal environment. Much more, however, needs to be learned about the availability of fish food and of productive organisms like tubificids before definite conclusions are possible. The question of whether or not the experimental marsh production will decrease and become similar to the reference area is unknown. Even if benthic production does decrease, the experimental marsh will still provide critical support of fish and wildlife resources that would otherwise not be attracted to an open-water shoal environment.

125. Fish, which were found in abundance with both experimental and reference marshes, were characteristic for the tidal freshwater James River, being mainly clupeids and cyprinids that are generally eurytolerant of a large range of environmental conditions. They feed largely on meiobenthic crustaceans and insect larvae. Tubificid worms, which were so abundant were apparently not heavily preyed on. Although because of the rapid digestion of their soft bodies, stomach contents analysis of the fish probably underestimated their importance.

126. Shore and wading birds, which prey on benthos, made extensive use of the intertidal areas around the experimental marsh (particularly the mudflat at the east end) and probably derived a large portion of their food from these areas.

127. The experimental marsh has proven to be more productive of benthos and of greater habitat value to fish and wildlife than the preexisting shoal. With time it is expected that the fluctuating conditions that characterized the benthic communities at the experimental marsh will stabilize and the overall benthic production (both macro- and meio-) will approach that of the reference marsh. There are major differences in the protection afforded the two marshes that may keep the experimental and reference marshes from becoming much more similar than they presently are. The experimental site, being an island in the main stream of the second largest river in the Chesapeake Bay, is subjected

to intense erosion from wind and water; the reference site is off the main stream, more protected from wind and tidal currents.

128. The feasibility of developing a marsh habitat that is of value to important fish and wildlife resources has been well documented and proven successful for the first 2 years of its existance at Windmill Point.

PART VIII: WILDLIFE

Materials and Methods

129. Birds seen or heard on the experimental site and on the James River berm (an upland peninsular area between the James River and the Herring Creek marsh) were recorded from 1 July 1976 to 30 August 1977 from censuses conducted approximately twice a month. A Herring Creek Marsh site was censused from 1 January to 30 August 1977. During the censuses, observers walked slowly through the area, flushing, identifying, and counting birds. Birds not directly in the study area were recorded, but not included in census data analysis. Nest searches were conducted in season and active nests mapped. Non-avian wildlife signs were noted: muskrat (*Ondatra zibethicus*) houses were mapped, mouse traps were set in 1977 to verify presence of rodents, and miscellaneous observations were recorded.

130. Bird species diversity was calculated using the Shannon index, which was also used to calculate a foraging or feeding category diversity. Relative abundance of birds in three major feeding categories at the experimental site was determined. The experimental and reference sites were compared using Dice's similarity coefficient. Data were presented by season, using the following dates:

late spring	16 April - 1 June
early summer	2 June - 15 July
late summer	16 July - 1 September
fall	2 September - 1 November
winter	2 November - 1 March
early spring	2 March - 15 April

Further details on methodology are found in Wass and Wilkins 1978.

Results and Discussion

Experimental site

131. The experimental site was used by a total of 85 species of birds, with species and numbers varying seasonally. Four species

combined to account for two-thirds of all the individuals present. Both density and numbers of species peaked in spring 1977 with highes in density because of a large number of ring-billed gulls (Larus delawarensis) resting on the mud flats, and highs in numbers of species reflecting migrating shorebirds feeding in the intertidal areas. High fall densities were due to Canada geese (Branta canadensis) and red-winged blackbirds (Agelaius phoenicius) resting and feeding. Lowest numbers of individual birds and species were recorded during early summer seasons of 1976 and 1977. Laughing gulls (Larus atricillis) were present in high densities in late summer.

132. Highest diversity of bird species and foraging diversity of individuals at the experimental site coincided with spring peaks of density and number of species. The lowest diversity occurred in fall 1976, when large flocks of red-winged blackbirds and Canada geese frequented the site. Foraging diversity of species, however, was highest in the fall, indicating use of the site by representatives of most of the 11 feeding categories recognized in the bird species present. Birds that eat fish, ground seed, and tidal invertebrates were most common, responding to the shallow water and mudflat of the marsh, the exterior beach and mudflat, and seeds of the intertidal and edge plant species.

133. Active nests of the mallard (Anas platyrynchos) and red-winged blackbird were found. One mallard nest was successful, another was not. Four red-winged blackbirds nests were seen in 1976 in beggar's ticks or cattail and 34 in 1977, all but 3 of which were in the 0.1-ha willow and alder zone. Twelve were active in 1977. High nest density in this zone probably can be attributed to the presence of a large number of peaches for defining territory. Nest density on the entire site was low, but much of the vegetation was not capable of providing a perch or nest support. There were about 5 nests/ha here, compared with an average of 102/ha in two Connecticut cattail marshes (Robertson 1973) and 30/ha in a cattail marsh in Wisconsin (Nero 1956). Nest success (based on the number that fledged young) was low at 11 percent, probably because of predation by rodents and egg-eating birds. This

compares to 46 percent in a Maryland freshwater marsh (Meanley and Webb 1963) and 11 to 48 percent (average 33 percent) in three New York freshwater marshes (Case and Hewitt 1963).

134. Three species of mammals, the muskrat, house mouse (Mus musculus), and marsh rice rat (Oryzomys palustris) were seen at the experimental site. Muskrats colonized the island by the fall of 1976 and built lodges around the island in the beggar's tick zone. They ate arrowhead, cattail roots, and pickerelweed extensively. Evidence of rodent use of red-winged blackbird nests was seen in early summer 1977; trapping in July yielded 1 house mouse and 25 rice rats. The house mouse may have been brought to the site by humans accidentally, or may have rafted to the island. Marsh rice rats are generally associated with marshes and either actively colonized the site or were rafted or carried to it. They may have had a significant impact on bird nesting success. Sharp (1967) documented their carnivorous feeding habits in a Georgia salt marsh in summer, including mention of Kale's (1965) study of predation on eggs and young of the long-billed marsh wren (Cistothorus palustris).

135. In time, several other mammal species should be seen on the island, based on the count of 22 species at Turkey Island, Presquile (Jackson et al. 1976). Further detail on mammal and bird use of the experimental site and observations of herptile and insect presence is given in Wass and Wilkins (1978).

Other sites

136. Because of differences in elevation, topography, and vegetation, the Herring Creek marsh site, the James River berm, and the experimental site showed little similarity in wildlife use. The primary difference appeared to be the extensive mudflats and other low intertidal areas present at the experimental site and absent at the other two. Similarities in bird use were highest in early spring 1977 between the Herring Creek and experimental sites; but, even then, only nine species were seen at both sites. Red-winged blackbirds nested at the Herring Creek site; 4 of 11 nests were active. Among the three sites, number of bird species, density, and diversity were lowest at the

Herring Creek Marsh site and intermediate at the James River berm, with the exception of diversity, which was slightly higher at the berm than at the experimental site. Birds most commonly seen at the Herring Creek site were the red-winged blackbird and three species of sparrow; most common at the berm site were the red-wing and five other species of songbirds.

Conclusion

137. The experimental site has become a diverse and atypical habitat in the context of the James River, and that is reflected in bird response to the site. The site's importance to migrants was especially noticeable, since low intertidal areas were heavily used for feeding and resting. Fish-eating birds fed in the site's interior and the adjacent river. Seed-eaters and insect-eaters responded to an abundant food supply in the fall. There was limited bird nesting and other wildlife colonization. The site's major impact is provision of resting and feeding areas for birds.

PART IX: OVERALL CONCLUSIONS AND RECOMMENDATIONS

138. The engineering feasibility of constructing a marsh with fine-textured dredged material was demonstrated by the Windmill Point marsh development site. The cost of the project, as compared with the traditional open-water disposal option, was increased primarily by the costs for dike design and construction. These costs were effected by the availability of a local sand deposit for the dike construction operation. The two-stage construction of a sand dike on a soft foundation was demonstrated using hydraulic dredging for material deposition and dragline shaping to achieve the necessary dike elevation.

139. Dike construction techniques believed responsible for dike settlement and localized failure were a serious problem but the failures were amenable to expedient repair using hydraulic dredging and bleeder pipe techniques. The dredged material disposal operations at Windmill Point achieved the solids retention required for marsh substrate development, which could not have been accomplished without the dike. Retention was far better than was achieved by traditional totally unconfined disposal techniques. The dredged material retention permitted the development of a fine-grained substrate along an elevation gradient that ranged from subtidal pools and creeks to upland elevations through a graded intertidal transition. The product of construction was a nutrient enriched substrate suited for marsh establishment.

140. Within 6 months following substrate construction, the unconsolidated and consolidated dredged material comprising the confined substrate and the dike contained approximately 75 different species of vegetation. Areas that were part of an original small marsh island had begun to revegetate and newly deposited sand and muddy material were being colonized by plant species native to local marsh and upland habitats.

141. Marsh plant establishment on nutrient enriched fine-textured dredged material from freshwater environments appears neither practical nor necessary. Efforts associated with a costly plant propagation program may ultimately be negated by natural vegetation invasion, competi-

tion and succession. In situations involving dredged material from freshwater systems that are neither fine-grained nor nutrient enriched, a plant establishment program is recommended to stimulate initial soil and plant development and afford substrate stability. In areas frequented by seasonal migratory waterfowl, protection of newly established vegetation against depredation is strongly recommended.

142. The dredged material disposal mode employed at Windmill Point resulted in the discharge of high suspended sediment loads. The design of the dike containment area together with the dredged material discharge operation created a flow-through system and resulted in the selective loss of high organic content, fine-textured materials. There was an apparent dissolution of forms of nitrogen and metals through the effluent discharge points that was greatest during active dredging and reduced during the period of dike dewatering. Within a 2-year period following marsh substrate development, the movement of nutrient and potentially toxic chemical substances through the dredged material marsh and reached equilibrium and observations of the Windmill Point marsh were comparable with those of a natural fine-grained marsh having a similar topographic and vegetational structure.

143. Concern with the transfer of dredged material associated metals and chlorinated hydrocarbon compounds (including Kepone) to vascular plants growing in the dredged material marsh was not supported by comparative studies between the Windmill Point and two natural marshes. Sediment metal and chlorinated hydrocarbon compound levels were not reflected in the marsh vascular plant community.

144. Total sediment analytical techniques were of little value in predicting either the mobilization of chemical substances from the dike containment during the following dredged material disposal or the uptake of metals by marsh vegetation. A computational dilution model that considered the mixing of the channel sediments with the river water during the dredging operation, together with information about sediment pore water chemistry, was effective for describing effluent quality. A sediment chemical partitioning scheme was useful for interpreting both effluent quality and plant metal uptake observations.

The refinement of an easily applied empirical technique such as the elutriate test with adaptations to conditions of marsh establishment is recommended. Also recommended is the refinement of sediment extraction techniques to characterize plant available metal levels in marsh sediments.

145. An assessment of the ecological value of the Windmill Point marsh to the fish and wildlife community identified its importance as a source of protective and reproductive cover and food for a large variety of commercially, recreationally, and trophically important animal populations. The dredged material marsh provided habitat to the fish community that was equal to or that exceeded the value of the preexisting shallow bottom in this freshwater tidal ecosystem. The habitat enhancement was related to a condition of habitat diversity. The complex of upland, intertidal vegetated and unvegetated, and shallow subtidal habitats with proximity to woody upland and open-water habitats was an important determinant of animal use. The periodically emergent sand and mudflats and marshes provided a feeding opportunity for a variety of avian species that had little or no access to the preexisting sublittoral resources.

146. Results of predation exclosure studies pointed to the errors of using standing crop data (i.e., counting the numbers and weight of animals) to document the resource value of aquatic substrates and documented the effects of fish and avian predation on reducing benthic invertebrate abundances and biomass. It is suggested that habitat evaluation procedures consider standing crop data with estimates of actual production and predation.

147. The benefits of marsh development could probably have been achieved as well, and the acute water quality perturbations could have been reduced by a dredged material disposal operation that provided more efficient retention of suspended solids. The result of greater residence time of suspended solids in the dike and the probable greater retention of highly organic materials would have effected a substrate as supportive of vegetative growth as the substrate developed during the project. The substrate resulting from higher sediment retention

would have had the added benefit cf organic characteristics believed to be very important in limiting: (a) the mobility of metallic and chlorinated hydrocarbon chemical substances, and (b) undesireable effluent water quality conditions.

REFERENCES CITED

Adams, D. D., D. Darby, and R. J. Young. 1978. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix F: environmental impacts of marsh development with dredged material: sediment and water quality, Vols I and II, Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Boyd, M. B., R. T. Saucier, J. W. Keeley, R. L. Montgomery, R. D. Brown, D. B. Mathis and C. J. Guice. 1972. Disposal of dredged material, problem identification and assessment and research program development, Technical Report H-72-8. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Brehmer, M. L. 1972. Biological and chemical study of Virginia's estuaries, VPI-WRRC-BULL No. 45. Water Resources Research Center, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 69 pp.

Bryson, R. A. and F. K. Hare, eds. 1974. World survey of climatology, Vol 11: Climates of North America. Elsevier Scientific Publishing Co., New York, N. Y.

Case, N. A. and O. H. Hewitt. 1963. Nesting and productivity of the red-winged blackbird in relation to habitat. Living Bird. 2: 7-20.

Conant, R. 1975. A field guide to reptiles and amphibians of eastern and central North America. 2nd ed. Houghton Mifflin Co., Boston, 429 pp.

Dredged Material Research Program. 1975. Progress report, James River marsh development study. Pages 2-4 in Notes news review etc., Miscellaneous Paper D-75-9. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Dias, R. K., M. Hedgepeth, and J. V. Merriner. 1978. Aquatic biology - nekton. Pages 55-78 in Virginia Institute of Marine Science, Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix D: environmental impacts of marsh development with dredged material: botany, soils, aquatic biology, and wildlife, Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Diaz, R. J. 1977. The effects of pollution on benthic communities of the tidal James River, Virginia. PhD. Thesis, Univ. Virginia, Charlottesville. 148 pp.

Diaz, R. J. and D. F. Boesch. 1977. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix C: environmental impacts of marsh development with dredged material: acute impacts on the macrobenthic community, Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Diaz, R. J., D. F. Boesch, J. L. Hauer, C. A. Stone, and K. Munson. 1978. Aquatic biology - benthos. Pages 18-54 in Virginia Institute of Marine Science. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix D: environmental impacts of marsh development with dredged material: botany, soils, aquatic biology, and wildlife, Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Doumlele, D. and G. Silberhorn. 1978. Botanical studies. Pages 79-88. in Virginia Institute of Marine Science. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix D: environmental impacts of marsh development with dredged material: botany, soils, aquatic biology, and wildlife. Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Environmental Laboratory. 1978. Preliminary guide to wetlands of the South Atlantic states, Technical Report Y-78-7. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Gambrell, R. P., V. R. Collard, C. N. Reddy, and W. H. Patrick, Jr. 1977. Trace and toxic metal uptake by marsh plants as affected by Eh, pH, and salinity, Technical Report D-77-40. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Garbisch, E. W., Jr. 1978. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix B: propagation of vascular plants, Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Hansen, D. J., A. J. Wilson, D. R. Nimmo, S. C. Schimmel, L. H. Bahner, and R. Huggett. 1976. Kepone: hazard to aquatic organisms. Sci. 193:528.

Jackson, R. S., J. F. Pagels, and D. N. Trumbo. 1976. The mammals of Presquile, Chesterfield County, Virginia. Virginia Sci. 27(2): 20-23.

Jones, J. K., Jr., D. C. Carter, and H. H. Genoways. 1975. Revised checklist of North American mammals north of Mexico, Occ. Pap. No. 28. Museum of Texas Tech Univ, Lubbock. 14 pp.

Kale, H. W., II. 1965. Ecology and bioenergetics of the long-billed marsh wren in Georgia salt marshes. Publ. Nuttall Ornith. Club 5.

Lee, C. R., R. M. Smart, T. C. Sturgis, R. N. Gordon, Sr., and M. C. Landin. 1978. Prediction of heavy metal uptake by marsh plants based on chemical extraction of heavy metals from dredged material, Technical Report D-78-6. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Lunz, J. D. 1978. Habitat development field investigations, Windmill Point marsh develoment site, James River, Virginia;

Appendix E: environmental impacts of marsh development with dredged material: metals and chlorinated hydrocarbon compounds in marsh soils and vascular plant tissues, Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Meanley, B. and J. S. Webb. 1963. Nesting ecology and reproductive rate of the red-winged blackbird in tidal marshes of the upper Chesapeake Bay region. Chesapeake Sci. 4:90-100.

Nero, R. W. 1956. A behavior study of the red-winged blackbird, II: territoriality. Wilson Bull. 68(2): 129-150.

Parker, R. D. 1975. Vegetation of Presquile, Chesterfield County, Virginia. Castanea. 40: 73-83.

Phillips, E. A. 1959. Methods of vegetation study. Holt, Rinehart, and Winston, New York, NY. 107 pp.

Robertson, R. J. 1973. Optimal niche space of the redwinged blackbird: spatial and temporal patterns of nesting activity and success. Ecology 54(5): 1085-1093.

Saleh, F. Y., G. F. Lee, and J. S. Butler. 1978. Kepone and other selected chlorinated hydrocarbon pesticides and PCB's behavior during hydraulic dredging of the James River near Hopewell, Virginia. J. Environ. Sci. Health. A13(4): 261-294.

Sharp, H. F., Jr. 1967. Food ecology of the rice rat, _Oryzomys palustris_ (Harlan), in a Georgia salt marsh. J. Mammol. 48(4): 557-563.

Silberhorn, G. M. and T. A. Barnard, Jr. 1977. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix A: assessment of vegetation on existing dredged material island, Technical Report D-77-23, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

U. S. Army Engineer District, Norfolk. 1977. Windmill Point marsh development site, James River, Virginia: chronology of island construction and technical support provided by the Norfolk District, IWD D-77-12. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Virginia Institute of Marine Science. 1978. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix D: environmental impacts of marsh development with dredged material: botany, soils, aquatic biology, and wildlife, Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Wass, M. and E. Wilkins. 1978. Wildlife resources. Pages 89-102 _in_ Virginia Institute of Marine Science. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix D: environmental impacts of marsh development with dredged material: botany, soils, aquatic biology, and wildlife, Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Wetzel, R. and S. Powers. 1978. Soils analyses. Pages 103-119 in Virginia Institute of Marine Science. 1978. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix D: environmental impacts of marsh development with dredged material: botany, soils, aquatic biology, and wildlife, Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

US GOVERNMENT PRINTING OFFICE: 1978-740-235/20

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Lunz, John D
Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; summary report / by John D. Lunz ... [et al.]. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
116 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-23)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit No. 4A11M.
Appendices C, D, E, and F published separately.
Appendices A and B on microfiche in pocket.
References cited: p. 113-116.
1. Dredged material. 2. Dredged material disposal. 3. Environmental effects. 4. Field investigations. 5. Habitat development. 6. Habitats. 7. James River. 8. Marsh development. 9. Sediment. 10. Vegetation development. 11. Waste disposal sites. 12. Windmill Point. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-23.
TA7.W34 no.D-77-23

1 of 1 WES TR D-77-23, Nov 77, by G. M. Silberhorn and T. A. Bernard, Jr. Appendix A.

APPENDICES A AND B

DREDGED MATERIAL RESEARCH PROGRAM

ENVIRONMENTAL EFFECTS LABORATORY
U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
P. O. Box 631
Vicksburg, Mississippi 39180