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DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-78-48

AN INVESTIGATION OF PHYSICAL CHEMICAL, AND/OR BIOLOGICAL CONTROL OF MOSQUITOES IN DREDGED MATERIAL DISPOSAL AREAS

by

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The Citadel
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Final Report

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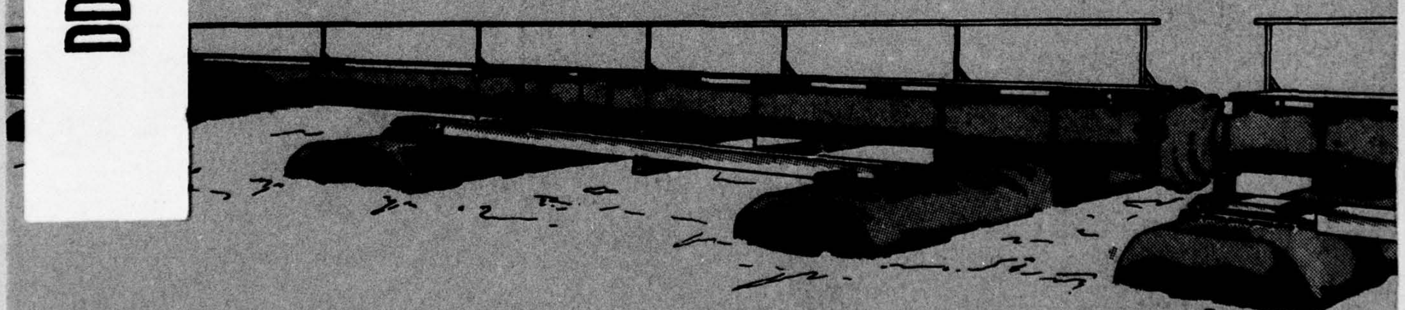

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SUBJECT: Transmittal of Technical Report D-78-48

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1. The report transmitted herewith represents the results of one of the research efforts accomplished as part of Task 2C (Containment Area Operations) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 2C was part of the DMRP Disposal Operations Project and, among other considerations, included research into various ways of improving the efficiency and acceptability of facilities for confining dredged material on land.

2. Confining dredged material on land is a relatively recent disposal alternative to which practically no specific design or construction improvement investigations had been addressed prior to the DMRP. Being a form of a waste-product disposal, dredged material placement on land has seldom been evaluated on other than purely economic grounds with emphasis nearly always on lowest possible cost. In the last several years, there has been a dramatic increase in the amount of land disposal necessitated by confining dredged material. Attention necessarily is directed more and more to the environmental consequences of this disposal alternative and methods for minimizing adverse environmental impacts.

3. Several DMRP work units have been designed to investigate improved facility design and construction including methods of considering and minimizing adverse environmental impacts during the design, construction, and management phases of the disposal area. An earlier DMRP study identified mosquitoes as being a potential problem associated with the confinement of dredged material. Consequently, this detailed study was undertaken by The Citadel, the Military College of South Carolina, to provide an understanding of the problem and to develop methods of reducing or eliminating mosquitoes associated with confined dredged material disposal areas.

4. Studies were conducted on the ecology and control of mosquitoes developing within dredged material disposal sites at coastal locations in several Corps of Engineers Districts. The investigation consisted of the following major phases: all known literature citing association of

mosquitoes and disposal areas was reviewed; a national survey of the attitudes and opinions of personnel from local mosquito-abatement districts, selected CE Districts, and State vector-control agencies was analyzed using national and regional controls; and an arthropod successional pattern was postulated based on soil weathering patterns.

5. Emergency traps were used to study arthropods associated with dredged material of various ages; studies were made comparing adult mosquito activity with selected weather variables. Results of limited tests using two insect-growth regulator (IGR) compounds are presented. More extensive tests were conducted using physical control measures including the use of rim-ditching techniques and the use of the Riverine Utility Craft or RUC. A listing of plant successional patterns, plant species associated with mosquito larvae, standing crop estimations, and species composition data from disposal sites is presented. Ornithological studies considered the species composition of birds utilizing disposal sites as a major part of mosquito ecology. Suggestions on mosquito test management plans, interagency cooperation, and future research are presented in the report.

6. The results of this study and the guidelines presented herein should provide the user with the ability to analyze mosquito problems associated with specific confined dredged material disposal areas. Guidelines on mosquito control during the planning, design, construction, and management of disposal areas should always be considered.

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

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

Studies were conducted on the ecology and control of mosquitoes developing within dredged material disposal sites near coastal locations in several U. S. Army Corps of Engineers (CE) Districts. Primary study sites were located in the Charleston District. The study consisted of the following major sections. All known literature citing an association between mosquitoes and disposal areas was reviewed. A national survey of the attitudes and opinions of personnel from local mosquito abatement districts, selected CE Districts and

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State vector control agencies was analyzed using national and regional controls. Studies on factors affecting the ecology of all arthropods within disposal sites were initiated including soil and water characterizations. An arthropod successional pattern was postulated based on soil weathering patterns. Emergence traps were used to study arthropods associated with dredged material of varying ages. Mosquitoes were collected from disposal sites as larvae and adults and identified. Studies were made comparing adult mosquito activity with selected weather variables. Site visitations were conducted to eight CE Districts where additional observations and collections were made. Comments were made regarding three types of mosquito control (chemical, physical, and biological) possibilities within dredged material disposal areas. Results of limited tests using two insect growth regulator (IGR) compounds are presented. More extensive tests were conducted using physical control measures, including the use of rim ditching techniques and the use of the riverine utility craft (RUC). Botanical studies were conducted concurrently with mosquito investigations. A listing of plant successional patterns, plant species associated with mosquito larvae, standing crop estimations, and species composition data from disposal sites is presented. Ornithological studies considered the species composition of birds utilizing disposal sites. Suggestions on mosquito pest management plans, interagency cooperation, and future research are stated with concluding remarks.

Appendix A presents the interagency perspectives on mosquito conditions and control in confined dredged material disposal sites. Appendix B lists significant data by regions, and Appendix C lists all mosquito species known to be associated with dredged material disposal sites. Appendix D summarizes the site visitations to the CE Districts, and Appendix E discusses the vegetation analysis of diked dredged material disposal sites. Appendix F presents a discussion of the occurrence of avian species within dredged material disposal sites.

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SUMMARY

This report represents the results of a series of studies conducted by an interdisciplinary research group at The Citadel, the Military College of South Carolina, for the Waterways Experiment Station of the U. S. Army Corps of Engineers (CE). The chief objective of this study was to analyze those conditions (biological, chemical, physical, and political) that affect the production of mosquitoes within dredged material disposal sites. The following disciplines were represented on the research team: general entomology, medical entomology, political science, general ecology, biological control, biometry, civil engineering, botany, and ornithology. During the study period selected members of the research team visited large numbers of dredged material disposal sites within the Charleston, South Carolina, CE District. These sites were considered as primary study locations. In addition to the primary study sites, some members of the team visited disposal areas in eight additional CE Districts. The sites visited represented a wide range of geographic conditions. This report is composed of 12 parts and 6 appendices. Major considerations and recommendations are summarized below.

Literature Review

All literature citing an association between mosquitoes and dredged material disposal sites was reviewed. Many of the references were in scattered government reports that have not been abstracted. The earliest reports (1939) of mosquitoes breeding within disposal sites came from New Jersey. Shortly after these reports, a number of states reported mosquitoes developing within dredged material disposal sites. This paucity of written materials indicates that the habitat was known, but poorly understood by most workers. General

references regarding mosquito identification and ecology are also included in this section.

Interagency Perspectives

A national survey was prepared and analyzed (using national and regional controls) that contrasted the attitudes and opinions of personnel from local mosquito abatement programs, selected CE Districts, and State vector control agencies. The survey revealed a high level of interest (85 percent return rate). The most frequent complaint cited by local mosquito abatement programs was lack of communication with their respective CE Districts. It was recommended as a result of this survey that CE Districts appoint a District "communicator" for dredged material policies and that every effort be made to advise mosquito abatement programs of dredging and other activities that affect mosquito ecology within disposal sites. It was also recommended that joint inspection programs be established between CE Districts and mosquito abatement personnel. It was felt that poor communication between CE Districts and mosquito abatement programs had resulted in many misunderstandings in the past.

Arthropod Successional Patterns

Studies were conducted to elucidate possible successional patterns of plants, soil, and arthropods that could in turn be related to mosquito patterns. Chemical characterizations of soil samples from several disposal sites with a history of producing mosquitoes were conducted. From these and other tests a picture of soil weathering stages was proposed. A total of eight different successional stages based on soil patterns were studied. Emergence traps were used to sample the arthropod fauna associated with these successional seres.

All of the data indicated that arthropods were using dredged material in greater numbers than had been expected. A table of all arthropods collected from disposal sites is presented in the text. As a result of this study, field workers can be trained to recognize the various dredged material stages (DM stages) and these can in turn be related to mosquito potential.

Mosquito Ecology

Larval mosquitoes were found to utilize a total of 14 separate and distinct larval habitats within various disposal sites that were visited. As a result of this study, mosquito surveillance personnel can be trained to inspect these habitats more quickly. The major sources of mosquitoes from most disposal sites studied were sump locations (low areas occurring in the disposal site), borrow pit swales, dike swales, and protective vegetation habitats. A single disposal area may contain all 14 habitats, a few, or they may be lacking altogether. The most common mosquitoes (for the east and gulf coasts) from disposal sites were found to be *Aedes sollicitans* and *Aedes taeniorhynchus*. This study further confirmed that mosquito fauna increases in species diversity as the disposal site ages. Of the eight successional stages (DM stages), only two (DM-4 and DM-5) were considered as highly productive sources of mosquitoes. Chemical characterizations of water from larval mosquito habitats were made. A total of 11 mosquito species were collected as larvae from disposal site aquatic habitats.

Adult mosquitoes were collected using modified New Jersey light traps powered by automobile batteries. A total of 3562 specimens representing six species were processed from the light trap catches. Only one species, *Uranotaenia sapphirina*, was collected by light trap that had not been p[illegible]iously collected in the larval state. Light trap catches were co[illegible]th weather data during the period of operation using a cross-covariance analysis technique.

Site Visitations

A total of eight CE Districts were visited for collection and observation purposes. In general, the mosquito fauna associated with dredged material disposal sites did not appear to vary greatly with the exception of west coast species and the fact that *Aedes taeniorhynchus* was not noted as a major pest species in the Philadelphia CE District. With some exceptions (noted in the text) the proposed DM stages appeared to be valid in all Districts contacted. All of the 14 larval mosquito habitats located in the primary study areas were also readily observed during the CE District site visitations. As a result of the site visitations, some confidence was gained as to the validity of the models proposed from the primary study areas.

Control Studies

Control studies were considered under three categories: biological, chemical, and physical. No biological control measures appeared practical at this time for dredged material disposal sites. A survey of current and future possibilities, however, was made. Several feasibility studies were made using new insect growth regulator (IGR) compounds. If proven environmentally safe, these materials may hold promise as chemical control tools. More extensive tests were conducted using physical control measures. The Riverine Utility Craft (RUC) was found to be useful in the dewatering of disposal areas. Soil amendments were found to be capable of reducing the formation of soil fissures (and therefore mosquito habitats) under test plot conditions. Preliminary testing of rim-ditching as a control measure was accomplished with limited success. A desirable by-product of this test was the rapid appearance of larval mosquito predators shortly after the establishment of tidal flushing action.

Botanical Studies

This portion of the study revealed a number of plant species that were associated with mosquito larval habitats. In general, those plants (mainly halophytes) that were capable of growing on fissured dredged material were associated with larval mosquitoes. Further research is needed to determine if specific plants are specifically attractive to various species of mosquitoes. A pattern of succession of plant communities was proposed and documented. Estimates of standing crop values of some plant species in pure stands in disposal sites were made and found to be higher than expected, indicating that dredged material could support some marsh plants luxuriously. A listing of plant species collected or encountered during the study was done by habitat preference, CE District, and as a pooled composite from all locations.

Avian Studies

Bird species are the major vertebrate fauna associated with most dredged material disposal sites. They are related to mosquito populations in two ways. They constitute a source of blood for mosquitoes and thereby may sustain a large breeding population of mosquitoes, and birds may function as reservoir host for a group of pathogenic arboviruses. For these reasons a study of the avifauna of disposal sites was included as a major part of mosquito ecology. Birds were found to utilize disposal sites in many ways and a complete listing of all birds known to be associated with the primary study sites of this report was compiled. Estimates were also made on the numbers and kinds of birds using disposal sites as rookeries.

Conclusions

This report has documented a number of unusual conditions that must be considered before plans for a mosquito pest management plan can be implemented. All dredged material disposal sites vary from one another, primarily in age and successional stages of the dredged material. Proper and timely surveillance is the initial step to mosquito abatement within disposal sites. Personnel must be trained to recognize the presence (or absence) of the 14 larval mosquito habitats that can develop within disposal areas. Inspectors also need the ability to recognize the various DM stages and plant successional seres. Aerial surveillance can be both useful and accurate if personnel are trained to observe closely the ecological markers mentioned in this report.

Mosquitoes can be controlled by a variety of conventional and unconventional methods in disposal sites. Inasmuch as all chemical control is temporary, caution should be considered before any organic chemical is used for a sustained period of time as a mosquito control agent. It is a known fact that sustained, sublethal contact with certain organic chemicals by mosquito larvae will induce genetic resistance to the poison. Nontarget organisms (i.e. marsh invertebrates) may also be harmed by the indiscriminate use of poisonous materials. When the above reservations have been considered and the use of chemicals is recommended, a number of chemical pesticides are available and effective. Inasmuch as the allowable use of many chemicals is subject to change, local recommendations must be consulted and no listing of pesticides was included in this report.

Many of the above problems (e.g. genetic resistance) are not encountered when physical control measures are employed against mosquitoes. These measures require longer periods of time for implementation, but the effectiveness is unquestionable. This report considered three physical control measures (use of the RUC, soil amendments, and rim-ditching). In general, almost any physical control measure that will allow for drainage and/or flushing actions by tides will eliminate mosquito larvae. The investigators of this report feel strongly that additional research is needed on biological and physical control measures within dredged material disposal sites.

In many cases a complex of government agencies was observed to affect environmental policy planning regarding mosquito control within disposal sites. In such an atmosphere, interagency cooperation becomes a necessity if rational measures are to be employed in mosquito abatement (this was especially documented by the attitude and opinion survey). In conclusion, mosquitoes can be controlled within dredged material disposal sites if proper consideration is given to the following items:

a. The peculiar ecology of disposal areas must be understood as distinct from the surrounding marsh or other environment.

b. A pattern of regular mosquito inspection and surveillance procedures must be established by the agency performing control services. These activities must also be related to rainfall patterns. Generally, removal of water (rain, tides, etc.) from a disposal site within 7 to 10 days will prevent the production of adult mosquitoes.

c. Personnel must be trained for both aerial and ground inspection procedures including the recognition of the 14 larval habitats cited in this report, the importance of the various DM stages, plant successional patterns, and the importance of bird-mosquito relationships.

d. A regular program of information exchange between CE Districts and mosquito abatement programs must be established. Every effort should be made to inform local mosquito abatement programs of disposal area management decisions. Procedures for local mosquito abatement program input into disposal site management should be developed.

e. In order to achieve an integrated control program for mosquito pest management in disposal sites, proper consideration to the roles of biological, chemical, and physical measures must be given. The ideal program should employ each option to the best, environmentally safe advantage.

PREFACE

The work described in this report was performed under Contract No. DACW39-75-C-0122 (Neg.), entitled "An Investigation of Physical, Chemical, and/or Biological of Mosquitoes in Dredged Material Disposal Areas", between the United States Army Corps of Engineers Waterways Experiment Station (WES), Vicksburg, Mississippi, and The Citadel, The Military College of South Carolina, Charleston, South Carolina. This research was sponsored by the Dredged Material Research Program (DMRP) under Work Unit 2C12.

This material represents a period of intense research centering around the many factors that affect mosquito ecology within dredged material disposal sites. Consideration was also given to the attitudes and opinions of those government agencies whose roles require some management of disposal sites.

The principal investigator and project director was Dr. Wm. Bruce Ezell, Jr., of the Biology Department of the Citadel. Dr. H. C. Chapman of the Gulf Coast Mosquito Research Laboratory wrote the section on the potential for biological control of mosquitoes within dredged material disposal sites (Part VII). Other investigators from The Citadel and their respective field of expertise included Dr. Robert P. Steed (political science: Part III, Appendices A and B); Dr. Daniel L. Kline (arthropod ecology: Parts IV and V); Mr. L. Joseph Vorgetts (mosquito ecology and weather analysis: Parts IV and V); Dr. Richard D. Porcher (botany: Parts VI and X and Appendix E); Dr. Dennis M. Forsythe (ornithology: Part XI and Appendix F); Dr. Edmond P. Ryan (civil engineering: Part IX); Mr. Lewis Cauthen (civil engineering: Part VI and Appendix D); and Col. Oren L. Herring (electrical engineering: Part V). Typists for the original manuscript were Linda Pope and Judy Wilson. Fiorentina Alvaro, Terri A. White, and Cindy E. Mustin prepared the final manuscript. Student assistants included Messrs. Dan W. Brooks, Jr., James D. Campbell, Glenn S. Avidon, and Ms. Louise M. Cauthen.

Appreciation is also due to the following personnel not associated with The Citadel. Dr. C. B. Loadholt of the Medical University of South Carolina provided assistance with the statistical analysis of weather variables and mosquito light trap catches; Messrs. Braxton Kyzer, John Carothers, and Lt. Randy Bolton of the Charleston CE District provided technical data and field assistance regarding various dredged material disposal sites for the primary study areas.

Many local mosquito abatement programs provided assistance and encouragement during the study period. Mr. Max M. Askey of the Charleston County Mosquito Abatement program was especially helpful in planning larval and adult mosquito surveys within the disposal sites of Charleston County. Personnel from this program also assisted in boat operations and light trap surveys. Messrs. Robert Zack and David C. Arnold of the Georgetown and Beaufort County Mosquito Abatement programs, respectively, assisted in larval survey and chemical control studies (Parts V and VIII). Dr. L. A. Williams, Jr., of the South Carolina Department of Health and Environmental Control assisted in the planning of public policy analysis and survey (Part III, Appendices A and B).

The following specialists graciously provided taxonomic identification and/or confirmation of arthropods collected for Parts IV and V of the study: R. F. Darsie (U. S. Public Health Service, Atlanta, Georgia); E. L. Mockford (Illinois State University); A. B. Gurney (USDA, Retired Scientist); G. W. Byers (University of Kansas); D. L. Wray (Raleigh, North Carolina); H. Frank (Florida Medical Entomology Lab); W. A. Connell (University of Delaware); W. B. Peck (Central Missouri State College); T. L. Erwin and O. L. Cartwright (U. S. National Museum); and R. White, R. D. Gordon, J. M. Kingsolver, T. J. Spillman, G. Steyskal, F. C. Thompson, W. W. Wirth, R. J. Gayne,

C. W. Sabrosky, M. B. Stoetzel, J. P. Kramer, J. L. Herring, R. W. Carlson, G. Gordh, A. S. Menke, P. M. Marsh, and D. P. Smith (USDA, Systematics, Washington, D. C.).

This study was also aided by smaller grants from The South Carolina Department of Health and Environmental Control and The Citadel Development Foundation. This volume also constitutes a final report to these agencies.

The contract was monitored by Mr. Newton Baker and Miss Marian Poindexter, Disposal Operations Project (DOP), and Dr. Luther Holloway, formerly of the Habitat Development Project, Environmental Laboratory (EL), WES. The study was under the general supervision of Mr. Charles C. Calhoun, Jr., Manager, DOP, and Dr. John Harrison, Chief, EL.

The Directors of WES during the period of the contract were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurements used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
feet	0.3048	metres
yards	0.9144	metres
miles (U. S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
square miles	2.589988	square kilometres
acres	4046.856	square metres
cubic yards	0.764555	cubic metres
ounces (U. S. fluid)	29.57353	cubic centimetres
pints (U. S. liquid)	0.0004732	cubic metres
gallons (U. S. liquid)	0.003785412	cubic metres
pounds (mass)	453.59237	grams
tons (short)	907.1847	kilograms
pounds (mass) per acre	0.000112	kilograms per square metre
miles (U. S. statute) per hour	1.609344	kilometres per hour
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AN INVESTIGATION OF PHYSICAL, CHEMICAL, AND/OR BIOLOGICAL CONTROL OF MOSQUITOES IN DREDGED MATERIAL DISPOSAL AREAS

PART I: INTRODUCTION

Background and Approach

The disposal of dredged material within confined land disposal areas appears to be increasing in many parts of the United States as a concurrent result of increased utilization of the nation's ports and waterways and environmental opposition to open-water disposal. Figure 1 indicates the approximate annual amounts of dredged material deposited within confined disposal areas in the various U. S. Army Corps of Engineers (CE) Districts. According to Harrison and Chisholm (1974) most of these disposal sites have been constructed in the past twenty years (prior practices included open-water disposal and unconfined land disposal). A report by Boyd et al. (1972) presented a summary of the major environmental problems associated with the disposal of dredged material and the need for further research on this topic. In recent years, a number of research studies have been published under the aegis of the Dredged Material Research Program (DMRP) of the U. S. Army Engineer Experiment Station (WES), Vicksburg, Mississippi. The serious student of dredged material ecology will want to consult the technical reports of this program. Among the current DMRP reports that were found to be especially useful to this study were the works of Harrison and Chisholm (1974), Kadlec and Wentz (1974), Murphy and Ziegler (1974), Reikenis et al. (1974), Wentz et al. (1974), Johnson and McGuinness (1975) and Skjei (1976).

2. While environmental opposition to some of the ecological effects of dredged material disposal in many coastal sections

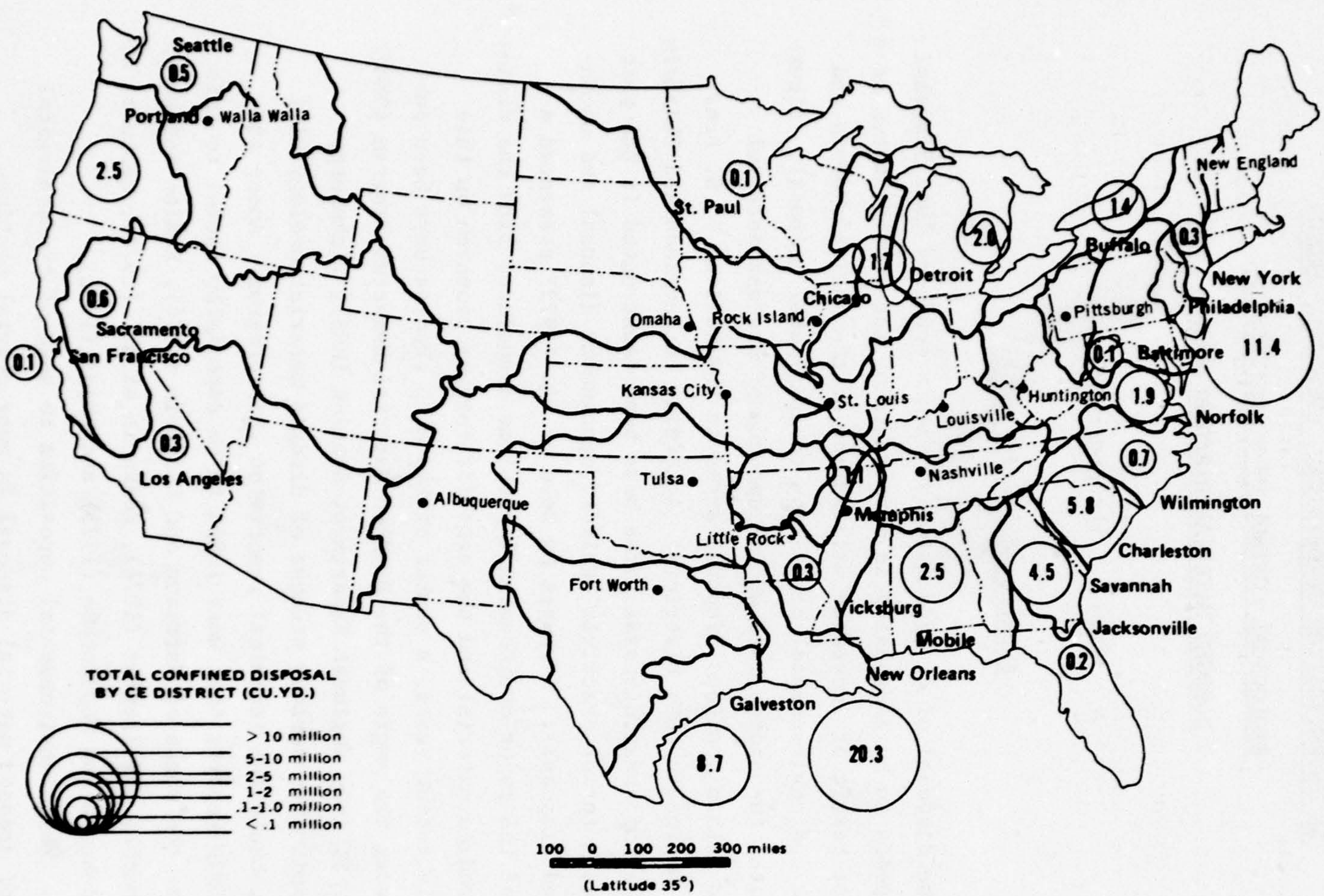


Figure 1

Total Confined Disposal by CE District (million cu yd)
(after Harrison and Chisholm, 1974)

centered around well-known problems such as objectionable odors, land-use problems, title disputes, loss of marshes, etc., the production of mosquito larvae within dredged material disposal sites constituted a more subtle, but far more serious, problem than was generally recognized by government agencies or the general public. This general lack of knowledge concerning the relationship of dredged material habitats and mosquito breeding may be attributed to the following factors:

a. Many confined disposal sites are inspected by Corps personnel and/or their respective contractors primarily before, during, and immediately after a pumping operation. The area is not usually checked in a regular manner in most districts during the pumping interim.

b. Many government (State and local) agencies charged with environmental concerns are either ignorant of the mosquito breeding problems associated with the dredged material habitat or they are unable to regularly inspect such habitats because the locations are too remote or inaccesible.

c. A given dredged material disposal site will not always produce mosquitoes. A wide variety of ecological factors appear to affect the noxious insect productivity of a given disposal area.

d. State and local government agencies are generally not as active in environmental opposition as citizens groups.

e. The dredged material habitat and its relationship to mosquito breeding is poorly understood even among professional entomologists and ecologists.

3. The purpose of this report is to disseminate available information concerning mosquito breeding problems to the Districts of the U. S. Army Corps of Engineers and other agencies concerned with current practices and resultant ecological effects of dredged material disposal operations in coastal regions of the United States. This report should serve as a stimulus for further research on the ecological effects of dredged material disposal and the resultant

man-made ecosystems (dredge islands) that develop after such operations.

Scope and Limitations

Purposes

4. This report presents the results of an interdisciplinary research group formed at The Citadel for the specific purpose of studying the interrelated ecological, political, and engineering problems associated with mosquito breeding on dredged material in selected coastal regions of the United States. For purposes of this study a dredged material disposal site means:

> an area of marsh or higher ground enclosed by a dike from the surrounding environment for the purpose of retaining a suspension of dredged material (formerly termed "spoil" in older publications) derived from a dredging operation.

This study was limited to a discussion of problems associated with diked (i.e. confined) disposal areas. Open-water disposal problems and fresh-water disposal techniques were not considered. The study dealt primarily with existing disposal sites for which pertinent data were available. In some cases, complete records regarding the contract history of disposal operations on a given area were not available. In the past such data were not considered important by many Districts. Recently, in the wake of increased environmental awareness by both private citizens and government agencies, this practice appears to have been reversed.

Outline of study

5. In view of the almost total lack of previous research in this specialized field of entomology, it was felt that an interdisciplinary approach would provide the greatest amount of practical and useful information in view of the short-term nature of the study (1-½ yrs.). The following outline indicates the basic pattern of

this approach:

<u>a</u>. A complete and comprehensive survey of interagency attitudes regarding mosquito control problems associated with the disposal of dredged material would be undertaken by a political scientist with computer analysis. Such a study would compare and analyze how opinions varied among CE District personnel against State and local agencies charged with mosquito control responsibilities.

<u>b</u>. Studies would be initiated that would partially establish (within the time frame of the study period) the pattern of arthropod succession within the various successional seres associated with the aging of confined dredged material disposal sites.

<u>c</u>. Studies would be initiated that would begin to elucidate the ecological limiting factors that affect mosquito production in the dredged material habitat. Such studies would establish the species composition of mosquitoes breeding within such habitats in the major geographic regions of the U. S.

<u>d</u>. Site visitations by an entomologist, a botanist, and a civil engineer would be conducted to the CE Districts of Galveston, Jacksonville, New Orleans, Norfolk, Philadelphia, Sacremento, and San Francisco.

<u>e</u>. Studies would be made to determine the current status and potential for using biological control techniques against dredged material mosquitoes.

<u>f</u>. Limited temporary control studies would be made using insect growth regulators (IGR's) against mosquitoes breeding within the dredged material habitat.

<u>g</u>. Studies would be initiated to determine the effectiveness of certain physical control measures against mosquitoes within the dredged material habitat.

<u>h</u>. Studies would be undertaken by a competent botanist and ornithologist to determine the major ecological relationships between mosquitoes and plant successional patterns and mosquitoes and avian species, respectively, within confined dredged material disposal islands.

PART II: OVERVIEW OF THE MOSQUITO CONTROL PROBLEMS ASSOCIATED WITH DREDGED MATERIAL DISPOSAL AREAS

Historical Background

Early references

6. Because of the remote location of most dredged material disposal areas and the fact that mosquito breeding usually develops some months after the cessation of disposal activity within these sites, entomologists were slow to understand the mosquito breeding potential within such areas. Among the earliest references to mosquito breeding problems within diked disposal areas is the report of Brooks (1939). This author noted that mosquitoes frequently developed within the vertical shrinkage cracks that develop as a dredged material disposal area begins to dry and consolidate. Brooks also noted that a common marsh plant, *Phragmites* sp., as a monoculture frequently sheltered mosquito breeding habitats.

7. During the years of World War II, scattered references to mosquitoes associated with dredged material disposal sites began to appear in the literature. Thom (1942) suggested that the tillage be employed as a possible control measure with "hydraulic fills" near South Amboy, New Jersey. Thom further suggested that this tillage should best be done after the first frost in order that the soil would be firmer for equipment operation. As a follow-up procedure he suggested that grasses such as "red top" might be introduced into the reclaimed disposal site. Thom (as did Brooks, 1939) believed that *Phragmites communis* Trinius might be counterproductive to mosquito control efforts. Later, Vannote (1945) noted that scarifying small hydraulic fills near Port-au-Peck, New Jersey, using disk harrows could be used as a limited mosquito control measure. Weathersbee (1945) cited hydraulic fills as a major problem for mosquito control efforts around the U. S. Naval Base in Norfolk,

Virginia.

Problems along the Atlantic Coast

8. During the decade of 1950-1960 several articles appeared in regional journals and obscure government publications. Most of these reports centered around the states of New Jersey and Delaware. Jobbins (1951) reported on experiments using greases to control wind eroded silt on dredged material disposal sites. Stivers (1951) reported that the U. S. Government (Corps of Engineers?) was cooperating with mosquito control efforts in dredged material disposal sites by insisting that final payment to a dredge contractor should be withheld "until permission was given by the mosquito commission that drainage had been restored." This report is the earliest record of cooperation in the literature between local mosquito commissions and the U. S. Government.

9. Ruth (1952) reported large flights of salt marsh mosquitoes associated with the disposal of dredged material in Norfolk, Virginia. His report is perhaps the earliest to stress the importance of mosquito control in the planning of dredged material disposal sites <u>before</u> the onset of the actual operation. Ruth also suggested the use of a cover material (topsoil) to prevent mosquito breeding after a dredged material disposal site has been drained of excess water.

10. A second report by Thom (1955) noted that most dredged material disposal areas tend to develop individual and particular biological characteristics. It was found that mosquito breeding potentials were difficult to predict from one disposal site to another. The ecological factors that cause one disposal area to breed more mosquitoes than another (perhaps nearby) site were not yet known. An interesting suggestion in this report is a discussion that mosquito eggs might be dredged into a disposal area by the dredged operation per se. Another field note of interest is Thom's observation that the appearance of "a green scum" (algae?) frequently serves as a harbinger of mosquito breeding activity. The report

concludes with a statement that experimental plantings of several grasses were not successful within dredged material disposal sites.

11. Kinsey (1958) noted that "...fills remain today as some of our worst mosquito breeding areas." Powers (1958) representing the U. S. Army Corps of Engineers stated that the States were responsible for dredged material disposal sites, but admitted that certain Corps of Engineers disposal areas were public health problems. Helm (1959) listed a number of specific details that might be agreed upon between dredging contractors for the Corps of Engineers and local mosquito abatement programs.

Recent reports of mosquito problems in disposal areas

12. Mason (1966) noted the appearance of a major mosquito problem in New Jersey following large-scale hydraulic pumping operations in marsh areas to allow for highway construction. Lomax (1967) noted the importance of seepage from under dikes around dredged material disposal areas as a factor affecting mosquito production. Lomax's report also notes a high degree of cooperation between a local mosquito extermination commission and the Corps of Engineers. Hydraulic fills are cited as mosquito breeding sources in the latest edition of Military Entomology Operational Handbook. (U. S. Army, 1971).

Local government agency reports

13. A number of local government reports were found to contain scattered information regarding the association of mosquitoes with dredged material disposal areas. Since these publications are not abstracted or frequently cited in literature reviews of mosquito biology, the authors recognize that the citations listed below are incomplete.

14. Fehn (1957) reported large broods of the common salt marsh mosquito, *Aedes sollicitans*, breeding within a dredged material dis-

posal area near Charleston, S. C. This report further noted that frequent rainfalls on dredged material disposal areas often led to repeated production of mosquitoes. Fehn's study is one of the early reports to mention the production of different mosquito broods within a single disposal area. Nelson (1960) further documented Fehn's conclusions. Mosquitoes breeding within dredged material disposal areas near Mt. Pleasant, S. C., were responsible for the initial organization by referendum in 1960 of the first county mosquito abatement program in South Carolina (Personal Communication, 17 June 1970, M. M. Askey, Jr., Director, Charleston County Mosquito Abatement Program, Charleston, S. C.). Askey (1972) further cited mosquito problems associated with disposal areas near McClellanville, S. C., during an unusually severe mosquito season that occurred in July-August of 1972.

15. Along the Georgia-South Carolina border in the Savannah District of the Corps of Engineers, a severe mosquito problem appears to have developed over the last 20 years. Two reports by the Chatham County Mosquito Control Commission (1967, 1969) document this problem. The drying of dredged material is also cited as a mosquito breeding source in an annual report by the Orleans Parish Mosquito Control Program (1968). Severe problems from *Aedes sollicitans* breeding within disposal sites have been reported from Hancock County in Mississippi (Personal Communication, 30 June 1975, C. B. Crosby, Director, Gulf Coast Mosquito Control Comm., Gulfport).

Use of hydraulic dredging to control mosquitoes

16. Not all references to dredging activities have negative connotations for mosquito control specialists. In some cases, hydraulic dredging techniques have been used to control mosquito breeding by ditch and drainage methods and in other instances dredged material has been used to fill in mosquito breeding habitats.

17. Among the early references to the use of hydraulic dredging for mosquito control purposes is the report of Lenert and Legwen

(1945). Osmun (1945) reported on the use of a mobile dredge for similar purposes. Darsie et al. (1953) commented on the elimination of *Mansonia perturbans** habitat by hydraulic fill operations along the C & D Canal in Delaware. Blaney (1955) and Minnich (1958) described the use of hydraulic dredging techniques to construct mosquito control ditches in California and Florida, respectively. Control of *Anopheles* mosquitoes (the vector species of Malaria) by hydraulic fill along the Panama Canal is mentioned in the larval control handbook of the World Health Organization (1973).

Nonmosquito problems
associated with the
disposal of dredged material

18. A few scattered references appear in the literature that relate nonmosquito arthropod problems within dredged material disposal sites. Altman et al. (1970a) and Altman et al. (1970b) noted the potential of dredged material disposal areas to breed biting midges of the genus *Culicoides* in the vicinity of the Panama Canal. Harrison & Chisolm (1974) noted that "flies" were sometimes associated with disposal sites, but they did not identify the species in question.

Environmental Impact Statements

19. The now common requirement of an environmental impact statement (EIS) prior to the onset of a new governmental or private project involving ecological changes seems to have been bypassed in the general area of mosquito control. Few references to mosquitoes specifically and the arthropoda in general could be located among a sample of 15 EIS's involving the disposal of dredged material. One impact statement (U. S. Army Engineer District, Charleston 1976c) noted the presence of the salt marsh mosquito, *A. sollicitans*, as an

*Now *Coquillettidia (=Mansonia) perturbans* adverse environmental effect of land dredged material sites. This statement further noted that the District would contribute towards the costs of controlling the mosquitoes if the problem developed into a serious public health problem. In another impact statement (U. S. Army Engineer District, Charleston (1976b), the observation was made that mosquito breeding within a proposed disposal area was expected to be minimal because the material to be removed from the channel consisted of sandy soil.

20. With these exceptions and possibly a few others, mosquitoes are not routinely cited as being an environmental factor in most impact statements. For example, no mention of mosquito breeding problems was cited in U. S. Army Engineer District, New Orleans (1974); U. S. Army Engineer District, Savannah (1975); U. S. Army Engineer District, Charleston (1975); U. S. Army Engineer District, Galveston (1975); U. S. Army Engineer District, Philadelphia (1975); and U. S. Army Engineer District, Charleston (1976a). Literature previously cited in paragraphs 6 through 15 would appear to have established the presence of at least some mosquito problems associated with the disposal of dredged material in these areas. Perhaps one reason why mosquitoes are not frequently cited in impact statements may be related to the fact that mosquito breeding conditions do not develop until some months after a dredged material disposal site is constructed.

Disposal Area Ecology: General References

21. The following general references were found to be of broad application to almost any investigation associated with the ecology of dredged material disposal areas. A number of the reports are in the form of unpublished government reports, but the serious student of dredged material ecology will want to consult all of these broad reports relating to wetlands management, plant relationships, avian

species, invertebrate fauna, and engineering studies.

Wetlands management

22. In recent years a number of manuals have appeared that offer guidelines pertaining to the disposal of dredged material and/or wetlands management. Among these series are the works of the South Carolina Wildlife and Marine Resources Department (1972, 1974); Marcellus et al. (1973); Murphy and Zeigler (1974); Johnson and McGuinness (1975); the Coastal Zone Resources Corporation (1975, 1976); and U. S. Army Engineer District, San Francisco (1976). For general material on the basic ecology of salt marshes, the work of Teal (1962) will provide a good introduction. A chapter (E-4) by Copeland and Dickens (1974) on dredged material ecosystems is especially useful. This work is contained in a larger work edited by Odum et al. (1974) on the coastal ecosystems of the United States.

Plant relationships

23. Carlson (1972) reported on plant succession on undiked disposal areas in Florida. This study noted the importance of soil weathering and elevation to plant survival on dredge islands. The following year Beaman (1973) reported on more detailed studies of plant community structure on undiked dredge islands near Sarasota, Florida. Pioneer studies on the use of smooth cordgrass, *Spartina alterniflora*, as a revegetation material on dredged material have been conducted by Woodhouse et al. (1972), Cammen et al. (1974), and Cammen (1976).

Avian relationships

24. The use of dredged material disposal sites by various bird species has been extensively reviewed by Soots and Parnell (1974 and 1975). While neither of these papers were concerned with mosquito breeding problems, they do provide valuable insights into many of the management problems associated with the disposal of dredged material. Lewis and Dunstan (1974) suggested that dredge islands might be used to establish mangrove communities of avifauna in the vicinity of

Tampa, Florida. The importance of dredged material disposal sites as bird rookeries and their possible relationships to arthropod borne diseases was cited by Ezell (1976). This report also proposed a dredged material successional pattern based on soil characteristics. Buckley and Buckley (1976) developed a series of guidelines for the management of colonially nesting birds. A portion of this work considered management suggestions for dredged material disposal sites.

Invertebrate fauna

25. Invertebrate fauna are usually not considered in management handbooks or EIS's, and dredged material disposal sites have proven to be no exception to this rule. No significant studies of the invertebrate fauna of diked dredged material disposal areas were located during this study with the exception of Carlson (1972) and Cammem (1976). Stickney and Perlmutter (1975) concluded that hydraulic dredging had little long-lasting impact on benthic communities adjacent to the Atlantic Intracoastal Waterway (AIWW). A study of the fauna within dredged canals was done by Adkins and Bowman (1976).

Engineering studies

26. Two engineering studies appear to have particularly useful ecological applications that could function in concert with mosquito management techniques. Windom (1972) studied chemical responses of natural salt marsh to dredging activities. Windom concluded that salt marshes can recover from undiked dredged material deposition if the dredged material is not too deep and held to a low elevation. A second useful engineering study is the work of Murphy and Zeigler (1974). Some of the construction techniques proposed for disposal areas (see Part IX of this report) may prove to be useful in mosquito abatement.

General Mosquito References

General reviews and references

27. The literature of mosquito biology is extremely large and

voluminous. The serious worker in mosquito control will want to consult three recent review publications. Service (1976) has summarized many important papers concerned with mosquito ecology. The U. S. Fish and Wildlife Service (1976) has summarized a number of studies concerned with mosquito control practices and their effects on the environment. Many of the older mosquito studies are cited in Carpenter and LaCasse (1955). A state-of-the-art summary of some of the major problems in biting fly control has been presented by Hudson (1972). Provost (1976) summarized the current case for source reduction of mosquitoes associated with salt marshes and Cheng (1976) has recently reviewed the known biology of marine insects, including salt marsh mosquitoes.

Taxonomic works

28. Taxonomic works of both immature and adult forms useful for this study included the keys of Carpenter and LaCasse (1955), King et al. (1960), Stojanovich (1960, 1961), Silverly (1972), Gjullin and Eddy (1972), Floore et al. (1976), and Darsie (undated). A great variety of related mosquito taxonomic literature can also be located through the Mosquito Data Bank of the University of Notre Dame (MODABUND).

General field manuals

29. In recent years various states have developed a wide variety of field manuals to meet the needs of subprofessional personnel employed in remote locations. Most of these publications stress mosquito control and/or management techniques. Among the better manuals of this variety are the works of Pratt et al. (1972), Mulhern (1973), Gresbrink et al. (1974), and Axtell (1974).

Nature of the Mosquito Control Problem within Dredged Material Disposal Sites

Introduction

30. A summary of the more important factors affecting mosquito control within dredged material disposal areas is presented in

Figure 2. An aerial view of a typical dredged material disposal site is presented as Figure 3. An understanding of the relationships implied in this figure is necessary to understand the rationale for the recommendations developed in Part XII of this report. The figure is seen as four congruent circles which intersect near the center. Long-term effects are shown below the center line; shorter term effects are indicated above this line. The four circles represent the major mosquito control factors that must be considered before any plan of successful pest management program can be implemented. The term "integrated pest management" is frequently employed to express a pest management plan that considers:

> "...the population dynamics of the pest species, utilizes all suitable technology and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury...in the context of the associated environment...." (Glass 1975).

The achievement of this ideal is represented in Figure 2 by the shaded center portion.

Public policy and
political considerations

31. The policies and procedures of the government agencies that either affect or deal with environmental policy planning are considered in section A of Figure 2. Part III of this report is an analysis of some of these factors. Of first priority under this section is the need for a properly funded mosquito abatement program. Closely allied with this feature is the need for sound environmental policy planning on the part of the CE Districts. The general persuasion and educational level of the public in the immediate areas surrounding dredged material disposal sites is an important political consideration. In some areas of the United States, the demand for mosquito control is high. In other sections, the requests for such services are solely limited to public health considerations. It also must be recognized that in some areas environmental restrictions

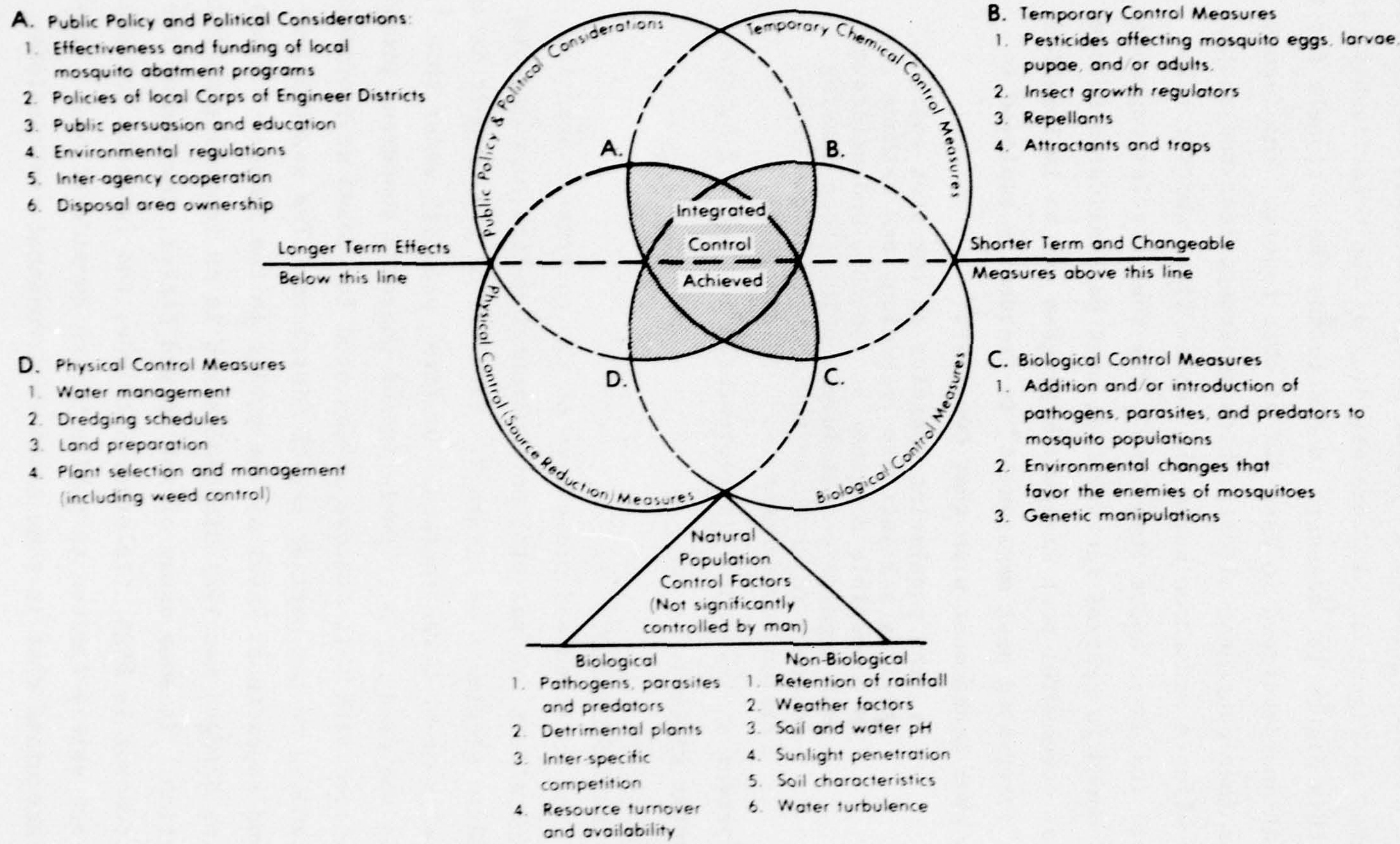


Figure 2

Summary of Mosquito Control Factors Affecting Dredged Material Disposal Sites

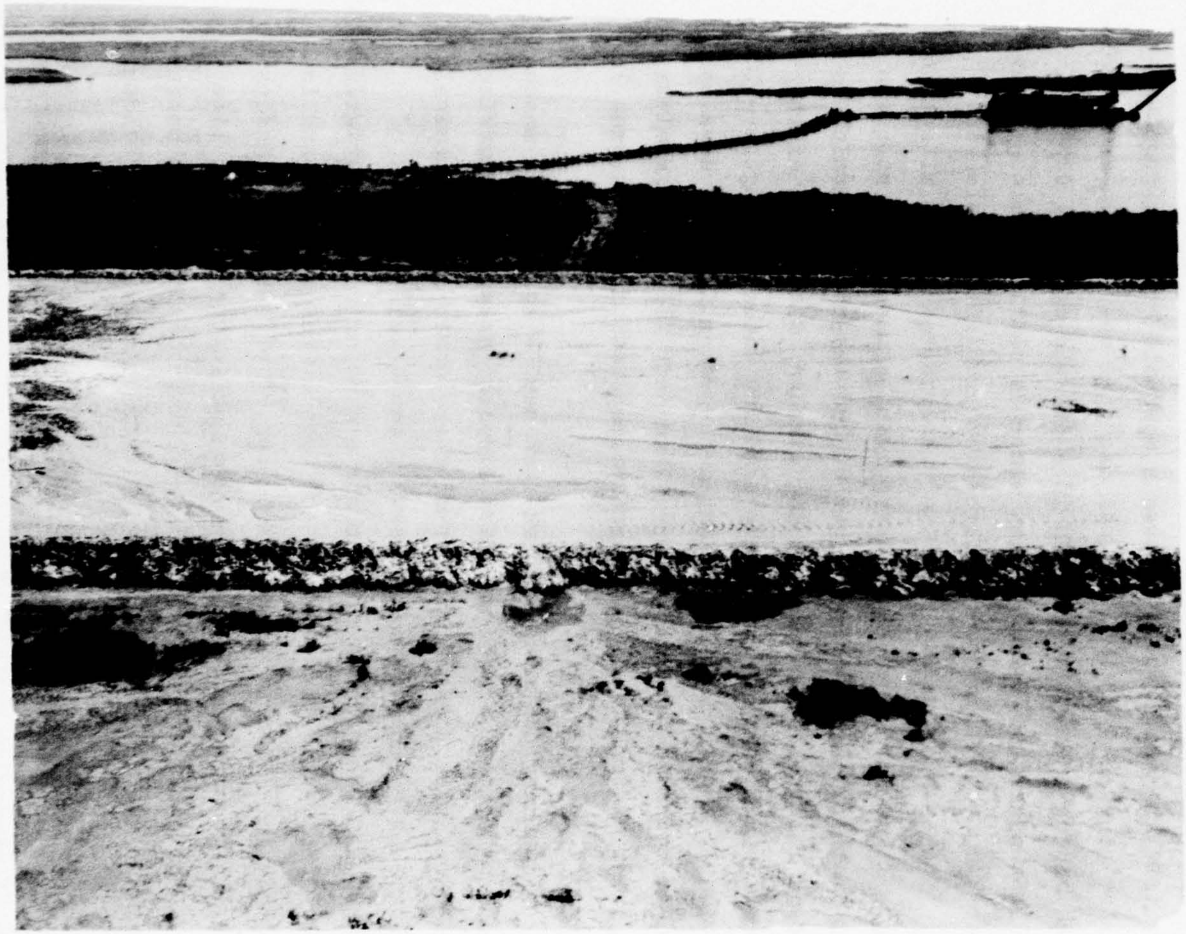


Figure 3

Typical Dredged Material Disposal Operation in Louisiana
(courtesy of the New Orleans CE District)

have often been devised with little or no concern for the reduction of breeding populations of mosquitoes. In some Districts, the ownership of a disposal site may be in question or the owner of a disposal site may initiate measures that cause a mosquito breeding problem that may be unrelated to the original dredging operation. For example, if a sand mining operation is begun in a dredged material disposal site and the operation leaves behind numerous shallow pools of stagnant water, a freshwater mosquito breeding problem will probably develop. Such a problem may be falsely attributed to the effects of dredging. It is important to differentiate between those mosquito problems that are due to dredging per se and those that develop as a result of later modifications of the disposal site. All of the above-mentioned factors point to the need for close interagency cooperation if a practical pest management system is to be developed for dredged material disposal sites. (See Part III for an analysis of the potential for future interagency cooperation in this area.)

Temporary control measures

32. Temporary control measures that may be applied for mosquitoes breeding within dredged material disposal areas are summarized in the B section of Figure 2. Most of these measures are chemical pesticides that effect the eggs, larvae, pupae and/or adults of mosquitoes. At the present time, there are no effective pesticides (ovicides) that are active against the eggs of mosquitoes found in dredged material disposal areas. A number of effective pesticides are available for the remaining three stages in the mosquito life cycle. Repellants provide personal protection against adult mosquitoes, but must be frequently applied directly to the skin or clothing of each individual.

33. Insect growth regulators (IGR's) are a new development in the area of temporary control of mosquitoes. Many of the growth regulators are "mimics" of natural hormone-like compounds that naturally occur in mosquitoes. Many of these compounds are absorbed

in the larval stage of the life cycle, but are only effective in the pupal stage. Part VIII of this report is concerned with the results of several field trials of IGR's against mosquitoes developing within dredged material disposal areas. A new technique for application of insect growth regulators is the "controlled release" (CR) formulation. This method involves encapsulation of the control agent which is activated and released into the habitat of the mosquito only after the habitat has been flooded. At the present time, there are no effective traps or attractants that appear to hold promise for controlling mosquitoes within disposal areas.

Reservations
concerning chemical control

34. It must be emphasized that all present chemical control measures applied against mosquitoes within disposal areas are of a temporary and short-lived nature. For this reason, sections A and B of Figure 2 are shown above the center line. All chemical pesticides work primarily against living stages of mosquitoes, but do not prevent mosquitoes from developing in the same location in the future. A second reservation about mosquito abatement programs that rely solely on chemical control is related to the phenomenon of insect resistance to chemical pesticides. It is generally recognized that the application of modern chemical pesticides against any given arthropod population will tend to place selective pressure on that population in favor of the development of resistance to the pesticide. In some cases, the over zealous use of organic chemical pesticides has resulted in high resistance to a variety of compounds. In some cases, the development of resistance to one compound may be accompanied by a concurrent resistance to a chemically related compound. The serious nature of the resistance phenomenon has been studied by Brown (1968). This paper noted that 97 species of insects and acarines of public health importance are now resistant to one or more chemical pesticides. Some entomologists believe that control of

mosquito larvae with pesticides is more likely to cause resistance than materials used to control adults. Because of the large larval populations that frequently occur with disposal areas and the inability to spread pesticides evenly over large areas this reservation would appear to have some validity concerning mosquito abatement practices used in disposal areas.

Biological control measures

35. Two circles are shown below the center line in Figure 2. Both of these components represent longer term abatement practices that might be applied against mosquitoes that breed within disposal sites. Section C (biological control measures) is concerned with those biological and/or organismic factors that might be introduced into a disposal area to control mosquito problems. Part VII of this report is concerned with the current state of the art of biological control measures that might be applied within dredged material disposal sites. Part IX of this report is a list of some engineering practices that might favor the introduction of mosquito enemies into disposal areas. Genetic manipulations represent an area of active investigation at this time. In the near future, some of these practices may be available for mosquito abatement.

Physical control measures

36. Section D of Figure 2 is concerned with physical control of mosquitoes. Common physical measures that are frequently employed against mosquitoes include water management, land preparation (including the use of drainage ditches, tillage, and dikes), and weed control. Dredging schedules have been added as a fourth factor to section D. This factor would apply only to mosquito control within dredged material disposal areas. Physical control measures are often termed source reduction in many mosquito abatement references. These measures require longer periods of time for implementation in a given area (hence they are shown below the center line of Figure 2), but the effects are often of greater benefit because the cause of the

mosquito breeding has been eliminated or reduced. For an excellent review of the philosophy of source reduction, see a recent paper by Provost (1976).

Natural population control factors

37. Natural population control factors are shown in Figure 2 as being balanced against the mosquito control measures that man seeks to apply within dredged material disposal areas. These baseline biological and nonbiological factors are those over which man has little or no control. Any plan of integrated pest management, however, must take these factors into account. Of the nonbiological factors listed in this section, probably the retention of rainfall and the dredged material characteristics are the most important ones. See Parts IV, VI, and IX for a further discussion on these two nonbiological factors. Of the biological factors listed in this section, little information is available and these factors will require intensive research in the future.

Summary of the disposal area mosquito problem

38. Mosquito breeding problems associated with dredged material disposal sites are a relatively recent phenomenon. The problem is still not generally recognized in many parts of the United States. Mosquitoes that result from disposal sites affect man in two ways. They may function as vectors of many diseases and as nuisance organisms that render many coastal areas unusable during "mosquito seasons." Figure 2 has reviewed the major factors that must be balanced against natural factors if an integrated pest management plan for mosquitoes is to be successfully implemented for the many disposal sites in the United States that produce mosquitoes. Future research and management plans will alter the proportions that the four factors (circles) play in mosquito control practices. For example, in some parts of the United States, physical control measures may be more effective for mosquito reduction than in another region. Perhaps

most important is component A (policy considerations). Unless an attitude of mutual respect and trust can be developed between the various agencies that affect environmental policy planning relating to the disposal and effects of dredged material, mosquitoes will continue to be a problem in many areas adjacent to disposal sites. Finally, it is usually the failure to recognize that more than one environmental factor is always involved in any mosquito control problem that causes a mosquito abatement effort to fail.

Outline of this Study

Locations of specific disposal sites

39. In the sections of this report that follow, the reader will be referred to various dredged material disposal sites that are located within the Charleston District of the U. S. Army Corps of Engineers. Many of these disposal areas were assigned numbers which refer to their location to Charleston, S. C., or another nearby city. Figure 4 illustrates the major dredged material disposal sites presently found in Charleston Harbor. Figure 5 illustrates the major disposal areas located along the Atlantic Intracoastal Waterway (AIWW) in the Charleston District. For the exact locations of the various numbered study areas referred to hereafter, the reader will need to refer to Figures 4 and 5.

Study outline

40. This study is divided into 12 parts. Sections III through VI are concerned with political, environmental, and biological conditions that surround the dredged material mosquito habitat. Sections VII, VIII and IX are concerned with the control of mosquitoes that develop within dredged material disposal areas. Sections X and XI are concerned with the flora and avifauna that utilize disposal sites concurrently with mosquito populations. Part XII lists the recommendations of the study group.

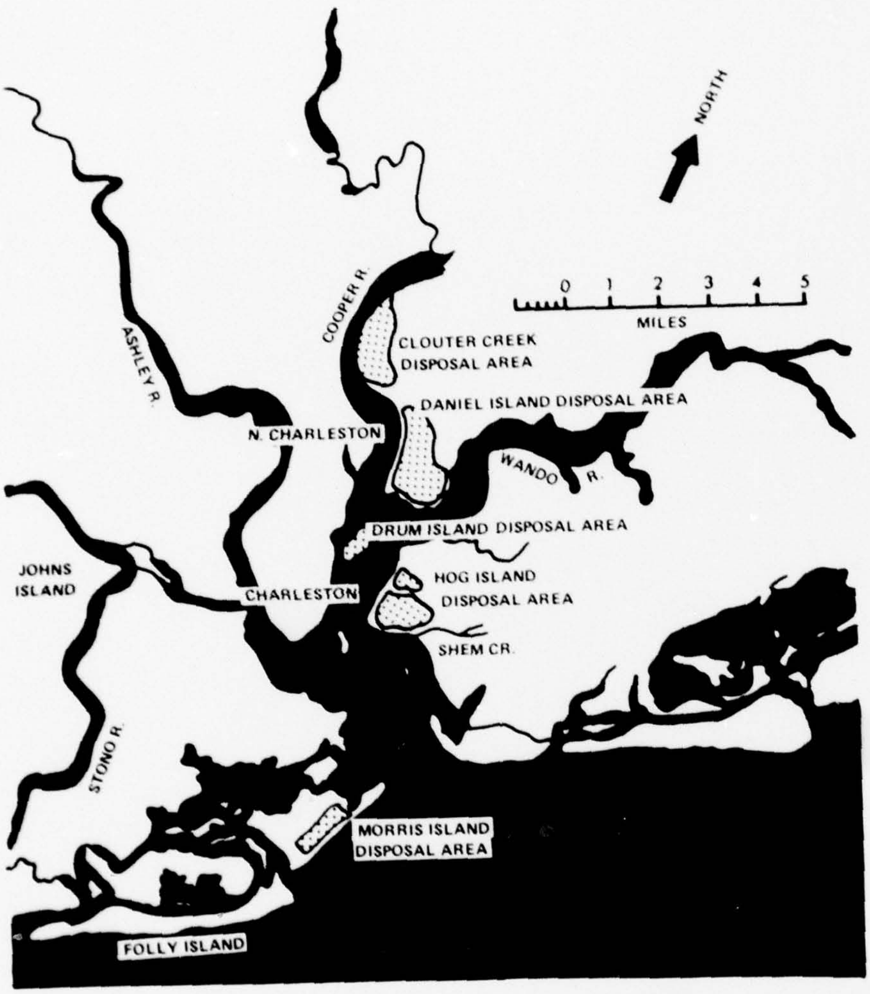
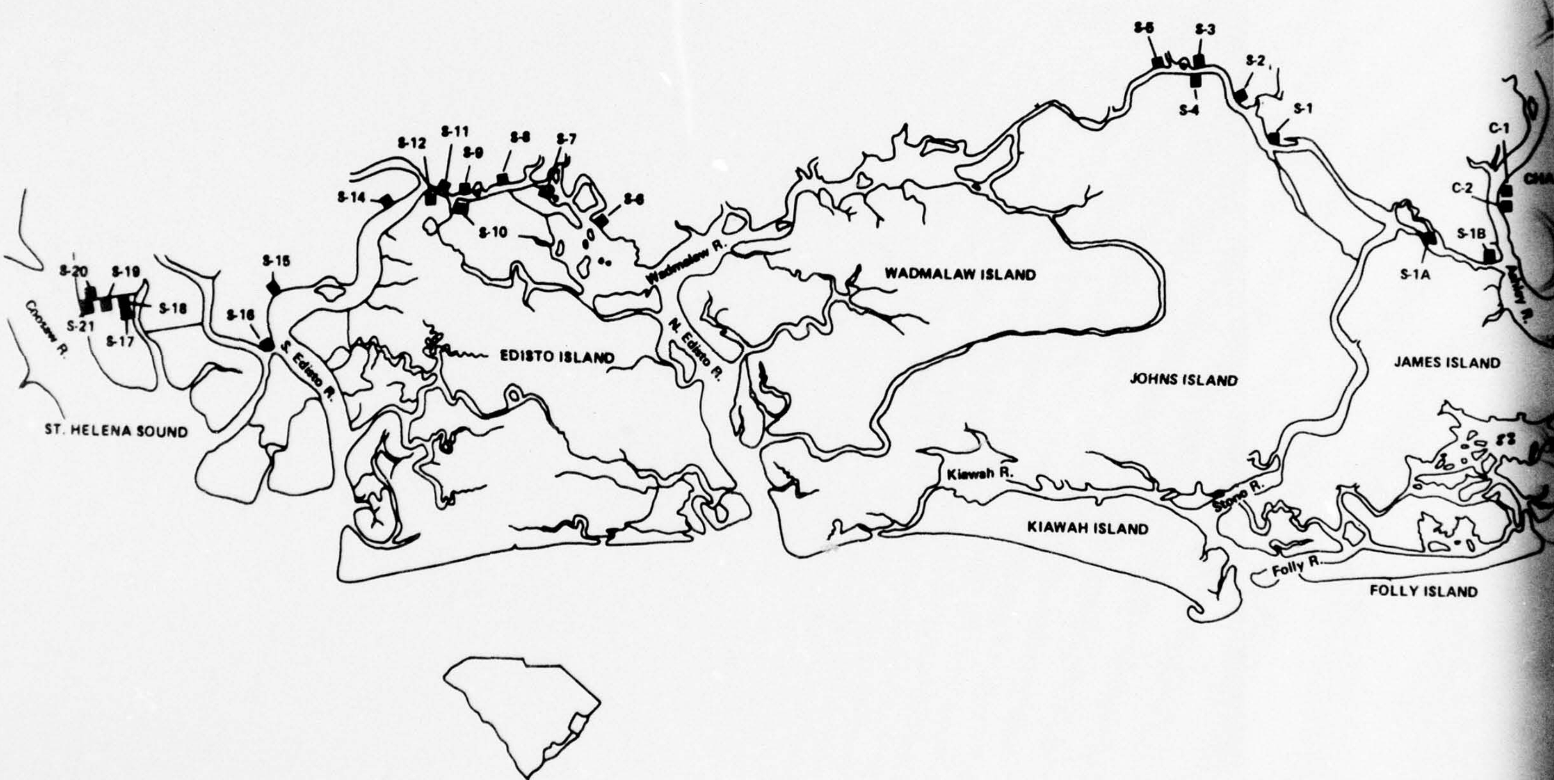


Figure 4

Major Dredged Material Disposal Sites in Charleston Harbor, South Carolina (after Forsythe, 1974)


S-5
S-3
S-2
S-4
S-1
C-1
C-2
S-1A
S-1B
S-12
S-11
S-9
S-8
S-7
S-14
S-6
S-10
S-15
S-20
S-19
S-18
S-21
S-17
S-16
Coosaw R.
Wadmalaw R.
WADMALAW ISLAND
EDISTO ISLAND
S. Edisto R.
N. Edisto R.
JOHNS ISLAND
JAMES ISLAND
Ashley R.
ST. HELENA SOUND
Kiawah R.
Stono R.
KIAWAH ISLAND
Folly R.
FOLLY ISLAND

Maj
Atla

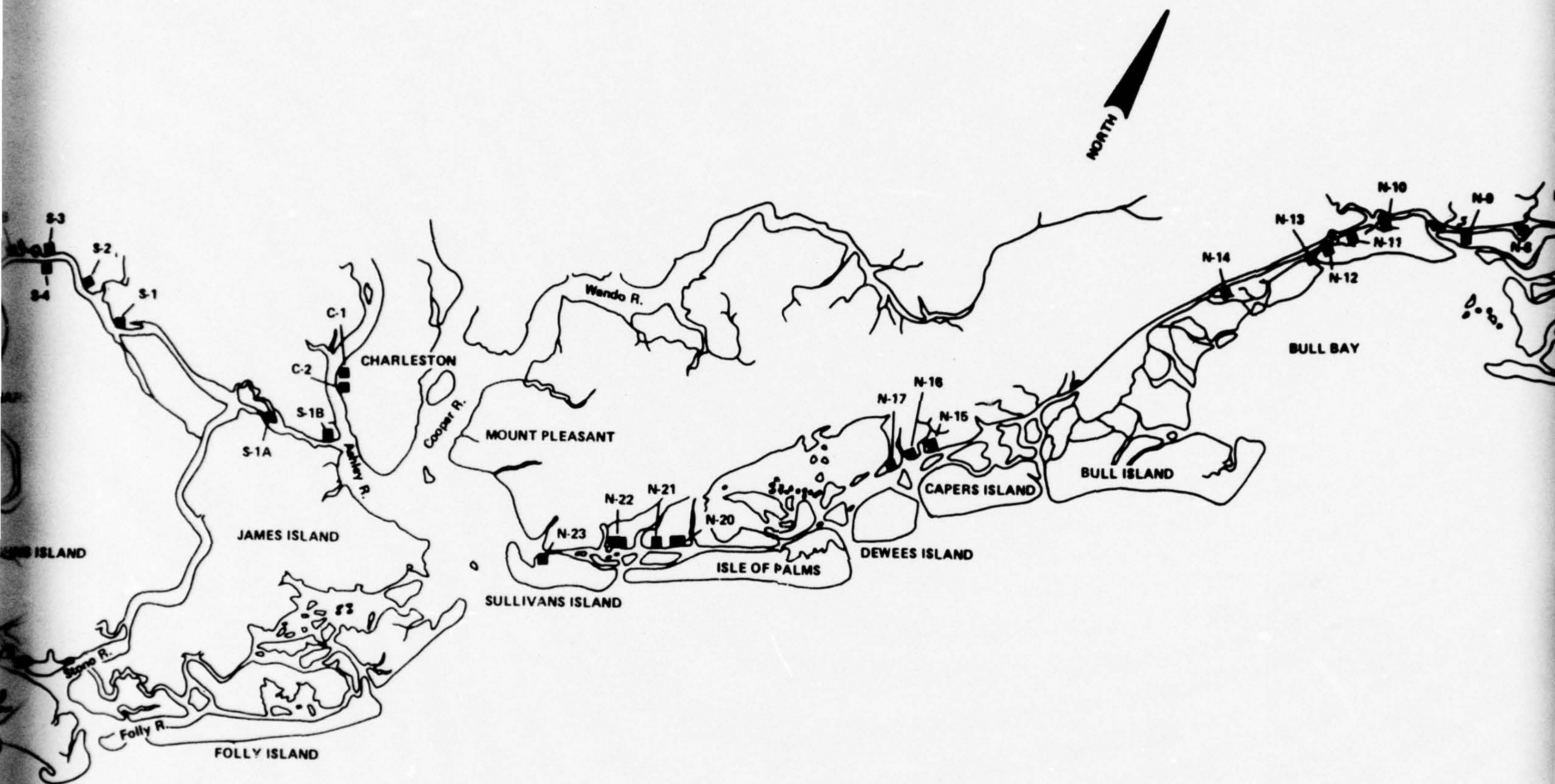
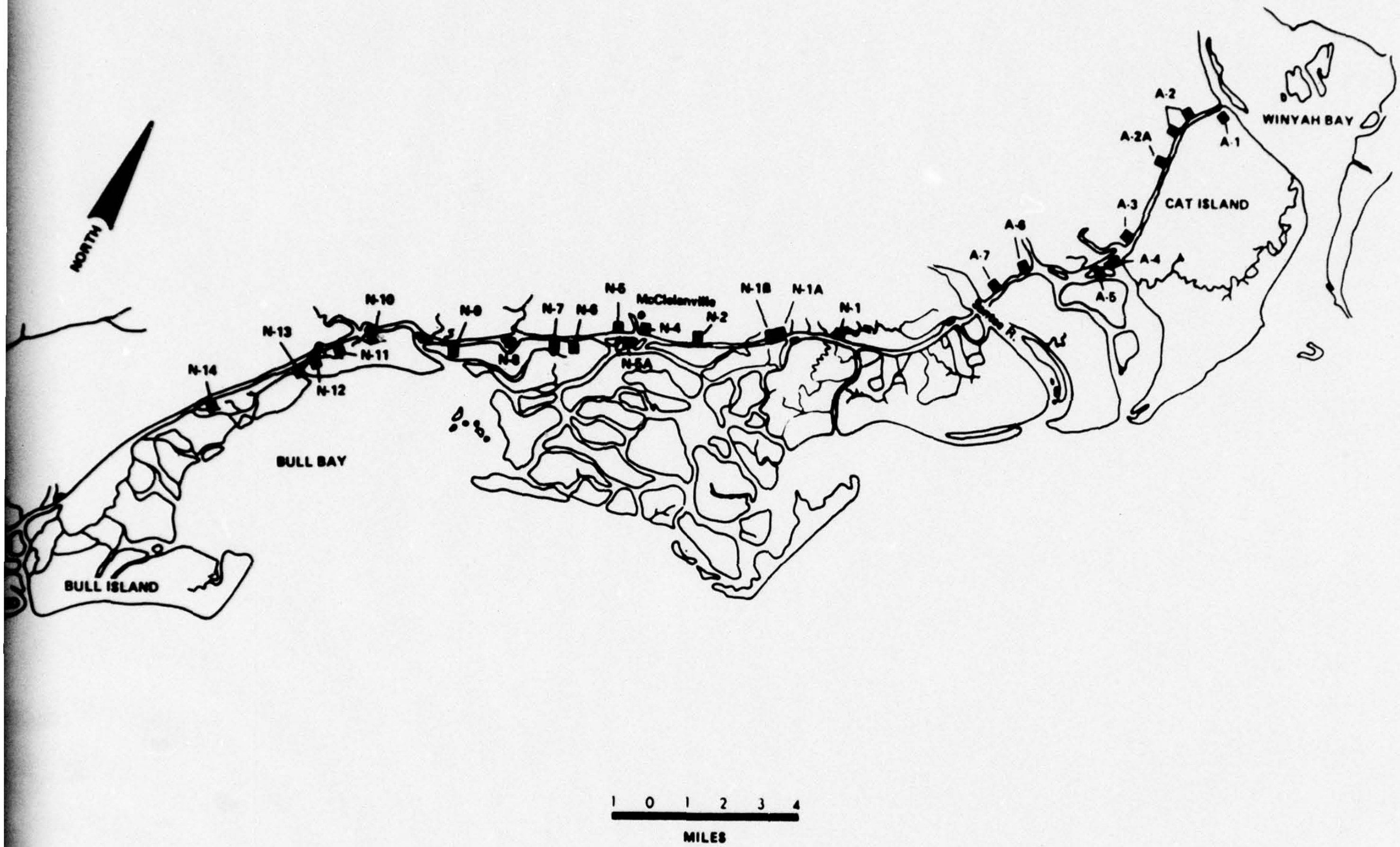


Figure 5

Major Dredged Material Disposal Sites along the Atlantic Intracoastal Waterway, St. Helena Sound to Winyah Bay, South Carolina

2


NORTH
A-2
A-2A
A-1
WINYAH BAY
A-3
CAT ISLAND
A-6
A-7
A-4
A-5
N-5
McClellanville
N-1B
N-1A
N-1
N-2
N-4
N-10
N-9
N-7
N-6
N-13
N-11
N-8
N-5A
N-14
N-12
BULL BAY
BULL ISLAND
1 0 1 2 3 4
MILES

3

PART III: SUMMARY OF STUDY OF INTERAGENCY PERSPECTIVES ON MOSQUITO CONDITIONS AND CONTROL IN CONFINED DREDGED MATERIAL DISPOSAL SITES

Introduction

41. At the outset of this study, it was decided that a detailed survey and analysis was needed of the three administrative levels of government that routinely affect mosquito control practices within dredged material disposal areas. In the past, many government agencies concerned with environmental policy planning associated with disposal sites simply planned their respective activities without regard for consultation with one another. In short, the past record of mosquito management within dredged material disposal areas was one of mutually exclusive activities among many government agencies.

42. Rising costs, environmental concerns, and many other factors, however, have recently forced many government agencies into positions of conflict or cooperation regarding the management of disposal sites. In view of these political realities, it was decided to include within the general research design of this project a section of limited policy analysis regarding certain aspects of mosquito control programs within confined dredged material disposal sites in selected CE Districts. These efforts were focused mainly on management practices and limits of responsibility as opposed to environmental policy formation and/or impact. It was the desire of the research team to study how officials in different government agencies (operating at different levels within the government) perceived both themselves and each other with regard to mosquito control problems within dredged material disposal sites. Prior to this report, no attitudinal studies on the nature of mosquito control problems could be located in the literature. For these reasons,

some attention to the attitudes involved in disposal area planning was believed to be justified.

Methods and Materials

43. A detailed outline of the materials and methods involved in the construction and analysis of the data gathered from this survey is presented as Appendix A. In summary, three questionnaires were constructed to study the attitudes, interactions and opinions of three levels of government. The agencies were:

- a. Selected CE Districts.
- b. Selected State vector control agencies.
- c. Selected local mosquito abatement districts.

The responses to these questionnaires from the three groups were then studied for:

- a. Their perceptions of the nature and extent of any mosquito control problems within a dredged material disposal site.
- b. Their perceptions of agency responsibility regarding a potential mosquito control problem associated with the disposal of dredged material.
- c. The perceptions of the degree of interagency cooperation needed or desired to alleviate the problems associated with mosquitoes breeding within disposal areas.

The results from the returned questionnaires were studied and analyzed by several techniques that are fully discussed in Appendix A.

Results and Discussion

44. The overall return rate for all questionnaires from all groups was 85 percent. This excellent return rate made it possible to analyze the data in two ways: as a national composite with all responses compared and by region (in order that regional differences

might be ascertained). The national survey data are presented with text in Appendix A; while the regional survey data are presented as Appendix B.

45. A detailed analysis of the results of this section of the study are presented in Appendix A. In summary, the data indicated that the three levels of government agencies had different perceptions of the nature and extent of mosquito control problems within dredged material disposal sites. One of the most significant differences was the perceptions of the present and future responsibility among the three groups for mosquito control efforts. Many of the respondents to the questionnaire felt that the Corps of Engineers should give voluntary aid to mosquito control programs that had documented breeding problems associated with the disposal of dredged material.

46. The data revealed very clear differences of opinion as to the current levels of communications among the agencies surveyed and future needs for interagency cooperation. The sharpest differences of opinion were detected for those questions that related to the need for increased mosquito control within diked dredged material disposal areas. A detailed discussion of the analysis of these data by national and regional groupings is presented in Appendix A. In conclusion, the survey data indicated that some mosquito control problems associated with the disposal of dredged material are political in nature and therefore cannot be solved by biological or engineering means alone. Another major consideration that can be detected from this section of the study is that more effective mosquito control measures within dredged material disposal sites will never be implemented until a reasonable degree of interagency cooperation at federal, state, and local levels is achieved.

PART IV: ARTHROPOD SUCCESSIONAL PATTERNS WITHIN DREDGED MATERIAL DISPOSAL SITES

Chemical Characterization of Dredged Material Associated Mosquito Breeding Locations

Introduction and rationale

47. The basic properties of soil and water chemistry will obviously influence the various plant and animal communities that develop on any habitat over a given period of time. This is especially true of dredged material disposal areas. As discussed in the later section on plant succession, disposal sites represent a man-made ecosystem in which the major physical force affecting successional patterns is that of the dredged material per se. The chemical nature of this material, its physical properties, salinity, pH, and oxidation-reduction potential, will influence both macrohabitats and microhabitats from the onset of the dredging operation until the soil reaches a stable climax condition. The purpose of this section of the report was to consider the chemical properties of dredged material associated with mosquito breeding and other arthropod emergence. The investigators wished to characterize those chemical factors that might be found associated with soil in which mosquitoes either laid their eggs or otherwise developed.

Literature review

48. General literature on soils and soils testing is abundant (e.g. Jackson 1958), but little information has appeared to date in the literature on the relationship of dredged material to mosquito oviposition and/or subsequent development. Knight and Baker (1962) considered the role of substrate moisture content of oviposition of certain salt marsh mosquitoes. These workers concluded that under laboratory conditions substrate moisture conditions of less than 45 percent were unattractive for egg laying activities by either *Aedes*

sollicitans or *A. taeniorhynchus* (both species of mosquitoes are common residents of dredged material disposal sites in many parts of the United States). Knight and Baker further concluded that maximum attractiveness occurred at approximately 65 percent. These studies were not duplicated under field conditions, but the authors concluded that the two species would probably oviposit on those marsh soils with similar moisture contents.

49. Cotnoir (1974) has cautioned that many standard soil tests were developed for soils other than marsh soils and therefore many procedures must be modified for the student of marsh soil chemistry. Jeane and Pine (1975) studied the environmental effects of dredging in Washington state. Studies for the DMRP on the chemical nature of dredged material include the works of Basco et al. (1974), Moore and Newbry (1976), and Blom et al. (1976).

Materials and methods

50. Study areas. The following study areas (see Figures 4 and 5) were selected for soil sampling:

a. South Drum Island, Figure 4.

b. North Drum Island, Figure 4.

c. Site N-20, Figure 5, Pt. B.

d. Site N-21, Figure 5, Pt. B.

Both Drum Island sites are estuarine in location and are located in Charleston Harbor, while N-20 and N-21 are located along the Atlantic Intra-Coastal Waterway (AIWW) near the towns of Sullivans Island and Isle of Palms, S. C., respectively. The sites were chosen because of their location, time of previous pumpings, age, and the fact that all had a history of producing mosquitoes. Two sites were selected from Drum Island (Figure 4). The northern area contained a 125-acre*

*A table of factors for converting U. S. customary units of measurements to metric (SI) can be found on page 13.

disposal site and was an active mosquito source during the study period. The southern end of Drum Island constituted a much older disposal site of approximately 50 acres. This area was considered as a climax site (see Part X for a discussion on this stage) and did not breed large numbers of mosquitoes during the study period. Sites N-20 and N-21 (Figure 5) were located on the west bank of the AIWW. Site N-20 had last received dredged material 5 to 6 years ago, while site N-21 had received fresh dredged material during a recent pumping operation.

51. Sample selection and location. The sample sites were selected on the following criteria:

a. The sample site was at least 50 ft. from any surface water.

b. The sample site was not located within any vegetative zones.

c. The sample site was at least 10 ft. from the retaining dike.

Five to six samples were taken from each site. Soil samples were taken to a depth of 18 in. with a 2-in.-diam core sampler approximately 24 in. long. Plastic liners were used with the core tool to facilitate field transfer of the samples. All samples were numbered in the field and field notes were taken on the nature of the sample site. All core samples were stored in an upright position for transportation back to the laboratory.

52. Sample processing. Samples for analysis were cut from the cores at the depths of 0 to 2 in. and 5 to 7 in. All soil samples were analyzed within 24 hrs. after returning to the laboratory. The samples were then dried at 200° Celcius under a 30-in. vacuum until the vacuum remained constant for 1 hr. The samples were then kept under vacuum until they cooled to ambient temperatures. The samples were finally processed by pulverization and separation until they passed through a 2-mm standard sieve.

53. Chemical tests. Soil conductivity data and percentage

composition analyses were determined by standard agricultural techniques. (Personal Communication, N. Page, 4 February 1976, Clemson University, Clemson, S. C.). Conductivity was measured with a Hach conductivity meter (Model 25.1) using a probe that contained two temperature compensated tungsten electrodes. The data were recorded as micromhos per centimeter and the cell constant was 2.0. Soil pH values were determined by processes outlined by the United States Department of Agriculture (1967) using a Leeds-Northrup pH meter with ranges from 0 to 14. The meter was assumed to be correct within ± 0.1 pH units and temperature compensation was manually corrected. A 7.0 pH combination probe was used with this meter. During the tests the meter was buffered with a 5.00 and 7.00 pH buffer or a 7.00 and 10.00 pH buffer depending on the soil ranges.

54. Oxidation-reduction potentials. Oxidation-reduction potentials were analyzed with an Orion ion analyzer using a platinum and calomel electrode. All readings were in absolute millivolts. The oxidation-reduction potentials provided a relative reference as to the state of electrical variation from site to site due to the oxidation or reduction of soil ions and compounds. These measurements were made directly on the sample cores by using specially constructed core inserts. The sleeve or core insert was drilled with small holes at the depth of 1 in. and the oxidation-reduction potentials were recorded when the meter became stable (normally 3 to 5 min.).

Results and discussion

55. The soil data collected from these tests on S. Drum Island, N. Drum Island, site N-20, and site N-21 are presented as Tables 1-4, respectively. Based on the observations presented in Part IV, it was determined that North Drum and site N-21 disposal areas represented very early successional stages, while the South Drum site was found to be representative of an older (climax) sere (See also Part X). Site N-20 was considered an intermediate location.

Table 1

Summary of Physiochemical Factors Affecting Dredged Material Habitats on S. Drum Island Disposal Area, Charleston Harbor, South Carolina, 1976

Sample No.*	pH	Conductivity Micromhos/cm	Redox Potential	Percentage of Sand	Silt	Clay
1s	6.85	2000	NM**	07.20	49.24	43.56
2s	6.70	7400	+145	09.35	43.09	47.56
3s	6.60	6500	NM	02.20	42.24	55.56
4s	6.90	3700	NM	26.40	50.04	23.56
5s	6.75	5300	+190	06.30	52.14	41.56
Avg	6.76	4980	+168	10.29	47.35	42.36
1ss	6.65	4500	NM	12.90	47.54	39.56
2ss	6.80	4200	+145	11.75	52.69	35.56
3ss	6.50	5000	NM	21.75	42.69	35.56
4ss	6.60	5200	NM	19.90	36.54	43.56
5ss	6.60	9500	+190	39.50	40.94	19.56
Avg	6.63	5680	+168	21.16	44.08	34.76

*s = surface sample, ss = subsurface sample.

**NM = nonmeasurable.

Table 2

Summary of Physiochemical Factors Affecting Dredged Material Habitats on N. Drum Island Disposal Area, Charleston Harbor, South Carolina, 1976

Sample No.*	pH	Conductivity Micromhos/cm	Redox Potential	Percentage of Sand	Percentage of Silt	Percentage of Clay
1s	6.80	20,000	-70	10.20	46.24	43.56
2s	6.75	33,000	-60	15.70	40.74	43.56
3s	6.85	12,000	-65	13.80	42.64	43.56
4s	7.00	18,000	-70	15.80	44.64	39.56
5s**	7.85	3,200	-10	46.60	33.84	19.56
Avg	6.85	20,750	-66	13.88	43.56	42.56
1ss	6.95	10,000	-180	14.50	45.94	39.56
2ss	7.30	24,000	-200	11.20	57.24	31.56
3ss	7.30	16,000	-210	02.60	53.84	43.56
4ss	7.30	17,000	-230	05.90	42.54	51.56
5ss**	8.00	3,000	+70	84.80	13.60	01.60
Avg	7.21	16,750	-205	8.55	49.89	41.56

*s = surface sample, ss = subsurface sample.

**s = Not in avg.

Table 3

Summary of Physiochemical Factors Affecting Dredged Material Habitats on Disposal Area N-20, Atlantic Intracoastal Waterway, Isle of Palms, South Carolina, 1976

Sample No.*	pH	Conductivity Micromhos/cm	Redox Potential	Percentage of Sand	Percentage of Silt	Percentage of Clay
1s	6.40	60,000	+80	29.30	27.14	43.56
2s	6.60	60,000	+60	34.30	26.14	39.56
3s	6.80	55,000	+70	16.90	32.34	50.76
4s	6.70	42,500	+70	36.10	24.34	39.56
5s	6.50	35,000	+50	26.70	25.74	47.56
6s	6.75	25,000	+75	58.10	18.34	23.56
Avg	6.63	46,250	+68	33.57	25.67	40.76
1ss	6.35	37,000	+100	24.70	29.74	45.56
2ss	6.45	25,000	+100	51.30	17.14	31.56
3ss	6.30	52,000	+130	29.20	27.24	43.56
4ss	6.35	57,000	+110	48.90	19.54	31.56
5ss	6.55	26,000	+120	25.70	30.74	43.56
6ss	6.70	24,000	+140	34.60	25.84	39.56
Avg	6.45	36,833	+117	35.73	25.04	39.23

*s = surface sample, ss = subsurface sample.

Table 4

Summary of Physiochemical Factors Affecting Dredged Material Habitats on Disposal Area N-21, Atlantic Intracoastal Waterway, Isle of Palms, South Carolina, 1976

Sample No.*	pH	Conductivity Micromhos/cm	Redox Potential	Percentage of Sand	Silt	Clay
1s	9.60	48,000	-50	51.00	25.44	23.56
2s	9.40	33,000	-65	81.40	07.04	11.56
3s	9.50	30,000	-60	59.70	28.74	11.56
4s	9.10	21,000	-80	44.10	32.34	23.56
5s	9.10	26,000	-70	20.00	48.44	31.56
Avg	9.34	31,600	-65	51.24	28.40	20.36
1ss	9.40	26,000	-165	73.70	10.74	15.56
2ss	9.10	31,000	-150	20.20	44.24	35.56
3ss	9.50	58,000	-130	29.20	31.24	39.56
4ss	9.00	22,000	-170	31.40	29.04	39.56
5ss	9.30	39,000	-160	51.80	20.64	27.56
Avg	9.26	35,200	-155	41.26	27.18	31.56

*s = surface sample, ss = subsurface sample.

56. South Drum site. As the oldest of the four sites, South Drum represented a chemical condition that might characterize the soils of older disposal sites after the height of their mosquito productivity. The average conductivity for the surface samples (Table 27) was 5000 micromhos per centimeter, while the subsurface fraction was determined to have an average of 5680 micromhos per centimeter. Since South Drum was the oldest disposal area available in the study area it can be assumed that leaching was minimal. Some individual measurements may be contradictory due to past surface distortions that may have allowed for the concentration of some compounds. The concentration of salts in small swales, for example, may mask the effect of sail leaching in some cases. The average surface pH moiety was 6.76, while the subsurface average was recorded at 6.63. In almost all cases it was observed that silt and clay were the major soil constituents of the dredged material from this site. Oxidation-reduction potentials give a relative indication of the chemical state of dredged material. As a general rule, older dredged material had a more positive potential. The South Drum samples indicated averages of +168 mv for both surface and subsurface samples. These figures represent readings that may not be fully representative due to the low soil moisture conditions present at the times the samples were collected.

57. North Drum site. Data collected from this relatively newer site (Table 28) (dredged material was approximately 1 year old) indicated average pH values of 6.85 and 7.21, respectively. Sample 5 (both surface and subsurface) was not used in computing averages because it appeared to be an aberrant sample when percentage composition data were considered. A check of the marked field site from which this sample was taken indicated that the site was atypical because it came from a sandy swale. Conductivity readings ranged from 16,750 to 20,750 micromhos per centimeter, for the subsurface and surface samples, respectively. Oxidation-reduction potentials

ranged from -66 to -205 mv in the subsurface and surface samples, respectively. With the exception of sample 5, silt and clay again were the predominant soil constituents.

58. Site N-20. The N-20 site was an intermediate aged disposal area that produced mosquitoes, but during the present study it was considered a marginal mosquito habitat. Dredged material at this site was approximately five to six years old. Mildly acid soils were found to average 6.63 and 6.45 pH units for the surface and subsurface samples. Surface conductivity averaged 46,250 micromhos per centimeter, while subsurface samples averaged 36,833 micromhos per centimeter. The average oxidation-reduction potentials had an average range from +68 to +117 mv for the surface and subsurface samples respectively. Field notes indicated that this site weathered faster than others observed during the study period. When the percentage composition of the soil samples was studied, it was noted that site N-20 contained a higher percentage of sand than was present in the two previous sites. This higher sand percentage may have been the key factor in advancing the soil succession through weathering.

59. Site N-21. This site was in an early stage, having received fresh dredged material within the past 6 months. Soil pH ranges were the most alkaline of the entire test series, with averages of 9.26 and 9.34 for the subsurface and surface samples, respectively. Conductivities were high, ranging from 31,600 to 35,200 micromhos per centimeter for average values for the surface and subsurface samples, respectively. These values were expected since the site was reasonably fresh and salt leaching was minimal. The average for oxidation-reduction potentials were -65 to -155 mv for the surface and subsurface samples, respectively. Sand as a soil constituent remained at high levels, indicating that site N-21 might weather rapidly in the future.

60. Comparative observations. The chemical data observed in

this study have centered around sites that produced mosquito larvae in the past or were assumed (N-21) to be capable of producing larvae in the future. In general, it was felt that soil weathering is accompanied by a gradual rise in soil pH. The fresher sites studied (N-21 and N. Drum) were more alkaline. The fresh dredged material along the AIWW (N-21) was especially alkaline. All of the pH values obtained were well within the values normally associated with developing mosquito larvae under field conditions. The slight pH change from alkaline to slight acid conditions was not considered significant as a limiting factor for developing mosquito larvae. The percentage composition of the dredged material may be a prime limiting factor in determining the time schedule for both plant and animal successional patterns. If the sand constituents are reasonably fine and well dispersed, it may be assumed that the soil weathering process (and also the mosquito production time span) may be reduced in direct proportions. As previously noted, site N-20 weathered faster than was considered normal and this may have been due to the high sand content of the dredged material. In the future, comparative composition studies may allow investigators to predict the length of mosquito productivity period of a given site by taking soil samples for percentage composition analysis. In general, the conductivity data indicated that the most saline conditions were encountered along the AIWW sites and were highest in those samples from newer sites.

61. Salt conditions were observed to affect both plant and mosquito successional patterns. A wide range of salinity conditions was thought to be one of the prime factors affecting the individual character of each disposal study area. Some sites with proper drainage were observed to lose their soil salts fairly rapidly, while other sites (N-20) that did not drain well tended to remain fairly saline even in an older state. Oxidation-reduction potentials confirmed the original hypothesis that as the dredged habitat ages the soil tends to move from a negative potential (i.e. reducing environ-

ment) to a positive potential (i.e. oxidizing environment).

Summary

62. The major chemical characteristics for this portion of this study are summarized in the following list:

- a. Soil samples were collected from four disposal areas that had produced mosquitoes in the recent past or were assumed to be capable of producing mosquitoes in the future.
- b. Tests to determine soil conductivity (salinity), pH, oxidation-reduction potential, and percentage composition were conducted.
- c. Soil chemistry changes were found to be correlated with observable field changes in both floral and faunal successional patterns.
- d. Soil conductivity (salinity) and percentage composition studies were deemed the most important factors studied during these tests.
- e. As the dredged material mosquito larval habitat ages (weathers), a slow and slight pH change from alkaline to mildly acid soil conditions was usually observed.
- f. As the dredged material ages (weathers), oxidation-reduction potentials change from negative to positive values. This indicates a change from a reducing to an oxidizing environment.
- g. An increase in both the amount and the dispersal of sand in the dredged material mosquito habitat can decrease the mosquito breeding potential of a given area.

Classification of Insect Habitats Based on Dredged Material Weathering Patterns

Rationale

63. As indicated in the previous discussion on physiochemical conditions, it was postulated at the outset of this study that both floral (see also Part X) and faunal (see also Part XI) changes would occur as a given dredged material disposal site began to change with the passage of time. It was further postulated that soil microhabitat changes could be associated with an arthropod successional sequence.

The purpose of this phase of the study was to characterize a hypothetical successional pattern based on dredged material characteristics.

Materials and methods

64. It was soon apparent that the weathering characteristics of dredged material would be the easiest parameter to observe under routine field conditions. Much of the data and classification system proposed under this section is the result of numerous field trips to a wide variety of dredged material disposal sites that were known to be of varying ages. During such trips, descriptions were made at each site as to obvious soil characteristics that might influence arthropod fauna. Among the disposal sites that were especially useful in formulating the classification system were AIWW sites S-1B, S-4, S-7, S-8, S-10, S-11, S-14, S-17, E-1, E-2, A-5, N-5, N-7, N-9, N-12, N-21, N-211, and N-23 (see Figure 5) and Charleston harbor sites including Drum Island, Morris Island, Clouter creek disposal area, and Hog Island (see Figure 4). Estimates of the approximate age of the various disposal areas were either known to the investigators or determined from the records of the Charleston District of the Corps of Engineers or the Charleston County Mosquito Abatement Program.

Results and discussion

65. Soil weathering patterns. As a direct result of many field observations of plant, avian, arthropod, and soil changes within various disposal sites, the following pattern of dredged material successional patterns is proposed. A total of eight successional stages or seres are proposed. Other stages may exist, but the investigators feel that the pattern proposed in this report has been shown to occur with regularity on a large number of dredged material disposal areas representing a wide variety of site sizes, types, geographical locations, and ages. The abbreviation DM (for dredged material) has been used to characterize the various seres.

66. DM-1 (supernatant liquid stage). As shown in Figure 6,

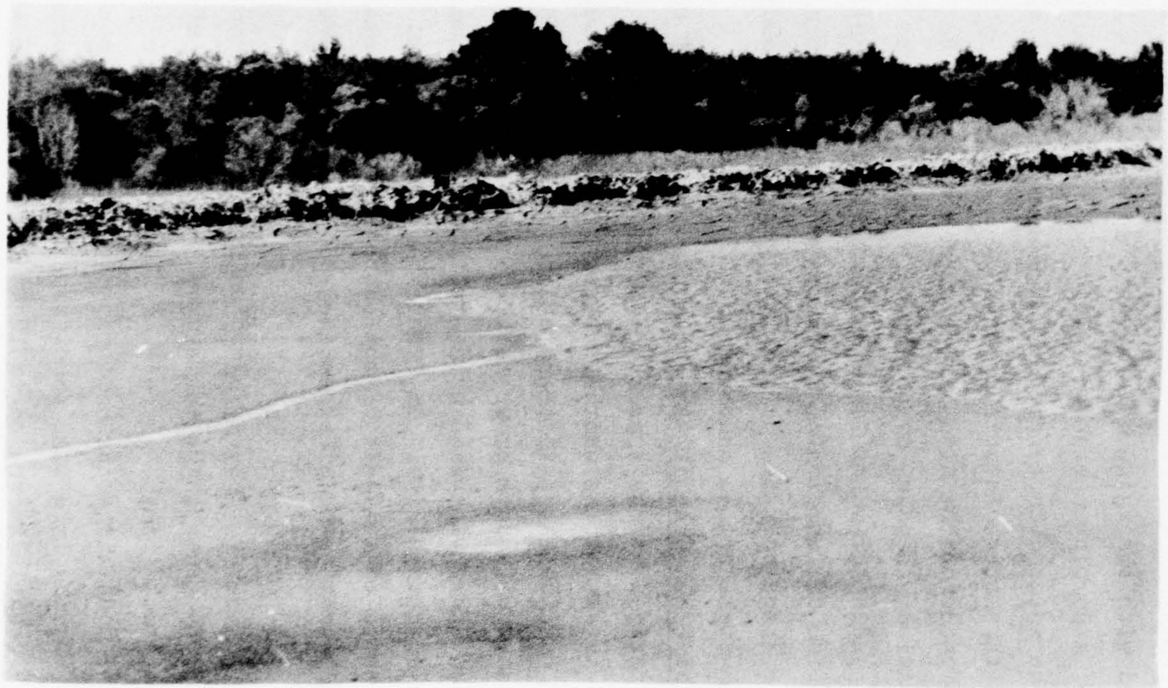


Figure 6

Dredged Material Weathering Patterns: DM-1 and DM-2,
(Supernatant Liquid and Bare Mud)

the DM-1 stage is characterized by the appearance of a clear to cloudy supernatant water over the entire surface of the dredged material disposal site. DM-1 is the first clearly identifiable successional stage associated with the aging of a given disposal site following the cessation of a pumping operation. This sere is the result of the separation of the water component from the dredged material slurry. The duration of this stage is a function of the drainage system employed or designed for the site. Supernatant water may be dissipated by percolation, seepage, evaporation, or runoff. Zero drainage results in the ponding of water for long periods of time, while the proper installation of functioning drainage weirs will reduce the duration of this stage to a few days. In Figure 6, DM-1 conditions are shown to the right of the photograph.

67. DM-2 (bare mud stage). As shown also in Figure 6, the DM-2 stage is characterized by the appearance of wide expanses of unbroken mud. This sere is always the shortest lived of the entire successional pattern. As indicated in the previous section, the DM-2 stage is associated with dark brown to black mud consisting in most areas of silt and clay, with sand being restricted to the immediate vicinity of the discharge site. In Figure 6 a broad band of DM-2 conditions are shown to the left of the photograph. The retaining dike is shown adjacent to an older undiked disposal area covered with vegetation.

68. DM-3 (incipient fissure formation stage). As shown in Figure 7, the DM-3 sere is characterized by the appearance of long, tenuous, shallow cracks in the surface of the dredged material. During early DM-3 conditions the soil fissures are rarely more than ½ in. in depth. During late DM-3 conditions the soil fissures widen and the depth is greatly increased to 10-40 inches. The onset of DM-3 conditions can occur overnight and (as will be related in subsequent sections of this report) also marks the onset of concern with noxious arthropods. As the fine silts and clays begin to

dehydrate unevenly, a mosaic of fissured soil is formed over the entire disposal site with the sole exception of sandy areas near the discharge sites. Normally a thin layer of oxidized soil (less than ¼ in. thick) will be found on the surfaces of the mosiac blocks of dredged material. At this stage of succession the dredged material is moist and unstable.

69. Diatomaceous deposits. Frequently encountered during this stage and stage DM-2 are thin wisps of diatomaceous deposits. These siliceous materials are the result of stranding of diatoms formerly suspended in the supernatant liquid stage (DM-1). These small planktonic algae undoubtedly play a role in the fertility of later stages of dredged material successional patterns. Diatoms were not confined to this stage, but were frequently observed in later DM stages. The most obvious appearance of diatomaceous deposits appeared to be limited to stages DM-2, DM-3, and early DM-4. In Figure 8, early DM-3 conditions are shown to the right while later DM-3 conditions are shown to the left. White diatomaceous deposits are shown to the left.

70. DM-4 (mature fissures stage). The change from DM-3 (incipient fissure formation) to DM-4 (mature fissure formation) is often subtle and difficult to recognize. As will be shown in other sections of this report, DM-4 conditions are extemely important and should be recognized and interpreted. As the dehydration of dredged material continues, DM-4 conditions are characterized by the appearance of deeper fissures (depths of 18 to 25 in. on the east coast and 20 to 40 in. on the west coast); wider separation of the mosaic blocks; change in the coloration of the surface (i.e., reducing to oxidative states); changes in the density of the mosaic blocks, with the subsurface soil becoming quite dense; and the formation of surface crust deposits. In profile view, a mosaic block now presents a moisture gradient with the upper portions of the block becoming dry while the lower portions of the block may remain moist and superficial almost

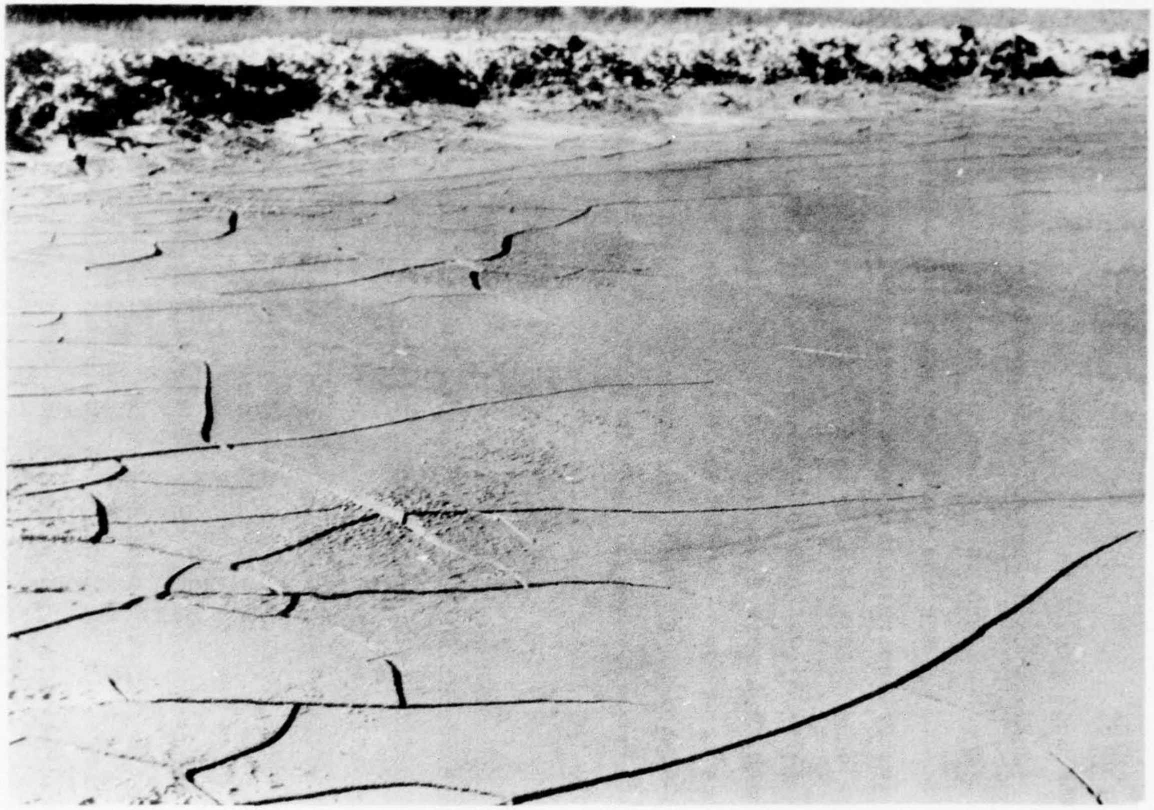


Figure 7

Dredged Material Weathering Patterns: DM-3
(Incipient Fissure Formation)

indefinitely. This fissured soil may now form additional fissures. Superficial fissures are defined as those soil crevices that develop during DM-4 conditions as opposed to the primary fissures of the DM-4 stage (see Figure 9-11). In this manner, the surface area of moist soil is now greatly expanded. However, water loss by evaporation and percolation is greatly reduced because rainfall is trapped in the bottom of the fissures. Such fissures form ideal mosquito breeding microhabitats. These conditions are enhanced when the percentage of sand in the dredged material is lower than the percentage of silt and clay. On the contrary, if the dredged material consists of a high percentage of sand, then DM-4 conditions may never appear.

71. Change from DM-3 to DM-4 conditions. Figures 9-11 illustrate the changes characteristic of the DM-3 to DM-4 transition. In Figure 9, very late conditions associated with DM-3 conditions are illustrated. Notice that the soil fissures have become deeper, but the surface of the mosaic has not formed a crust nor superficial fissures. Zonation of the profile is likewise not yet evident. In Figures 9 and 11 (DM-4 conditions), the surface of the mosaic has formed a crust, a change in coloration is evident, and additional superficial fissure formation can be observed. While not illustrated, if the mosaic blocks were to be observed in profile, those from Figure 9 would not exhibit zonation, while those from Figures 10 and 11 would exhibit definite soil zones and an observable moisture gradient. The fine surface crust characteristic of later DM-4 conditions is especially evident in Figure 11.

72. Later DM stages. Following DM-4 (mature fissures stage), two successful possibilities may occur. If seed sources for volunteer vegetation are present (see description of waste areas in Appendix D), then DM-5 conditions (vegetated mature fissures stage) may develop. Under DM-5 conditions the integrity of the initial fissure formation is maintained and soil weathering is retarded. The appearance of volunteer vegetation, changing from DM-4 to DM-5

Figure 8

Dredged Material Weathering Patterns: DM-3
(Incipient Fissure Formation with Diatomaceous Deposits)

Figure 9

Dredged Material Weathering Patterns: Late DM-3
(Incipient Fissure Formation)

Figure 10

Dredged Material Weathering Patterns: DM-4
(Mature Fissures)

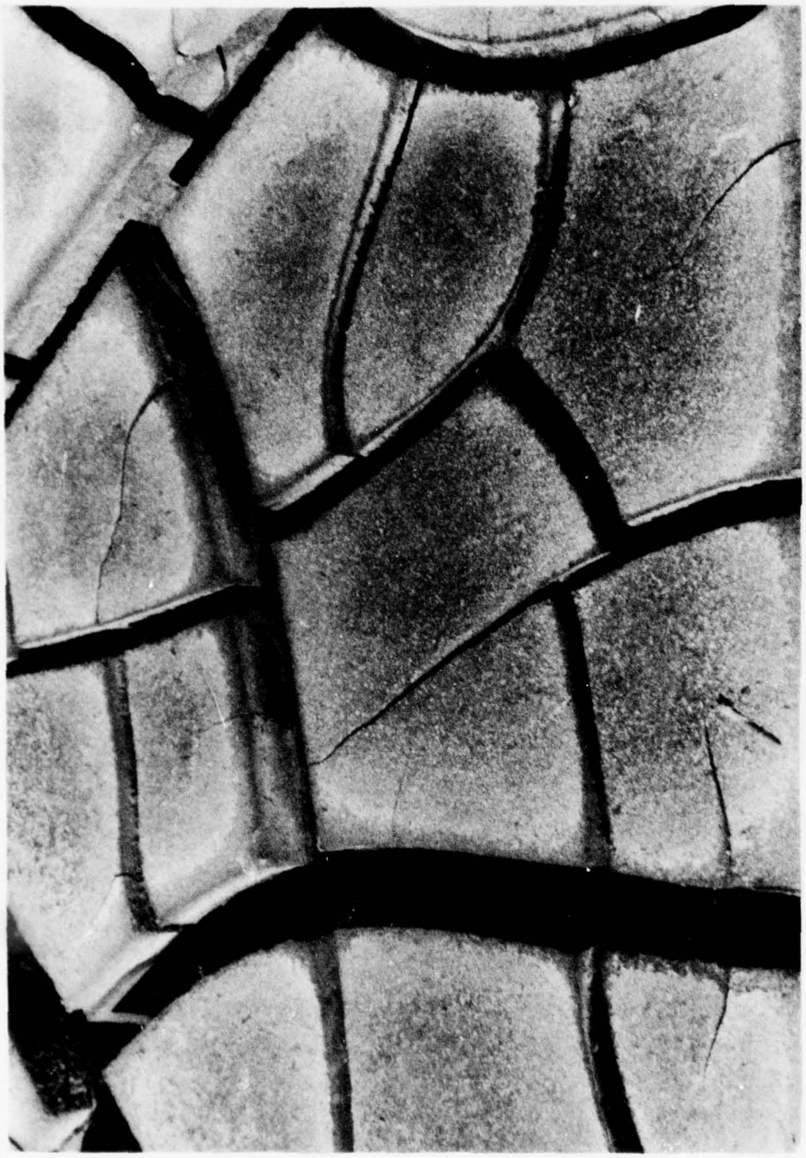


Figure 11

Dredged Material Weathering Patterns:
Detail of DM-4 Conditions

conditions, on disposal sites tends to ensure that a site will remain productive as a mosquito breeding location for a longer period of time than would be the case if volunteer vegetation were restricted or retarded (due to a lack of seed sources). If this later condition is indeed the case, then DM-6 conditions are established. DM-6 conditions are characterized by the appearance of severely weathered soil and the disappearance of soil fissures. DM-6 conditions are shown in Figures 12 and 13. In Figure 12 little evidence of soil fissures can be observed and the few volunteer plants are obviously young and developed after the weathering process occurred. It is important to note that these conditions (DM-6) would not have occurred if volunteer vegetation had developed during the DM-3 or DM-4 stages. In this manner, it is obvious that DM-6 soil conditions develop more rapidly if volunteer vegetation is reduced or nonexistant. A detail of soil weathering or DM-6 conditions is illustrated in Figure 13.

73. DM-7 weathered fissures with vegetation. A special sere that is not always found during the successional cycles associated with dredged material microhabitats is the DM-7 condition. This stage is characterized by the maintenance of woody and herbaceous plants on fissured dredged material. The fissures may be partly filled with dredged material, but still capable of holding rainwater. This stage (not illustrated) was observed on a few older sites that had not received dredged material on a regular basis. The otherwise climax vegetation (see Part IV) that occurred frequently included cedar and other tree species. A summary chart of these relationships is presented in Figure 23 in the next section.

74. DM-8 climax conditions. As noted in Part IV, statements about climax conditions are made with some reservations due to the short-term nature of this report. Some of the observations noted for climax conditions may change as additional data become available. Climax conditions (DM-8) are associated with loosely packed soils with no visible evidence of fissure formation. The plant species

Figure 12

Dredged Material Weathering Patterns: DM-6
(Weathered Fissures)

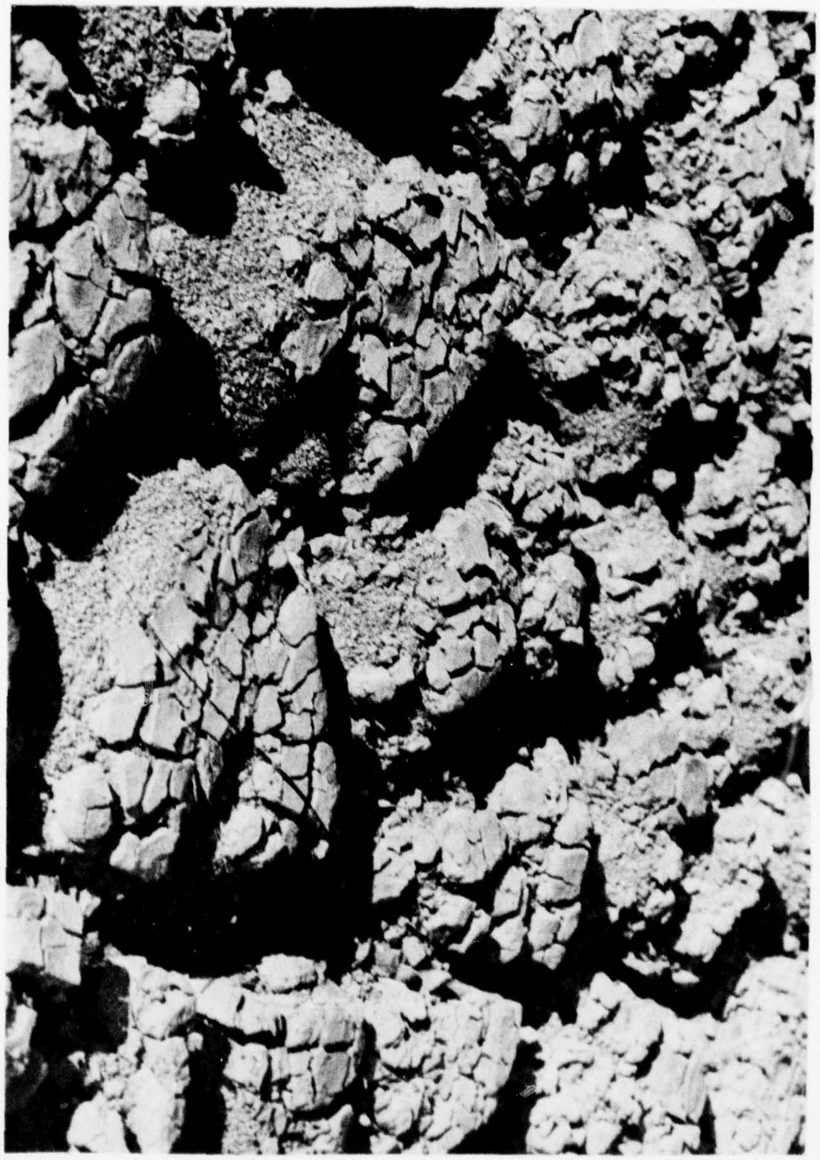


Figure 13

Dredged Material Weathering Patterns:
Detail of DM-6 Conditions

associated with climax conditions (Part IV) are also found in climax soil conditions. Two possible plant communities are common at this stage of succession. A monoculture of *Phragmites communis* or a mixed group of trees and woody shrubs. Under some conditions *Phragmites* apparently persists indefinitely. Most of the older disposal sites visited during the course of this study, however, appeared to stabilize with the tree and woody shrub stage. Climax (DM-8) conditions have been previously illustrated as Figures D3 and E9 in the appendices.

Summary

75. In summary, the following points should be noted:

- a. A comparative study of arthropods and soil weathering conditions revealed that eight successional stages were commonly observed.
- b. From the standpoint of noxious arthropod surveillance, it is extremely important that stages DM-4, DM-5, and DM-7 be recognized and understood.
- c. As a given dredged material site begins to age, the later stages are less predictable than the earlier seres.
- d. Stages DM-5 and DM-6 may be deleted during some successional cycles. Figure 23 presents a summary of these bypass routes.
- e. Stages DM-6 or DM-7 usually preceed the climax sere.
- f. The presence and development of volunteer vegetation during DM-3 or DM-4 stages tends to retard soil weathering and the entire successional cycle.
- g. The entire successional cycle is normally repeated with the onset of additional dredged material during a pumping operation.

Arthropod (Nonmosquito) Successional Patterns Associated with Dredged Material Weathering Patterns

Rationale

76. Having established in the previous section the more obvious

types of dredged material successional patterns as stages DM-1 through DM-8, the next procedure was to determine if a definite arthropod community could be associated with some of the more important soil successional seres. The purpose of this section was to identify those species of arthropods that appear to be common and representative of the selected dredged material (DM) seres and to determine the relative degree of association of these arthropods with DM stages.

77. Ecological succession is considered in this report as an orderly and progressive replacement of one community by another until a relatively stable community is established. (Smith 1974). The reservations and problems noted with successional studies in Appendix D also apply to studies of arthropod succession. As was the case with the plant successional studies, two types of successional patterns are recognized for arthropods, primary and secondary. Primary succession occurs where certain areas were previously devoid of life. Secondary succession occurs in those areas that are disturbed by man, animals, or natural forces, including fires, wind, storms, floods, and dredging.

Literature review

78. General references. Several investigators (Odum and Pinkerton 1955, Cooke 1967, Margalef 1968, and Odum 1969, 1971) have developed models of succession. According to these models, the early stages of succession are characterized by relatively few species, low biomass, and largely extrabiotic sources of nutrients. Energy is channeled through relatively few pathways to many individuals of a few species and biomass production is high. The food chains are short, linear, and largely grazing. The mature stages of succession are characterized by many species, high biomass, and a nutrient source largely organic in nature. Energy is channeled down many diverse pathways and shared by many units. Food chains are complex and largely detrital.

79. Smith (1974) has noted that as successional seres pass from immature to mature stages a number of changes occur including: 1) stratification and diversity changes, 2) niche changes from broad, general niches to narrow specialized roles, and 3) changes in both the diversity of species and the number of niches available (due to stratification). In summary, diversity increases with maturity. One problem with this model observed by the investigators is the fact that the model proposed is mainly concerned with aquatic systems, and that the applicability to terrestrial systems is questionable. Dredged material disposal sites offered an opportunity to study secondary arthropod succession in a terrestrial habitat.

80. Arthropod references. Few studies have been conducted on the general arthropod populations that can be associated with marine habitats and modified marine habitats (disposal sites). Metcalf and Osborn (1920) conducted classical studies on intertidal insects in North Carolina. Davis and Grey (1966) conducted the first comprehensive survey of salt marsh insect populations. McMahan et al. (1972) compared the arthropod fauna from sewage-exposed and sewage-free salt marshes. Only two references were located that directly concerned arthropods associated with the disposal of dredged material. Carlson (1972) and Cammen (1976) studied arthropods associated with the disposal of undiked dredged material. Carlson (1972) noted that arthropod utilization of undiked dredge islands increased with island age. Cammen (1976) noted that elevation and tidal influences significantly affected the types of invertebrate fauna that would colonize an undiked disposal site. No studies were located that were concerned with the arthropods associated with the disposal of dredged material within diked disposal areas.

Materials and methods

81. Emergence trap techniques. In order to determine the relationships between the dredged material (DM-1 through DM-8) stages prescribed in the previous section and the appearance and

abundance of the various insect species, a detailed study of several DM stages was made using insect emergence traps (1 m square) as described by Gaydon and Adkins (1969). Preliminary investigations indicated that six DM stages could be investigated on available disposal sites in the Charleston, S. C. area. With the exception of DM-1 (supernatant liquid stage), one emergence trap was placed within disposal areas that exhibited the following stages:

- a. DM-2, (bare mud sere)
- b. DM-3, (incipient fissures sere)
- c. DM-4, (mature fissures sere)
- d. DM-5, (mature fissures with vegetation sere)
- e. DM-6, (weathered fissures sere, with limited vegetation)
- f. DM-8, (climax sere with mixed trees and woody shrubs).

Since it was impossible to follow a complete successional cycle on any one site within the time frame of the study, several dredged sites in various stages of succession were used. As one site ceased to provide a habitat, the emergence trap would then be moved to another disposal site that provided the needed habitat. Sites utilized during this phase of the study included several locations on Drum Island and Daniel Island in Charleston Harbor (Figure 4) and AIWW sites N-20, N-21, and N-22. A new disposal site on the Ashley River, C-1, was used late in the study. The ages of the sites selected ranged from fresh deposits of dredged material to older sites that had not been pumped for over 15 years. The emergence traps were operated continuously from 1 August 1975 to 3 April 1976. Trap collections were made once a week. At the time of insect collection, the traps were moved to a fresh location that possessed the same DM stage to avoid depleting the arthropod population or attracting insects not normally found on the site.

82. Specimen processing. Collections from the six sites were sorted and separated to taxonomic families and more complete

identifications (in most cases to species) were made by specialists at the Insect Identification and Beneficial Insect Introduction Institute of the United States Department of Agriculture in Beltsville, Maryland, or one of their cooperating specilists.

83. Trap effectiveness and design. The traps utilized for this successional survey proved to be effective and collected large numbers of a great variety of insects and other arthropods. The low profile of the traps (6 in. height) did not attract vandals except on two occasions. Vapona ® strips used as a killing agent were found to be effective for periods of approximately 1-½ months. Almost all specimens were recovered in good condition and subsequent identifications were time-consuming, but possible for almost all of the material collected.

84. Other collecting techniques. Some water samples were collected from the DM-1 stage using the standard mosquito larval dipper. Dippers were also used to sample water from fissured soil and other localized habitats that contained rainwater. On two occasions during field trips to disposal sites near Houston, Texas, and Topsail Beach, N. C., sweep net collections were made for two hours to sample flying insect species associated with diked dredged material disposal areas. These samples were not considered as important as the emergence traps (which were associated with breeding activities).

85. Species diversity. One method of describing and comparing animal communities is to estimate and compare the species diversity of different communities. This method has gained wide acceptance among ecologists especially since the work of the late Robert MacArthur in studies of avian communities (MacArthur 1957, and 1960, and MacArthur and MacArthur 1961). This measure of an animal community provides an estimate of the relationship between the number of species in a given community and the total number of individuals present in that same community. The relationship between number of

species and number of individuals (diversity) is a useful parameter for this studv because changes in community structure occurring with time will produce changes in the estimates of diversity within the community.

86. Diversity can also be viewed as an estimate of the likelihood of selecting an individual of a given species from the population of all individuals of all species present in a community when a random sample is taken. An extreme sample is a "communitv" in which all individuals are members of the same species. In such a case, any and all samples would yield an individual of the same species. Thus, the chance of selecting a member of that species in a sample is 100 percent and the diversity is zero. This tyne of reasoning is the basis of mathematical methods for representing species diversity. One of the most commonly used methods is the Shannon-Wiener (also called Shannon-Weaver) Index. This method was chosen to estimate the diversity of the six habitats sampled. The number of each species used to compute species diversity indices are the results from emergence trap samples. The form of the Shannon-Wiener equation used here to calculate the diversity indices (D) is that nrovided by Cox (1972) which states the formula in terms of base 10 logarithms:

$$D = 3.3219\ (\log_{10} N - \frac{1}{N} \Sigma n_i \log_{10} n_i)$$

Where:

N = total number of individuals of all species

n = number of individuals of the i^{th} species

3.3219 = conversion factor to convert from $\log_{10}$ to $\log_2$

This index for species diversity in a given ecosystem varies from zero for communities having only one species (monoculture) to very high values for communities with many species and fewer individuals per species.

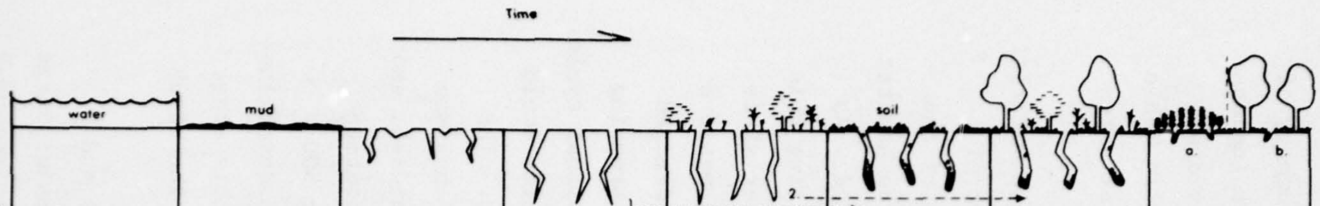
Results and discussion

87. A summary of the results of this section and the nrevious

section on insect habitats is presented in Figure 14. A summary of the arthropod species collected and computed Shannon-Wiener indices from this phase of the study is shown in Table 5. An individual taxonomic listing of the arthropods collected is presented in Table 6. The sweep net collections from dredged material disposal sites are presented in Table 7.

88. DM-1: supernatant liquid stage. Since the dredged material slurry is mixed with several parts water for every one part of dredged material, the duration of this stage is a function of the fate of the water component. As previously mentioned in the habitat section, the duration of this sere may be short or prolonged. As indicated in Figure 14, mosquito breeding did not occur during this stage of the successional pattern. When fresh dredged material is added to any of the subsequent DM stages, the successional pattern always reverts to DM-1. Therefore, the addition of fresh dredged material in some cases may temporarily eliminate mosquito breeding conditions. This effect was not permanent, as the successional cycle had merely been reset to a previous sere. Few insect species could be collected from the DM-1 stage despite intensive efforts. The most commonly collected insects from this stage were water boatmen (Hemiptera: Corixidae), dragonfly nymphs (Odonata: Libelluidae), and immature larvae of midges (Diptera: Chironmidae). Water boatmen populations were sometimes very large--sometimes exceeding 500 specimens per dipper of sample water. No positive species determinations could be made on these specimens. The duration of this stage was as short as one week and as long as six months during the study period.

89. DM-2: bare mud stage. Intensive investigations and determinations were conducted on this sere, the earliest major stage of arthropod importance. As the supernatant water is lost from DM-1 conditions, physical changes become evident within the disposal site. This clear supernatant liquid is lost by drainage, percolation,



Duration (Avg.)	Up to 6 mos.	1 day-2 mos.	4-6 wks.	1-3 yrs.	2-8 yrs.	1-3 yrs.	10-25 yrs.	3 yrs. ....
Stage	DM-1	DM-2	DM-3	DM-4	DM-5	DM-6	DM-7	DM-8
Community Type	Supernatant liquid	Bare mud	Incipient fissures	Mature fissures	Mature fissures with vegation	Weathered fissures	Weathered fissures with vegetation climax	a. Climax Phrag-mites ; Mixed b. Climax Vegetation
Dominant Insect Species	Water boatmen (Hemiptera Corixidae) Dragonflies (Odonata Libelluidae) Midges (Diptera: Chironomidae)	Shore flies (Diptera Ephydridae) Springtails (Collembola) Humpbacked flies (Diptera Phoridae) Many Resting Insects	Shore flies (Diptera Ephydridae) Long-legged flies (Diptera: Dolichopodidae Small dung flies (Diptera: Spaeroceridae) and a wide variety of Ants (Formicidae) Beetles (Carabidae & Staphylinidae) Wasps (Cynipidae) & many other lesser species	Mosquitoes (Diptera: Culicidae) also Beetles (Coleoptera) other flies (Diptera) Wasps (Hymenoptera) Earwigs (Dermaptera) Thrips (Thysanoptera) Moths (Lepidoptera)	Essentially the same as DM-4	Great decrease in numbers & variety of flies (Diptera) Increase in diversity of other insect species	Great variety of insect species but a great decrease in total number collected	Great variety of insect species but a great decrease in total number collected
Mosquito Utilization (Breeding)	0	0	0	+++++	+++++	+	++	+ ?

1. By-Pass Route from DM-4 to DM-6 (DM-5 is not always found in the successional cycle)
2. By-Pass Route from DM-5 to DM-7 DM-6 is not always found in the successional cycle)
3. By-Pass Route from DM-6 to DM-8

Figure 14

Summary Diagram of Insect Habitats Based Upon Dredged Material Weathering Patterns

Table 5

<u>Summary Listing of the Relative Diversity of Insect Orders, Families, and Species Collected in Box Emergence Traps During Different Successional Stages of Development on Diked Dredged Material Disposal Sites in Charleston County, South Carolina</u>

Seral Stage	No. Orders	No. Families	No. Species	Shannon-Wiener Indices (D)
Mud (DM-2)	7	25	37	2.1712
Incipient fissures (DM-3)	8	31	54	10.7357
Mature fissures (DM-4)	9	38	61	9.2101
Vegetated mature fissures (DM-5)	9	40	61	8.9915
Weathered fissures (DM-6)	9	38	56	8.079
Climax (DM-8)	11	51	95	8.827

Table 6

Taxonomic Listing and Relative Abundance of Insects Collected in Box Emergence Traps During Physical Succession on Diked Dredged Material Disposal Sites in Charleston County, South Carolina

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Category	Total Number of Specimens Collected					
COLEOPTERA						
Anthicidae						
Anthicus sp.	1	0	0	2	0	0
Carabidae						
Bembidion sp.	48	372	25	0	1	0
Paratachys sp.	0	13	16	5	2	1
Stenolophus sp.	1	5	3	0	5	5
Tachys sp.	0	0	0	0	0	1
Chrysomelidae						
Systena elongata	0	0	0	1	0	0
Cocinellidae						
Scymus (Pullus) loweii	0	0	0	5	0	1
Curculionidae						
Genus?	0	0	0	0	4	3
Helodidae						
Cyphon sp.	0	0	1	0	0	1
Heteroceridae						
Neoheterocerus pallidus	1	38	58	9	0	3

(continued)

(Sheet 1 of 11)

Table 6 (continued)

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Catagory	Total Number of Specimens Collected					
Mordellidae						
Mordella sp.	0	0	1	0	0	0
Nitidulidae						
Carpophilus mutilatus	0	0	0	0	5	0
Scarabeidae						
Myrmecaphodius excavaticollis	0	0	1	1	1	2
Staphylinidae						
Aleocharinae						
Aleochara sp.	0	1	3	5	0	6
Falgaria sp.	0	0	2	6	0	2
Genus?	13	28	15	23	1	4
Oxytelinae						
Anotylus insignitus	0	0	0	0	0	1
Carpelimus spp.	143	1033	659	107	1	11
Thinobius sp.	0	0	2	69	28	0
Paederinae						
Lobrathium sp.	0	0	2	1	0	9
Scopaeus spp.	0	0	0	0	0	3
Staphylininae						
Hyponygrus sp.	0	3	0	0	0	9
Neobisnius ludicrus	0	4	2	3	0	33

(continued)

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Table 6 (continued)

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Category	**Total Number of Specimens Collected**					
COLLEMBOLA						
Entomobryidae						
Lepidocyrtus cyaneus	4	17	0	5	47	0
Lepidocyrtus beaucatcheri	4	29	0	0	37	0
Orchesella ainsliei	0	0	0	0	109	1
Seira buski	0	0	0	0	7	0
Seira platani	0	0	0	0	2	0
Isotomidae						
Isotoma cinera	0	0	0	0	3	1
Sminthuridae						
Sminthurinus minutus	0	0	0	0	0	1
DERMAPTERA						
Carcinophoridae						
Euborellia annulipes	0	2	2	13	2	27
Labiduridae						
Labidura riparia	0	0	0	11	3	11
DIPTERA						
Canaceidae						
Canace macateei	4	330	5	1	0	3

(continued)

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Table 6 (continued)

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Category	**Total Number of Specimens Collected**					
Cecidomyiidae						
(several taxa)	1	5	6	20	3	144
Ceratopogonidae						
Culicoides furens	3	2	3	0	1	0
Culicoides hollensis	4	9	6	2	8	1
Dasyhelea atlantis	2	3	68	98	0	67
Forcipomyia fuliginosa	0	0	9	9	0	13
Forcipomyia genualis	0	0	21	13	0	17
Forcipomyia (Thyridomyia) tenuichela	0	7	605	865	5	109
Chironomidae						
Orthocladiinae	0	0	0	0	2	179
Chloropidae						
Conioscinella sp.	0	0	0	4	0	0
Eugaurax sp. *(quardrilineata complex)*	0	0	0	1	0	1
Hippelates dissidens	0	2	0	1	0	1
Hippelates pusio	0	3	0	0	0	2

(continued)

(Sheet 4 of 11)

Table 6 (continued)

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Catagory	**Total Number of Specimens Collected**					
Thaumatomyia glabra	0	0	0	1	0	0
Thaumatomyia pulla var. *punctum*	1	0	0	104	0	1
Dolichopodidae						
Chrysotus sp.	0	0	1	0	0	1
Dilophus sp.	0	0	1	0	0	0
Thinophilus sp.	4	5	6	1	0	1
Drosophilidae						
Drosophila tripunctata	0	0	0	0	0	2
Scaptomyza adusta	0	11	5	7	1	22
Scaptomyza pallida	0	0	0	0	0	2
Scaptomyza vittata	1	10	4	8	1	22
Empididae						
Drapetis sp.	0	2	26	12	0	19
Ephydridae						
Atissa pygmaea	113	1488	575	43	25	0
Ceropsilopa coquilletti	0	0	0	1	0	0
Discocerina obscurella	0	0	2	0	0	0

(continued)

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Table 6 (continued)

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Category	**Total Number of Specimens Collected**					
Lamproscatella dichaeta	1404	13812	269	25	1	5
Scatella favillacea	0	0	2	0	0	0
Scatophila ordinaria	91	794	715	671	3	4
Muscidae						
Lispe sp.	1	45	0	2	1	4
Mycetophilidae						
Leia sp.	0	0	3	0	1	88
Otitidae						
Euxesta n. sp.	0	0	0	1	0	0
Phoridae						
Dohrniphora sp.	17	127	14	10	7	2
Dohriniphora cornuta	6	15	2	0	0	3
Megaselia sp.	21	214	29	38	116	55
Puliciphora sp.	2	23	0	3	4	1
Psychodidae						
Psychoda spp.	3	4	2	26	0	50
Scatopsidae						
Genus?	0	1	1	21	1	13
Sciaridae						
Bradysia sp.	0	18	36	208	21	696

(continued)

(Sheet 6 of 11)

Table 6 (continued)

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Catagory	Total Number of Specimens Collected					
Sphaeroceridae						
Leptocera spp.	18	1310	79	15	2	38
Tachinidae						
Elfia sp.	0	3	2	0	0	0
Tipulidae						
Erioptera (trimicra) pilipes	0	2	0	0	0	2
Limonia (Dicranomyia) gladiator	1	3	1	0	0	2
Limonia (Rhipidia) domestica	0	2	0	0	0	2
Limnophila sp.	0	1	0	0	0	1
HEMIPTERA						
Reduviidae						
Genus?	0	0	0	10	1	0
Saldidae						
Pentacora sphacelata	10	65	53	1	1	1
HOMOPTERA						
Aphididae						
Aphis craccivora	0	3	8	15	46	7
Cicadellidae						
Macrosteles fascifrons	0	0	3	0	99	4

(continued)

(Sheet 7 of 11)

Table 6 (continued)

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Catagory	**Total Number of Specimens Collected**					
Cixiidae						
Pintalia dorsivittatus	1	0	11	41	3	0
Delphacidae						
Prokelisia marginata	0	6	0	0	0	0
HYMENOPTERA						
Aspidae						
Lysiphlebus sp.	0	0	0	0	0	1
Bethylidae						
Dissomphalus apertus kieffer	1	0	1	41	0	0
Braconidae						
Apanteles sp.	1	0	0	0	1	15
Aspilota sp.	2	1	2	1	0	4
Heterospilus sp.	0	0	0	0	0	1
Alysiinae, genus?	0	0	0	0	0	1
Ceraphronidae						
Ceraphron sp.	0	0	0	0	2	3
Cynipidae						
Hexacola sp.	124	461	4	9	1	23
Kleidlotoma sp.	0	2	0	0	0	1
Trybliographa sp.	0	10	0	0	0	1

(continued)

(Sheet 8 of 11)

Table 6 (continued)

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Catagory	**Total Number of Specimens Collected**					
Encoilinae, genus?	0	0	0	0	0	1
Diapriidae						
Psilus sp.	0	0	0	0	1	1
Trichopria sp.	0	5	12	12	1	18
Encyrtidae						
Copidosoma sp.	0	1	1	0	5	13
Eulophidae						
Euplectrus sp.	0	0	0	1	0	0
Horismenus sp.	0	0	0	0	5	10
Tetrastichus sp.1	0	0	0	0	0	4
Tetrastichus sp.2 (=*Aprostocetus sen* Burke)	0	0	0	0	1	0
Tetrastichus sp.3	0	0	0	0	0	1
Formicidae						
Hypoponera sp.	0	0	0	0	0	1
Monomorium viridum peninsultatum	0	0	0	0	0	1
Partrechina sp.	2	3	0	2	1	4
Ponera pennsylvanica	0	0	0	0	0	1
Solenopsis invicta	21	51	2	13	6	2

(continued)

(Sheet 9 of 11)

Table 6 (continued)

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Catagory	**Total Number of Specimens Collected**					
Ichneumonidae						
Orthocentriane	0	0	0	0	0	1
Mymaridae						
Gonatocerus sp.	0	0	0	0	0	1
Platygastridae						
Leptacis sp.	0	0	0	0	2	14
Pompilidae						
Anoplius sp.	0	0	2	0	0	0
Pteromalidae						
Eupteromalus sp.	73	1036	9	6	3	2
Spalangia sp.	0	0	0	0	0	2
Scelionidae						
Calotelea sp.	0	0	1	5	1	1
Telenomus sp.	0	0	0	0	0	1
Trimorous sp.	0	0	2	0	0	1
Sphecidae						
Liris aequalis	0	0	0	0	1	0
Vespidae						
Polistes fuscatus bellicosus	0	0	0	4	0	0
LEPIDOPTERA						
(unidentified taxa)	3	0	7	12	1	19

(continued)

(Sheet 10 of 11)

Table 6 (concluded)

Seral Stage:	Mud	Incipient Fissures	Mature Fissures	Vegetated Mature Fissures	Weathered Fissures	Climax
	(DM-2)	(DM-3)	(DM-4)	(DM-5)	(DM-6)	(DM-8)
No. of Samples	27	43	36	36	34	36
Taxonomic Catagory	**Total Number of Specimens Collected**					
ORTHOPTERA						
Gryllidae						
Velarifictorus micado	0	0	1	4	6	15
Blattidae						
Parcoblatta sp.	0	0	0	0	0	6
PSYCHOPTERA						
Ectopsocidae						
Ectopscopsis cryptomeriae	0	0	0	0	0	7
Lachesillidae						
Lachesilla nubilis	0	0	0	0	0	1
THYSANOPTERA						
Thripidae						
Genus?	0	1	1	0	0	2

(Sheet 11 of 11)

Table 7

Insects Collected By Sweepnet During Trips to Dredged Material Disposal Sites in Topsail, North Carolina (NC), and Houston, Texas (TX)

Taxonomic Catagory	Location Collected
COLEOPTERA	
Chrysomelidae	
Trirhabda bacharidis	NC
Mordellidae	
Mordellistena sp.	NC
Phalacridae	
Stilbus apicalis Melsh	TX
DIPTERA	
Ceratopogonidae	
Culicoides furens (Poey)	NC
Culicoides hollensis Melander & Brues	NC
Cuilcoides stellifer (Coq.)	NC
Culicoides variipennis (Coq.)	TX
Dasyhelea grisea (Coq.)	NC
Chironomidae	
Tanypus sp.	NC
sp. of Orthocladiinae	NC
Chloropidae	
Hippelates dissidens (Tuck.)	TX
Hippelates particeps (Beck.)	NC
Dolichopodidae	
Thinophilus ochrifacies Van Duzee	NC
Thinophilus sp.	NC
Ephydridae	
Atissa pygmaea (Haliday)	NC

(continued)

(Sheet 1 of 3)

Table 7 (continued)

Taxonomic Catagory	Location Collected
Dimecoenia spinosa (LW.)	NC, TX
Discocenia obscurella (Fallen)	NC
Lamproscatella dichaeta (LW.)	NC, TX
Paralimna decipiens (LW.)	TX
Parydra imitans (LW.)	NC
Polytrichophora sp.	NC
Scatella favillacea (LW.)	TX
Scatella picea (Walker)	TX
Scatophila spp.	NC, TX
Sciaridae	
Bradysia sp.	NC
Sphaeroceridae	
Leptocera (Rachispoda) atra (Adams)	NC, TX
Tethinidae	
Pelomyia coronata (LW.)	TX
Tipulidae	
Erioptera (Trimicra) pilipes (Fabricius)	NC
HOMOPTERA	
Aphididae	
Hyalopterus pruni (Geof.)	NC
Cicadellidae	
Macrosteles lepida (Van Duzee)	NC
Scaphoideus tergatus Delong	NC
Delphacidae	
Prokelisia marginata (Van Duzee)	NC
HYMENOPTERA	
Braconidae	
Heterospilus sp.	NC

(continued)

(Sheet 2 of 3)

Table 7 (concluded)

Taxonomic Catagory	Location Collected
Formicidae	
Formica pallidefulva Latreille	NC
Pteromalidae	
Lamprotatini, Genus?	TX
Urolepis sp. near *rufipes* (Ashm.)	TX

(Sheet 3 of 3)

and/or evaporation, leaving behind a soupy suspension of sediment which frequently becomes associated with algal growth. As previously mentioned, manv of these algae are diatoms. During this study. four families of beetles (Coleoptera), a single family of springtails (Collembola), twelve families of true flies (Diptera), five families of bees and their allies (Hvmenoptera), a single family of leafhoppers (Homoptera), and a family of moths (Lepidoptera) were collected from emergence traps used for sampling the bare mud stage. A detailed listing of the individual species associated with these families is presented in Table 6. While most of the insect species collected from this stage are not of known ecomonic importance to man, it is interesting to note that three different species of the biting midge group (Ceratopogonidae) were collected in small numbers from this sere. These midges are also known as "punkies," "sand flies", and "no-see-ums." Two of these species, *Culicoides furens* and *C. hollensis*, are of interest because they are major pest species. Most literature about the breeding of these two species lists the natural salt marsh as their natural habitat. Additional studies are needed to determine if dredged material disposal areas serve as breeding sites for these species. Of the noneconomic species, one of the most interesting groups collected were species of Ephydridae (shore flies) which occurred in large numbers during this stage. Two species, *Atissa pygmaea* and *Lamproscatella dichaeta*, were especially common. While some of the species collected may have been using the disposal areas as a resting site, the breeding of the dominant species of Diptera (families Ephydridae and Phoridae) was confirmed by the isolation of the larvae of these groups from dredged material washings. Mud samples were washed through sieve series and the residue was subjected to salt flotation to locate larvae. A total of 27 collections, representing 27 weeks, were processed from this sere. The mud stage is not significant as a source of mosquitoes.

90. <u>DM-3 incipient fissure stage</u>. As previously mentioned in other sections, the change from DM-2 to DM-3 conditions is often quite rapid and may occur on a large disposal site in a matter of days. As the fine sediments dehydrate and contract, the soil particles pull apart and separate to form primary soil fissures (see previous section). As this dehydration process becomes more evident, soil fissures become deeper and wider with a resultant mosaic of fissured soil. The duration of this stage ranges from four to six weeks in many locations. The most important aspect of this stage was the high diversity and extremely high productivity of animal biomass. This high diversity was not immediately obvious until the Shannon-Wiener Indices were computed. Table 5 indicates that this sere had the highest diversity index of the entire study ($D = 10.7357$). During field collections, however, large numbers of both individuals and species were evident from the trap collections taken from this stage. This extremely high diversity index had not been anticipated by the investigators at the outset of the study. It has been postulated (see literature review of this section) by a number of workers that later successional stages have greater diversity than earlier stages in a successional cycle. This study, on the contrary, suggests that arthropod diversity rapidly becomes greatest shortly after the retreat of the supernatant water and the development of soil fissures. A few explanations might be offered to account for the virtual explosion of arthropod populations within this stage (DM-3) of succession. The formation of soil fissures (the hallmark of DM-3) results in many microhabitats that offer protection, food, a selection of moisture ranges, and bacterial and algal growth conditions which support animal life. DM-3 conditions offer both terrestrial and aquatic microhabitats (when the incipient fissures are partially water filled) in contrast to the previous state (DM-2) which offered only a restricted, shallow water habitat that was uniform throughout the entire disposal area. Further research is needed to isolate

those early plant growth patterns (bacterial, algal, etc.) that sustain the great abundance of arthropod life associated with this incipient fissure-forming sere.

91. Arthropod species associated with DM-3 conditions. As previously indicated, the investigators began to suspect that DM-3 conditions were highly productive for arthropods shortly after the early trap collections from this stage were examined. A total of 54 species, representing 31 families from 8 orders of the Arthropoda, were collected during this study. Tables 5 and 6 enable the reader to compare and contrast the numbers of both species and individuals collected from this sere. Of special interest are the moderate numbers of Carabid beetles (commonly known as ground beetles) from the genera *Bembidion* and *Paratachys*. Both the adults and larvae of most carabids are predaceous and are therefore beneficial insects. The largest collection of rove beetles (Family Staphylinidae) was taken from traps placed over DM-3 conditions. A total of 1033 individual specimens of *Carpelimus* spp. were collected. As DM-3 conditions give rise to DM-4, DM-5, and other seres, the numbers of this group rapidly decline. Since the rove beetles are also predaceous, it is reasonable to assume that these arthropods are also beneficial.

92. Among the other families and groups of insects collected from this sere are moderate numbers of the springtails, *Lepidocyrtus cyaneus* and *L. beaucatcheri*. As noted in Table 6, these two sibling species were collected from DM-3 and DM-6 conditions, but were virtually absent from DM-4, DM-5, and DM-8 stages. Among the flies (Order Diptera) the largest numbers of the beach flies (Family Canaceidae) were collected from DM-3 conditions. As can be seen from Table 2, a total of 330 species of *Canace macateei* were collected during this study. The latest edition of the standard American textbook on insect taxonomy (Borror et al. 1976) lists this family of Diptera as "rare and unlikely to be encountered." Only five

species of this family are known to occur in the United States and the larvae are known (Borror et al. 1976) to feed on algae stranded along shorelines. The presence of algae and the interphase of aquatic and terrestrial microhabitats during DM-3 has already been noted and the presence of these conditions probably accounts for the abundance of this rare group of insects. Very small numbers of biting midges (family Ceratopogonidae) occurred during this stage. As noted in the previous comments on DM-2 conditions, it continues to be doubtful that dredged material disposal areas are a significant source of these noxious pests, since such small numbers were taken by the emergence traps used in this study. However, in view of the work of Altman et al. (1970a, 1970b) in Central America, additional work and surveillance on the possible breeding of this important group of noxious flies should be continued.

93. From the large and extensive family Chloropidae (eye gnats and allies), only a few specimens were collected from disposal sites in DM-3 conditions. The investigators believe, however, that these data should be interpreted with some degree of caution. During field trips relating to other aspects of this study, consistent numbers of adult eye gnats were observed within dredged material disposal areas. On several occasions large numbers of eye gnats were observed to swarm over fissured soil under DM-3 and DM-4 conditions. These field observations indicate that dredged material disposal sites may constitute a yet unrecognized source of eye gnats.

94. Extremely large numbers of three species *(Atissa pygmaea, Lamproscatella dichaeta,* and *Scatophils ordinaria)* of the family Ephydridae (shore flies) were collected from traps operated over DM-3 conditions. As a disposal area ages, the numbers of these species gradually decline, but their abundance under DM-3 conditions was unusual and striking. Unlike the canaceid flies, the ephydrids are quite common and it is reasonable to suspect that such flies would be common within dredged material disposal areas. Until this

study, however, their utilization of disposal areas as breeding sites was not definitely established or known. This study documents the DM-3 conditions as the most productive stage for ephydrid production. These flies are not considered economically important to man.

95. Moderate numbers of humpbacked flies (Family Phoridae) were collected under DM-3 conditions, representing three species (see Table 6). Muscid flies of the genus *Lispe* were also collected in moderate numbers from DM-3 conditions. The small dung flies (Family Sphaeroceridae) are frequently collected from organic sources and excrement. A total of 1310 individuals of a single undetermined species of the genus *Leptocera* were collected from DM-3 conditions. This family (Sphaeroceridae) is classified as rare by Borrer et al. (1976).

96. Among the nondiptera, two remaining groups were found to be abundant during DM-3 conditions. Of the true bugs (Order Hemiptera), a single predatory species, *Pentacora sphacelata*, was found to be common under DM-3 conditions. This species was also collected from DM-2 and DM-4 conditions in moderate numbers. Three species of the order Hymenoptera were noted as important. From the family Cynipidae large numbers of an undetermined species of the genus *Hexacola* sp. were collected from all seres with DM-3 being the most productive. A second parasitic wasp species, *Eupteromalius* sp., of the family Pteromalidae was collected from DM-3 conditions. It is thought that both these species are parasites of the small Diptera previously cited. The largest numbers of the imported fire ant, *Solenopsis invicta*, were collected from DM-3 conditions. The moderate numbers of this species collected from SM-3 traps probably reflects the presence of other prey species. It was not felt that the numbers of this species shown in Table 6 accurately reflect the true numbers of imported fire ants that utilize dredged material disposal areas. The well-known mounds of this species were never constructed under emergence traps.

97. In summary, DM-3 conditions produce a large number of both individual insects and insect species. This rapid rise in species diversity and numbers is perhaps most attributable to the change in habitats (i.e., from uniformly aquatic to a mixture of multiple microhabitats). The dominant species of Diptera are probably parasitized by two wasp parasites. With the possible exception of the eye gnat group (some supporting data) and the biting midge group (yet to be demonstrated in the United States), the highly productive DM-3 stage does not appear to produce noxious arthropods. Mosquitoes are absent during this sere, but it is postulated that some mosquito oviposition may begin under late DM-3 conditions.

98. DM-4: mature fissure stage. A total of 36 collections, representing 36 weeks of activity, were studied for this stage of succession. As will be shown in later sections of this report (Part V), DM-4 conditions represent the onset of major mosquito breeding within dredged material disposal sites. The change from DM-3 to DM-4 conditions is often difficult to recognize and understand. Details of this interphase and transition have already been presented in the previous section (see paragraph 71). A total of 61 species representing 38 families from 9 orders were collected from this sere. Among the beetles (Order Coleoptera) 6 families were collected, while the flies (Order Diptera) were represented by 15 families. Other groups collected included the orders Hymemoptera, 9 families; Homoptera, 3 families; Hemiptera, 1 family; Lepidoptera, 1 family; Orthoptera, 1 family; Thysanoptera, 1 family; and Dermaptera, 1 family. The Shannon-Wiener Index for this stage was computed to be 9.2101 (D-Value).

99. Arthropods associated with the DM-4 condition. Among the Diptera of the family Ceratopogonidae, large numbers of the nonpest species, *Forcipomyia tenuichela*, were collected from DM-4 conditions. This species was never collected in any significant numbers until after the soil had hardened and oxidized to a considerable extent

(i.e. DM-4 conditions). Most of the representatives of the family Ephydridae (numerous under DM-3 conditions) began to decline under DM-4 conditions. A single species of the genus *Bradysia* (Order Diptera: Family Sciaridae) showed an increase under DM-4 conditions that was to continue until the establishment of climax (DM-8) conditions. From Table 6, it may be inferred that this species continued to increase in numbers during every stage except DM-6. Among the beetle species (Order Coleoptera: Family Carabidae), the previously mentioned predator, *Bembidion* sp., underwent a drastic decline. This fall in *Bembidion* sp. collection may reflect a concurrent decline of its prey species. Another beetle species, *Neoheterocerus pallidus*, was collected in moderate numbers from this sere. After the decline of DM-4 conditions, this species also declined rapidly. The staphylinid beetles *Carpelimus* spp., illustrated a pattern of preference for fissured soil. Several species were abundant during stages DM-3, DM-4, and DM-5, but absent on those DM stages that did not exhibit fissured soil conditions.

100. In summary, while there was a slight rise in the numbers of species collected from DM-4 conditions (from 54 on DM-3 to 61 on DM-4) the species diversity index declined (from a D-value of 10.7357 on DM-3 to 9.2101 on DM-4). The overall numbers of individuals collected declined. DM-4 conditions represent the first DM stage to be concerned with mosquito breeding conditions.

101. DM-5: vegetated mature fissures. As summarized in Figure 14, the DM-5 conditions are associated with the growth of succulent halophytic plants and other volunteer vegetation (under less saline conditions). The presence of this stage as a viable sere is a function of the availability of seed sources and soil weathering conditions. An isolated disposal site with few seed sources and a low dike (that may allow for rapid drying and weathering conditions) will normally undergo a transition from DM-4 to DM-6 (weathered fissures). If this is indeed the case then DM-5 conditions are

bypassed (see Figure 14, bypass route 1). A more common occurrence, however, is the development of DM-5 conditions due to the presence of viable seed sources and slow soil weathering conditions. As will be discussed in the next section, both DM-4 and DM-5 are capable of supporting large larval populations of several different mosquito species.

102. A total of 36 collections, representing 36 weeks of activity, were processed for identification and analysis from the DM-5 sere. A total of 61 species representing 40 families from 9 orders of the Arthropoda were finally separated from this specialized habitat. Common plants that frequently occur in association with the emergence traps during this part of the study were *Salicornia bigelovii*, *Borrichia frutescens*, and *Suaeda linearis*. The role of this vegetation is undoubtedly important in the development and maintenance of the DM-5 habitat. Such vegetation prevents the penetration of sunlight, lowers the temperature, raises the relative humidity, and tends to raise the organic content of both the water and soil in the surrounding vicinity. When the raw numbers (see Table 5) are compared, the species diversity appears to be roughly the same as the DM-4 stage (i.e., 61 species collected from both seres, but two additional families are represented in the DM-5 stage). A study of the Shannon-Wiener Indices, however, reveals an overall decline in species diversity, from a D-value of 9.2101 for DM-4 to a D-value of 8.9915 for DM-5). Family separations included true flies (Diptera), 15 families; wasps and allies (Hymenoptera), 9 families; beetles (Coleoptera), 7 families; leafhoppers and allies (Homoptera), 2 families; true bugs (hemiptera), 2 families; earwigs (Dermaptera), 2 families; springtails (Collembola), 1 family; moths and butterflies (Lepidoptera), 1 family; and crickets and allies (Orthoptera), 1 family.

103. Arthropods associated with the DM-5 condition. While most of the changes in arthropod patterns are obvious from inspection of

Table 6, a few observations regarding some of the more prominent species warrant comment. In general, predatory beetles underwent a drastic decline in both numbers and diversity. Of the carabids, only *Paratachys* sp. remained on this habitat in small numbers. The decline in predatory beetles is interesting in light of the fact that protective vegetation (to support additional prey species) is present for this habitat. Moderate numbers of several species (*Carpelimus* spp. *Thinobius* sp., and an unknown species of the subfamily Aleocharinae) of staphylinid beetles remained present during this stage, but in likewise declining numbers.

104. With the exception of a single species (*Lepidocyrtus cyaneus*) collembolans were completely absent from DM-5 collections. Earwigs (order Dermaptera) were collected in increasing numbers over the previous habitats. Among the order Diptera, large collections were made of two species of ceratopogonids (*Dasyhelea atlantis* and *Forcipomyia tenuichela*) from the DM-5 habitat. Vegetated mature soil fissures were found to be the most productive sources for both of these species of midges. DM-5 habitats were observed to be a major source of the gnat species, *Thaumatomyia pulla* var. *punctum*, (Diptera: Chloropidae). The ephydrid and phorid flies continued to utilize DM-5 conditions, with these three species present in moderate numbers. Moderate numbers of the dipteran family Sciaridae were collected as a single species. (*Bradysia* sp.). All other varieties of arthropods were collected in small numbers as will be seen in Table 2.

105. DM-6: weathered fissures. As summarized in Figure 14, DM-6 conditions are associated with weathered soil conditions and scanty plant life. Soil fissures are not a major component of this habitat. DM-6 conditions are associated with those disposal sites that are denied access to plant seed sources or are subject to harsh environmental conditions that do not favor the introduction and growth of plants. As can be seen from Figure 14, DM-6 conditions

allow for a bypass of DM-7 conditions. To summarize, if DM-6 conditions develop and are sustained for a reasonable period of time (1 to 2 years), then it may be assumed that the weathered fissures with vegetation (DM-7) stage has been circumvented. With the passage of enough time, all dredged material disposal areas eventually become vegetated, but the speed of the initial plant colonization efforts will determine if DM-7 or DM-8 conditions will prevail following formation of mature soil fissures (DM-4 stage).

106. A total of 34 collections, representing 34 weeks of activity, were processed for identification and analysis from this successional sere. A total of 56 species representing 39 families from 9 orders of the Arthropoda were finally separated from this habitat. Plant species (as indicated previously) were absent from this sere and were therefore not associated with trap locations. Both the raw data and the computed Shannon-Wiener index (D-value of 8.079) indicated that species numbers and diversity had declined from all of the previous habitats except DM-2 (mud conditions). Family separations included true flies (Diptera), 11 families; wasps and allies (Hymenoptera), 11 families; beetles (Coleoptera), 5 families; leafhoppers, aphids and allies (Homoptera), 3 families; springtails (Collembola), 2 families; earwigs (Dermaptera), 2 families; true bugs (Hemiptera), 2 families; moths and butterflies (Lepidoptera), 1 family and crickets and allies (Orthoptera), 1 family.

107. Arthropods associated with DM-6 conditions. Only a few specimens of predatory beetles were collected from this habitat. The greatest numbers of springtails (order Collembola), however, were collected from this stage. Of special interest is a moderate collection (109 specimens) of *Orchesella ainsliei* from DM-6 conditions. With the sole exception of one species of the phorid flies (*Megaselia* sp.), most of the true flies (order Diptera) underwent a uniform depression in collection numbers. Only one species (*Atissa pygmaea*) of the once numerous ephydrid flies continued to utilize the DM-6

habitat. Among the homopterans, moderate numbers of aphids and leafhoppers were isolated from DM-6 conditions. All other insect species collected from this habitat were scanty and in many cases represent only incidental collections.

108. DM-8: mixed climax conditions. As summarized in Figure 14, two possible climax conditions are believed possible for most dredged material disposal sites in the east and gulf coasts of the United States. Only the mixed vegetation climax habitat was sampled with emergence traps. A *Phragmites* climax study was not available to the investigators for this study. As also noted in Appendix D, the mixed climax stage studied for insect emergence consisted of uniform ground cover that was rich in decaying organic matter. A complete canopy of trees consisting of *Baccharis* sp., *Morus alba* (white mulberry), and *Celtis laevigata* (hackberry) covered all parts of the study area.

109. A total of 36 collections, representing 36 weeks of activity, were considered for this habitat. Many of the species were collected on only one or two occasions and therefore should be considered as incidental records, but not necessarily major components of the insect fauna associated with DM-8 conditions. A total of 95 species representing 51 families from 11 orders of the Arthropoda were processed for identification and analysis. Despite this apparently large increase in species diversity, the Shannon-Wiener index was computed to 8.827 (only slightly larger than the DM-6 habitat D-value of 8.079). This continued decrease in the Shannon-Wiener indices is due to the fact that a decrease in numbers of specimens had occurred. Family separations included true flies (Diptera), 17 families; wasps and allies (Hymenoptera), 13 families; beetles (Coleoptera), 7 families; springtails (Collembola), 3 families; roaches and crickets (Orthoptera), 2 families; earwigs (Dermaptera), 2 families; leafhopper and aphids (Homoptera), 2 families; book lice (Psocoptera), 2 families; and the orders Hemiptera, Lepidoptera, and

Thysanoptera with 1 family each represented.

110. Arthropods associated with DM-8 conditions. The collections from DM-8 conditions revealed the greatest variety of insect specimens as had been suspected at the outset. Some caution is advised whenever emergence traps are used, however, as the traps are nonselective and also capture those insects that are merely resting in a given area. Inspection of Table 6 will reveal many species that are undoubtedly in this catagory.

111. The beetles (Coleoptera) were collected in greater variety from this habitat than was the case with DM-6 conditions. Table 2 reveals an interesting variety of Staphylinidae taken from this sere. DM-8 conditions were the only location from which the small springtail (Collembola) *Sminthurinus minutus* was taken. Moderate numbers of two earwig (Dermaptera) species, *Euborellia annulipes* and *Labidura riparaia*, were also associated with this habitat. DM-8 conditions yielded the largest numbers of Dermaptera specimens. Table 6 also lists a wide variety of Diptera. Of special interest is the increase in the catch of *Leia* sp. of the family Mycetophilidae (fungus gnats). Over 80 specimens of this species were collected from DM-8 conditions, while other seres collected few or none of this species. Among the phorid flies (humpbacked flies), it is interesting to note that *Megaselia* sp. was collected consistently from all six seres. The largest collections of any species taken from this habitat were the 696 specimens of the sciarid fly (dark-winged fungus gnats) of the genus *Bradysia*. Almost all other specimens were scanty and in most instances represented by only a few specimens.

112. Sweep net collections are useful to provide information on common flying species of insects that may be located within a given disposal area. The results of two sweep net collections within disposal areas near Houston, Texas, and Topsail Beach, N. C., have been presented as Table 7. While these samples, taken over a two-hour period in mid-afternoon, are useful in a qualitative sense,

they are not regarded as being of equal value to the emergence trap data in significance.

Summary

113. In summary, emergence traps were operated over six of a possible eight successional seres. Emergence traps were not operated over DM-7 habitats as no suitable study area could be located. Individual aquatic collections were made from DM-1 conditions as emergence traps were not feasible for use over the supernatant liquid stage. Cameron (1972) has cautioned against interpreting insect diversity without proper regard to seasonality phenomena. For this reason, some of the data presented must be considered only in the light of the short-term nature of this report. The investigators believe, however, that the species presented represent the major varieties of arthropods that are most likely to be encountered on dredged material disposal sites commonly located along the southeast coast of the United States. The major considerations of this section are summarized below.

- a. A total of seven different successional seres, representing seven different habitats for arthropods, were sampled.
- b. A catalog of the numbers of different species of arthropods was assembled.
- c. Species numbers were compared against species diversity by computing Shannon-Wiener indices.
- d. The successional pattern was determined to have several bypass routes. Stages most commonly bypassed included DM-5 (vegetated mature fissures), DM-6 (weathered fissures), and DM-7 (weathered fissures with vegetation climax).
- e. The highest species diversity indices were found to be associated with DM-3 conditions (incipient fissure formation stage).
- f. Successional seres DM-4 and DM-5 (mature fissures and vegetated mature fissures, respectively) were found to be the most common sources of large numbers of mosquito larvae.

g. With the passage of time there was a slow decrease in species diversity from the high values observed with DM-3 conditions.

h. The lowest species diversity values were obtained from DM-6 (weathered soil) conditions.

i. The species diversity indices did not follow the more classical pattern of increasing species diversity concurrent with increasing age of the ecosystem.

PART V: ECOLOGY OF MOSQUITOES ASSOCIATED WITH DREDGED MATERIAL DISPOSAL SITES

Prevalence of Larval Habitats for Mosquitoes Within Dredged Material Disposal Areas

Rationale and literature review

114. From the outset of this study it was felt that a thorough characterization of the many possible larval habitats for mosquitoes within dredged material disposal areas should be conducted. Preliminary inquiries and initial observations (see Part II) indicated that most local mosquito abatement programs and Corps of Engineers Districts were frequently unaware of the extent of mosquito breeding possible within dredged material disposal sites. Only a few mosquito abatement programs and/or Districts maintained any type of mosquito surveillance activities within such sites. With the exception of the classical references (see pages 32-35), no references were located in the literature that characterized mosquito larval habitats that develop in dredged material disposal sites.

Materials and methods

115. Field trips were conducted to a large variety of dredged material disposal sites in a number of Corps of Engineers Districts. During these field trips extensive conversations were held with local mosquito abatement personnel, state health officials, university entomologists (where available), and selected personnel within the CE District and field offices. A list of these resource personnel is given in Appendix F. A summary of the District site visitations is given in a later section. More extensive observations were possible over longer periods of time on those disposal areas located within the Charleston District. A listing of the many disposal areas that were visited for this section of the report has been presented in Figures 4 and 5. In many cases, it was possible to observe Charleston District disposal sites over extended periods of times both

before and after dredging and disposal operations.

Results and discussion

116. Composite summary of larval habitats. A summary diagram of all the known mosquito breeding habitats that exist within dredged material disposal areas is presented in Figure 15. A listing in this figure means that on more than one occasion mosquito larvae were collected from the habitat. It should be understood that the diagram is a composite impression and that all of the habitats listed would never occur within a single disposal site. The figure is also a temporal composite figure, with some of the habitats developing and dissappearing during the successional cycles previously mentioned (see Part IV). Some of the habitats occurred more often in certain sections of the United States than others. Other habitats were always associated with certain methods of dike construction.

117. Fissured soil (the generalized habitat). As mentioned in Part IV, the formation of extensive soil fissures or DM stages 4 through 7 was invariably the best preliminary indication of the mosquito breeding potential of a given site. This overall habitat is shown in several locations in Figure 15 as item 2. Once such fissured soil is located, it is desirable to estimate the water holding capacity and drainage of this site. As a general rule, however, it may be stated that fissured soil in low, poorly drained habitats within dredged material disposal areas will support mosquito larvae if sufficient water is allowed to stand for approximately 10 days under summer conditions in most parts of the United States. Fissured soil usually occurs in a wide variety of locations on any given site. The mosquito breeding potential of the various stages of fissured soil have been previously estimated in Figure 14 (Part IV) of this report.

118. Dike swale. The dike swale habitat was a minor mosquito habitat that was frequently encountered during this study in a variety of locations. This small swale is usually the result of dredged

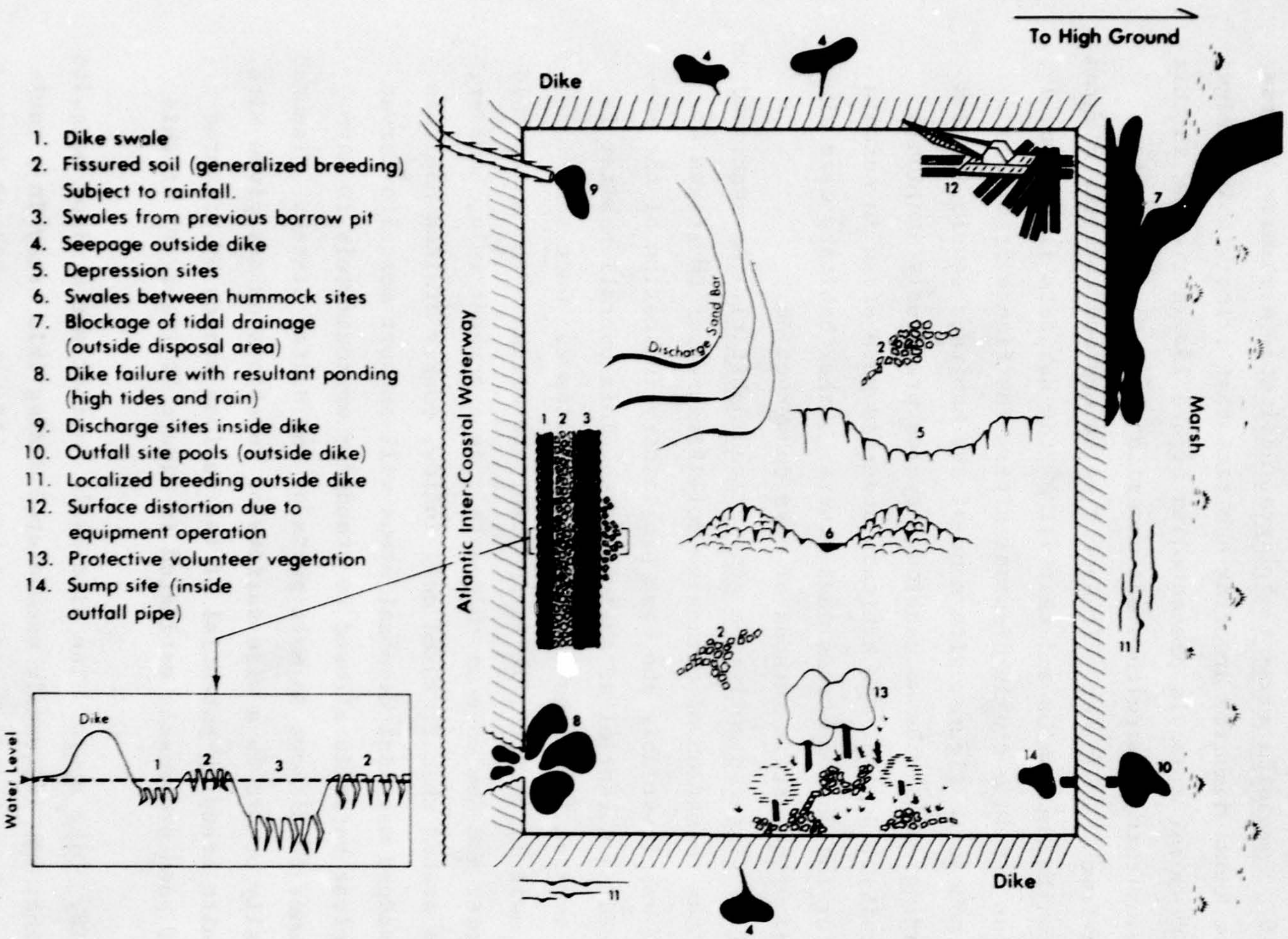

Figure 15

Composite Diagram of Possible Mosquito Breeding Habitats Associated with Dredged Material Disposal Areas material sinking or falling away from the dike proper. The dike swale is illustrated as item 1 of Figure 15 in both polar and profile views. As dredged material begins to shrink during the drying process, the soil will tend to adhere to the dike creating an "adhesion gradient" that causes the swale to form and hold small quantities of water. A photograph of this adhesion gradient and its resultant swale are shown in Figure 16. In many cases unusual amounts of water were located in dike swales. From Figure 16, it is obvious that the dike swale receives a large amount of water as runoff from the dike. During any mosquito surveillance inspection, it is imperative that the poorly drained dike swales be sampled for water and mosquito larvae. During numerous field trips undertaken during this study, it was not uncommon to encounter disposal sites whose larval mosquito populations were confined to this dike swale habitat. Mosquito breeding is not uniform within the dike swale habitat, but usually confined (except during periods of heavy rainfall) to the lower portions of the disposal site. The amount of water within the dike swale is normally not significant (never observed to threaten the dike), but this small source of water does constitute a source of mosquito larvae that can be easily overlooked. Inspectors of disposal sites should be trained to check the lowest elevation point of the dike swale habitat for the presence of mosquito larvae. This technique is mentioned because many field workers will tend to use the discharge site of a disposal area as a boat landing and in such cases, caution must be made to insure that low areas are actually inspected. At this point it should be noted that the discharge site is invariably the highest elevation within the disposal area.

119. Borrow pit swales. Borrow pit swales are major sources of mosquito larvae and develop only on those disposal areas that have been used more than once or have undergone dike reconstruction. In many areas of the United States, it is a common practice to take the dike materials from a borrow pit located within the disposal area

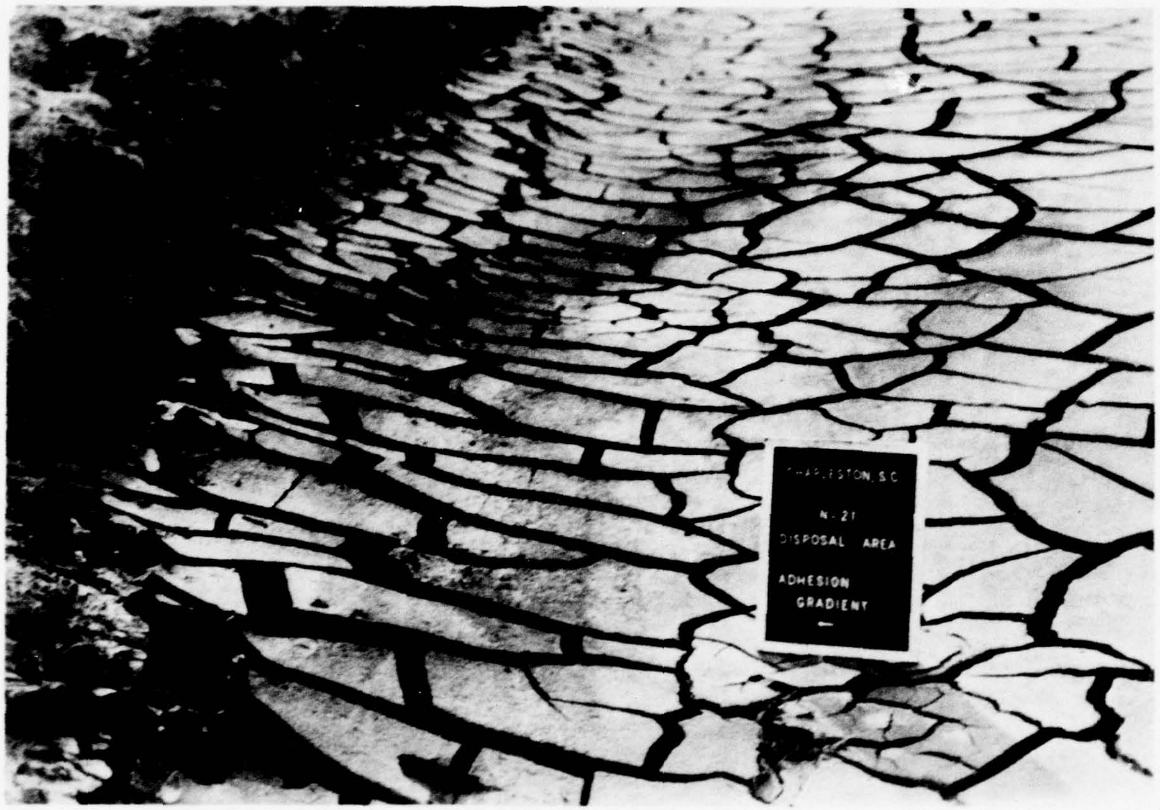

Figure 16

Adhesion Gradient with Resultant Dike Swale Habitat per se. In some cases, dike materials cannot be taken from outside the disposal site area. Murphy and Zeigler (1974) have described this dike construction as "incremental dike construction." These authors correctly noted that "the quality of the dredged material may greatly affect the ultimate dike dimensions and stability." A second, less frequently employed method of dike construction is the "interior dike" method. This method employs a system of new dikes that are added to the disposal area always on the inside of the previous dike. Both of these dike rebuilding methods result in borrow pits that are frequently associated with mosquito breeding. Two mosquito breeding problems are common following such operations. First, the borrow pit per se tends to collect and hold water and thus may become a source of either fresh or brackish water mosquitoes. With the onset of the flow of dredged material into the disposal area, the borrow pit is usually filled and the surface of the disposal area becomes uniform for a short period of time. As the dredged material begins to dehydrate, however, a swale soon appears that follows the exact conformation of the previous borrow pit. The borrow pit swale is therefore seen as the natural result of dredged material consolidation in the old borrow pit. Borrow pit swales are one of the most common habitats for mosquitoes within dredged material disposal areas. The difference in the depth of the borrow pit swale compared against the dike swale is shown in profile view as items 1 and 3 in Figure 15. The greater depth of the borrow pit swale accounts for its longer life and greater productivity as a source of mosquitoes.

120. Dike seepage. Many disposal areas in the U. S. are confronted with the problem of dike seepage. Normally this is regarded as an engineering problem and possibly a threat to the integrity of the dike. Pools of stagnant, seepage water adjacent to disposal area dikes also represent frequent sources of mosquitoes. In some cases seepage pools near disposal sites may be the only habitat actively producing mosquitoes. Seepage pools were commonly observed

near the lower elevations of many disposal areas during this study. Mosquitoes were observed to favor those seepage pools that occurred near the upland sides of the disposal sites, as such habitats were less likely to have tidal flushing action. In some limited cases, where the materials used for dike construction varied in quality, localized sources of seepage were easily located. In such instances, outside mosquito breeding was directly attributed to the presence of seepage pools. An example of seepage pools as a disposal area habitat for larval mosquitoes is shown as Figure 17.

121. Depression and hummock sites. Depression and hummock habitats for larval mosquitoes are illustrated as items 5 and 6, respectively, in Figure 15. Depression habitats are areas of fissured soil that are located within sunken areas of dredged natural disposal sites. Such habitats were observed to vary in size from less than 1 sq m to several square meters. The lower elevation of these areas allows the depression habitat to collect and hold water for sustained periods of time. This presence of water may allow also the depression site to become colonized with volunteer plants which also tend to maintain the habitat as an active source of mosquito larvae. It was frequently observed that depression sites could be located near the center of dredged material disposal areas. Aerial surveillance is the only known method for rapidly locating such isolated habitats. In contrast to the depression site habitat (associated with a lowering of the immediate elevation), hummock swales develop between two upraised areas of dredged material (see Figure 15, item 6). Hummock sites were always associated with one or more portions of dredged material undergoing a rise in elevation above the surrounding material. The hummock and depression habitats were not observed to be major mosquito habitats and were never located in great numbers. It is important to note, however, that in both cases subtle changes in the elevation of fissured dredged material greatly affect the ability of these two habitats to hold water for sustained periods of

Figure 17

Dike Seepage Habitat in Galveston CE District time.

122. Blockage of tidal drainage. In some states, dredged material disposal sites have been constructed over tidal creeks in such a manner that tidal flushing and drainage are blocked. This blockage usually results in the ponding of water outside disposal area dikes in shallow, irregular marsh depressions. This habitat is illustrated as item 7 of Figure 15. It is expected that this habitat will be present whenever disposal areas are constructed without regard to natural tidal drainage patterns. A related problem associated with the blockage of tidal creeks is the undermining of the foundation of the disposal area dike. In some extreme cases, this blockage of tidal creeks may destroy portions of disposal area dikes. In other cases, tidal blockage results in ponding only during unusually high tides. In these cases, field inspectors should be trained to observe temporary ponded habitats that may only exist during storm or spring tides.

123. Dike failure. Dike failure with resultant ponding inside the dike within fissured soil is illustrated in Figure 15 as item 8. In several cases, the investigators observed poorly constructed dikes that failed due to the erosive action of wind driven tides. When a dike is broken in such a manner that tidal water may enter the disposal area and subsequently flood large areas of fissured soil, larval mosquitoes may develop. It is important to separate tidal flooding of fissured soil from tidal flushing of a disposal site. In the case of the former, the ponding of water on fissured soil generates a mosquito breeding habitat. In the latter case (flushing action), ebb and flow drainage is created and mosquito breeding may be eliminated. In summary, if a dike is breached allowing tidal water to enter a disposal area and become trapped, then it is reasonable to suspect that a mosquito breeding habitat has been established that will support larval mosquitoes after almost every unusually high tide (e.g. storm tides, spring tides, etc). In other cases where

tidal waters were not trapped and regular tidal flushing allowed for both drainage as well as the presence of mosquito larval predators, the presence of this "flushing action" eliminated mosquito sources. A disposal area with a broken dike that allowed for desirable tidal flushing is presented in Figure 18. It is therefore extremely important that all dike failures that are exposed to tidal action be monitored to ascertain the relationship of the breach to mosquito breeding.

124. Outfall and sump habitats. Outfall site pools and sump pools are illustrated in Figure 15 as items 10 and 14, respectively. Outfall sites are always located immediately below a drainage weir outside a dredged material disposal area. In most cases, such weirs tend to scour (by water runoff) a drainage ditch into the marsh away from the weir. Outfall sites were not observed to be major habitats for larval mosquitoes, but in some instances large larval concentrations of several species of mosquitoes were located in stagnant outfall pools that had become covered over with marsh vegetation and therefore did not drain properly. Field inspectors should be trained to routinely check all drainage weirs for larvae. In many cases, this habitat may be eliminited through the use of hand ditching tools to connect the pool to the surrounding marsh. In contrast to the outfall sites, sump habitats were found to be the most common sources of mosquito larvae within dredged material disposal sites. A sump site is defined as that area of soft, fissured dredged material located near the lowest elevations within a disposal area. Such sites are usually associated with drainage weirs. These habitats support mosquito larvae more often than outfall sites (only a few feet away) because they almost never drain or undergo desiccation except under the driest possible conditions. In general, it may be stated that the sump habitat is the most likely source of mosquitoes within a given disposal area. Aerial overflights of a disposal area will quickly give an investigator the location of low elevation sump sites.

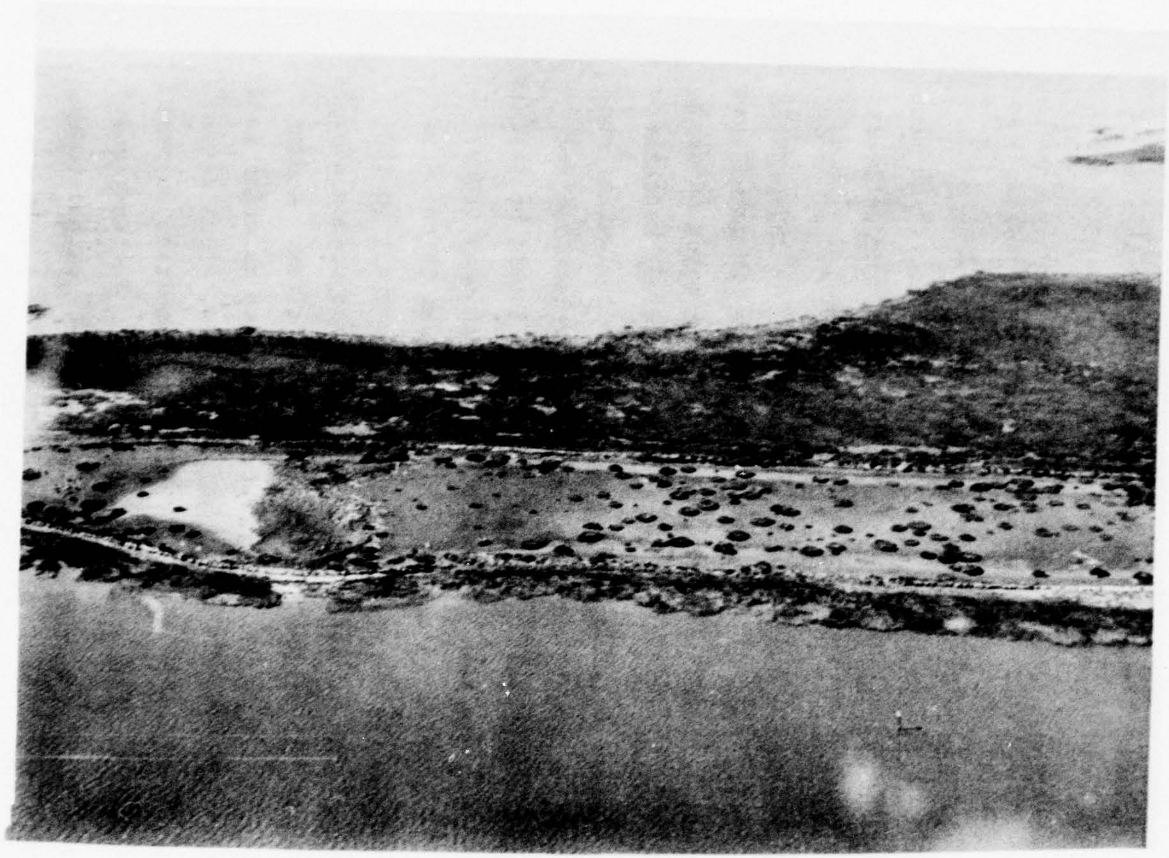

Figure 18

Aerial View of Dike Failure Habitat with Tidal Flushing Apparent (center), Charleston CE District

It cannot be emphasized too strongly that the sump habitat was the most common source of larval mosquitoes observed during this study.

125. Localized breeding outside disposal areas. In some instances, certain characteristics of dike construction may create small pockets of mosquito breeding habitats. This habitat is illustrated in Figure 15 as item 11. The most frequent type of breeding habitat that was observed in this catagory was caused by the presence of shallow depressions that were located outside of disposal area dikes. Some of these depressions appeared to be caused by tidal erosion and dike slumping. Once the presence of such localized habitats has been established, physical control measures, such as ditching, may be employed with success.

126. Surface distortion. The operation of large mechanical equipment within dredged material disposal areas such as draglines and "marsh buggies" may create temporary or long-lasting localized larval mosquito habitats. This habitat is shown as item 12 in Figure 15. A photograph of mosquito breeding conditions that developed within a dredged material disposal site following heavy equipment operation is present in Figure 19. Surface distortion habitats are usually filled in during the next pumping of dredged material, but their presence may create future mosquito habitats by causing swales to develop as the new dredged material begins to settle and consolidate. Because mosquito habitats are commonly associated with swales and other depressions that may develop as a result of previous surface alterations, it is extremely important from the standpoint of mosquito control that surface distortion of dredged material by heavy equipment to be held to a minimum. An example of the large numbers of mosquito larvae that were observed to concentrate in this habitat is presented in Figure 20.

127. Discharge site habitat. The discharge site habitat is illustrated in Figure 15 as item 9. Discharge sites are defined as those semipermanent pools that are formed as a result of the scouring

Figure 19

Surface Distortion by Mechanical Equipment Operation
within a Dredged Material Disposal Site
(note resultant larval mosquito habitats)

Figure 20

Detail of Surface Distortion Habitat Showing a High Concentration of Mosquito Larvae action of the dredged material as it is released into the disposal area. It was immediately evident to the investigators that those disposal areas that did not employ splash pads had the deeper discharge pools. The discharge habitats were not found to be major sources of mosquitoes, due in part to their small size and the fact that such sites tended to have semipermanent water present. Discharge habitats were found to support mosquitoes when the sites had dried thoroughly and adult mosquitoes had oviposited on the resultant moist soil. The semipermanent presence of water also allowed for the presence of aquatic predators. In this manner, it was deduced that discharge sites tend to produce mosquitoes only during wet periods that follow very dry conditions. It is important that the fissured soil normally contained within dredged material disposal sites is alternately wet and dry (allowing for mosquito egg deposition), while the discharge site tends to remain reasonably wet. Since the drying phase usually does not develop on discharge sites, such areas usually are not significant sources of mosquitoes. The proper use of concrete splash pads (as frequently specified in some Corps of Engineers contracts) near the discharge pipe would effectively prevent the formation of this habitat.

128. Protective volunteer vegetation. This habitat is illustrated in Figure 15 as item 13. The accurate location and mapping of unusual concentrations of volunteer vegetation within a dredged material disposal area are important aspects of a good mosquito surveillance program. During the field investigations for this study, this habitat ranked third in importance as a mosquito breeding habitat. In some cases such vegetated sites may be the only larval habitat present within an entire disposal area. An ideal example of a mosquito breeding in this category is presented in Figure 21.

Summary

129. In summary, the following factors related to mosquito larval habitats within dredged material disposal areas have been

Figure 21

Protective Vegetation Habitat within a Dredged Material Disposal Site (note the lack of soil weathering where plants have been removed) considered.

- a. A wide variety of mosquito larval habitats were found to exist within dredged material disposal areas.
- b. Some habitats were found to be associated with particular successional stages.
- c. The most common sources of mosquito larvae within dredged material disposal sites were the sump, borrow pit swale, dike swale, and protective vegetation habitats.
- d. Following mechanical equipment operation within dredged material disposal areas, localized mosquito larval habitats are a commonplace occurrence.
- e. A number of mosquito larval habitats of lesser importance were also identified and characterized. Many of these habitats develop only under specialized conditions.
- f. Surface alterations within dredged material disposal sites tend to produce swales shortly after the consolidation of fresh dredged material. These swales are identical in size, shape, and pattern to their precursor depressions. An example of this phenomenon is the development of a borrow pit swale in the original borrow pit locations following a fresh pumping of dredged material.
- g. Under optimum conditions, mosquito emergence from dredged material disposal sites usually occurs within 7 to 10 days after a rain. Removal of water from the site during this period will disrupt the mosquito's life cycle and alleviate the problem.

Survey of Larval Mosquitoes Associated with Dredged Material Disposal Areas

Rationale and review of literature

130. In addition to the characterization of mosquito larval habitats, it was felt by the investigators that a survey should be conducted of larval mosquitoes developing within or near dredged material disposal sites. Due to the remote locations of many disposal sites and capricious nature of natural rainfall patterns, a systematic survey was not possible. It was decided that larval samples

would be collected from as many different known larval habitats as possible from a wide variety of disposal sites. The mosquito breeding potential of the various stages of dredged material successional patterns has been previously presented in Figure 14. From this diagram it will be seen that stages DM-4 and DM-5 are the most common seres associated with larval mosquitoes. Data are scanty or not available concerning the breeding potential of stage DM-8. Data presented in Figure 15 indicate all the known larval habitats that are possible for a dredged material disposal site. No references, other than the classical references cited in Part II, were located that pertained to larval collection techniques for dredged material disposal sites.

Materials and methods

131. Collecting methods. Larvae were collected whenever possible from 12 February 1976 to 15 September 1976. All larvae were collected from one of the larval habitats depicted in Figure 15 within or near a disposal site. Natural mosquito sources that were not associated in any way with disposal sites were ignored. Larvae were sampled with the traditional mosquito larval dipper (1-pt capacity), but a more reliable method for detecting the presence of mosquito larvae from the various fissured soil habitats involved the use of the household "baster." Basters are plastic cylinders tapered on one end and equipped with a rubber bulb on the opposite end. Basters were superior to dippers because they could be inserted into the fissured soil habitat in locations where the dipper could not be used.

132. Qualitative sampling. From the outset of the study the investigators were faced with a choice of sampling methods, subject to rainfall, travel (boat) conditions, and personnel needs. Inasmuch as this study represents the first attempt to study mosquito ecology within disposal sites, it was decided that qualitative larval sampling from a large number of sites under good rainfall conditions

would provide more information regarding mosquito species diversity than quantative sampling from a few locations. Quantitative data from three different disposal sites are presented on adult mosquitoes in a later section.

133. Sample sizes. A total of 210 samples were collected. The size of the larval samples varied from single larval collections to large collections of more than 3000 individuals. If collections were larger than 50 specimens, then aliquot portions were examined. Frequently, it was necessary to maintain larvae in the laboratory for several days growth before preservation. When possible the number of larvae per dipper sample was recorded (LPD), and the number of adult mosquitoes alighting on the investigator in 1 min of time was noted as a landing rate count (LRC). Both of these techniques are standard estimates of mosquito activity, but not all species of mosquitoes can be estimated in this manner. Some larval collections were submitted to the investigators through the courtesy of the Charleston County Mosquito Abatement Program.

134. Significance of larval collections. The finding of larval mosquitoes within dredged material disposal areas is significant in that it is then known that the species actually used the site as a breeding habitat. The finding of adult mosquitoes is of less importance as the mosquitoes may have flown into the disposal site, but may not sctually have used the disposal area as a breeding habitat. When both larvae and adults are found within a disposal site, however, the cycle is then complete. Inspection of the data collected revealed a great similiarity of species and collection data. It was decided to present a summary of the larval collection data on a species basis as opposed to individual collection data.

Results and discussion

135. General observations. Mosquito larvae developing within dredged material disposal sites were dependent on natural rainfall for their aquatic habitats. It is extremely important to

note that the eggs of the most common species of mosquitoes associated with disposal areas are known to oviposit on damp soil and not standing water. For this reason the dry periods that affect disposal sites are also important in the life cycles of mosquitoes associated with dredging. In general, prolonged dry periods over dredged material disposal sites allow the eggs of the more common mosquito species to accumulate. In contrast, periods of alternating wet and dry periods tend to produce more broods of mosquitoes with fewer numbers. A large disposal area consisting of fissured soil in DM-4 or DM-5 conditions will attract mosquitoes that oviposit almost continually during a prolonged period of dry weather. In this manner an "egg build up" occurs and spectacular concentrations of adult and larval mosquitoes are observed shortly after the dry disposal site becomes flooded by rain. This observation has important implications for the monitoring of the mosquito breeding potentials. Careful monitoring of rainfall data from a wide variety of sources will usually allow for reasonable predictions of mosquito breeding within disposal sites. It is essential that the rainfall data be gathered from gauges located within or very near the actual disposal sites and that as many gauges be utilized as practical.

136. Larval collecting techniques. It is also necessary that personnel charged with the inspection of disposal areas for mosquito larvae be trained to locate the wide variety of potential larval habitats (see Figure 15). In many cases during this study larvae were collected in large numbers from very restricted habitats. For example, a large (200-acre) disposal site in one instance was found to support larval mosquitoes in only one restricted location. This site was approximately 1000 sq ft near the outfall sump of the disposal area. The ramaining portion of the site did not support any larval mosquitoes, but the sole source was determined to be the sump habitat. It is also important to note that traditional breeding sources may change within a given disposal area with the passage of

time. A dike swale that was observed to support larval mosquitoes in one case for over two years did not support any larvae from the third year onward because of soil weathering (a change from DM-4 to DM-6 conditions, see also Figure 14).

137. Weathered soil subsurface fissures. One unusual microhabitat that was encountered on several occasions was the weathered soil subsurface fissure. This microhabitat is defined as a small crevice that develops within a primary fissure from weathered surface soil. These subsurface fissures usually occur during early DM-6 conditions or late DM-4 and DM-5 stages (see Figure 14). The weathered soil subsurface fissure is the result of a resuspension of weathered soil that has been washed or blown down into the original primary fissure. Following a heavy rainfall and subsequent evaporation, the weathered soil forms a new subsurface fissure. In this manner, a new smaller crevice can now be observed near the base of the original soil fissure. In order to properly check a disposal site for mosquito larvae it is essential that personnel be trained to locate and sample from this specialized microhabitat. Those sites that have subsurface fissures will usually support mosquito larvae, especially if the habitats are located near areas of lower elevation.

138. *Aedes sollicitans*. The most common mosquitoes collected as a larvae during this study were *Aedes sollicitans*. This species was also the only species that was collected in small numbers during the winter and early spring months of 1976 from dredged material disposal sites. Collections varied from small numbers of larvae that made their first appearance on the Morris Island Disposal site (Figure 4) on 12 February 1976 to extremely large collections that were made on Ashe Island (see Figure 5, S-18) on 22 June 1976. The standard LPD counts varied from a low of 1 to a high of 400 during the 1976 survey season.

139. *A. sollicitans* was commonly taken from all habitats previously shown in Figure 15, but the most common collection sources

were determined to be the dike swales, borrow pit swales, sump areas, and dike failure sites (see items 1, 3, 14, and 8, respectively, of Figure 15). Larvae of this species were also commonly associated with DM-4, DM-5, and DM-7 conditions. While quantitative tests were not conducted, it appeared that the earlier seres of dredged material succession pattern (DM-4 and DM-5) were the usual locations for the vast bulk of the *A. sollicitans* collections. *A. sollicitans* were never collected from the permanently flooded portions of a disposal site. A list of plant species associated with mosquito larval habitats is presented in Appendix A. It is extremely important to review the fact that this species is known to oviposit on moist soil, but not flooded areas. For this reason the abundant moist soil associated with most dredged material disposal sites tends to attract female mosquitoes seeking sites for egg deposition. Hatching of the larvae may be associated with rainfall within a disposal site or tidal flooding of fissured soil due to dike failure. The eggs have been reported to be extremely resistant to drying and cold winter conditions. This fact may account for the large broods of *A. sollicitans* eggs that occur on some disposal sites following a prolonged period of dry, warm weather. The percentage of the eggs that hatch on any given flooding is known to vary. Woodward and Chapman (1970) noted that a total of 41 separate floodings were needed to completely hatch all available mosquito eggs in natural salt marsh. *A. sollicitans* has been collected from a wide range of coastal habitats in the United States and Canada, from New Brunswick to southern Texas (King et al. 1960). The species is also capable of using certain inland habitats. During this study, *A. sollicitans* was the major mosquito species developing within dredged material disposal sites. *A. sollicitans* larvae were regularly collected from over 45 disposal sites during 1976 for this study.

140. *Aedes taeniorhynchus*. The second most numerous mosquito species collected during this study was *Aedes taeniorhynchus*,

sometimes termed "the black salt marsh mosquito." Unlike *A. sollicitans, A. taeniorhynchus* did not normally appear in significant numbers in the study areas until late May of 1976. Collections varied from a single larval specimen (frequently found in close association with large numbers of *A. sollicitans*) to over 350 larval specimens that were collected on separate occasions from disposal sites S-7 and S-8 (see Figure 5) on 21 July 1976. Large numbers of *A. taeniorhynchus* were collected from a wide variety of sites during late July and late September from 39 different disposal sites during the 1976 survey. The investigators were unable to quantify any significant differences between the larval habitats (with disposal areas) of *A. sollicitans* or *A. taeniorhynchus* as the two species were almost invariably collected together. The exact niche partition between the larvae remains a matter of needed future research. *A. taeniorhynchus*, like *A. sollicitans*, may utilize nonmarsh habitats and nondisposal sites for oviposition and the appearance of large numbers of adults of either of these two species in a given area does not necessarily mean that disposal areas are the source of the mosquitoes, unless living larvae can be detected from the site in question. For this reason, it is extremely important that some larval sampling for the dominant mosquito species be conducted on a continuing basis within most dredged material disposal sites.

141. *Aedes atlanticus*. A total of five specimens of this species were collected from a larger sample that contained other mosquito larvae from disposal area S-11 on 27 May 1976. An additional collection was made on 29 May that yielded three more *A. atlanticus* larvae. Site S-11 (see Figure 5) during the time of these collections was an older disposal area classified as DM-8. It is important to note that the adults (female) of *A. atlanticus* cannot be separated from the adults of *Aedes tormentor*. This fact makes the collection of larvae of these two species more significant. It is not thought by the investigators that *A. atlanticus* is a major mosquito species

associated with the majority of dredged material disposal sites in the United States. The species was not collected again during the study period.

142. *Aedes vexans*. *Aedes vexans* was collected infrequently during this study, but other workers (see site visitations) report this species to be reasonably common within dredged material disposal areas. *Aedes vexans* was collected from Drum Island disposal site (see Figure 4) on different occasions. The habitat was an older portion of the site characterized as stage DM-8. Older sites that yielded *Aedes vexans* on at least three separate occasions included sites S-10, S-11, N-7, and E-3 (see Figure 5). While not common on disposal sites during this study, it is important to note that *A. vexans* is the dominant inland mosquito species in many parts of the U. S. It is more commonly associated with floodwater conditions in woodland areas and along alluvial plains. A total of 88 larvae of these species were collected from 4 April to 15 September 1976 from the study sites listed above.

143. Anopheline mosquitoes. Dredged material disposal sites are not known to be major sources of anopheline mosquitoes as these species are normally associated with freshwater swamps and other permanent bodies of water. Three anopheline species of mosquitoes were collected as larvae during this study. *Anopheles bradleyi* were the most commonly collected anopheline larvae. This species was collected on 12 different occasions from 16 April to 16 September 1976 from sites S-11, Albemarle Island (S-1B), A-2A (Georgetown County), N-7, and Drum Island (see Figure 5). King et al. (1960) have commented on the affinity of this species for brackish waters. A total of 55 specimens were collected during 1976, ranging from a low of 1 larva to a high collection of 12 larvae.

144. *Anopheles atropos* is also known to breed in brackish waters and was rarely encountered during this study. Only two locations, Drum Island and Albemarle Island, yielded larvae of this

species. Larval determinations of both *Anopheles bradleyi* and *A. atropos* were confirmed by a taxonomic specialist (Personal Communication, 19 February 1976, Dr. Richard F. Darsie, Jr., Vector Biology and Control Div. of the U. S. Public Health Service, Center for Disease Control, Atlanta, Ga., 30333). The earliest collection of this species was 6 May 1976 and the latest collection occurred on 11 October 1975. Little is known about *A. atropos* except for its well-known breeding preferences for salt and brackish waters. King et al. (1960) have suggested that *A. atropos* is more tolerant of strong brackish waters than *A. bradleyi*. Larvae of *A. atropos* were collected by Griffitts (1937) in water ranging from 0.8 to 3.4 percent salt concentrations. It is suspected by the investigators that *A. atropos* may be more common on dredged material disposal sites than collections would indicate. A total of 12 specimens of *A. atropos* were collected on four occasions from the two disposal sites (under DM-5 conditions) during this study.

145. Only nine specimens of *Anopheles quadrimaculatus* from four disposal sites were collected during the 1976 survey. The earliest collections occurred on 3 May and latest collections were located on 26 August 1976. Collection sites included Drum Island, Albemarle Island, Hog Island, and S-11 (see Figures 4 and 5). *A. quadrimaculatus* is considered an important vector species of malaria, but it is not considered to be a major component of the culicid fauna of dredged material disposal sites.

146. *Culex* spp. Two species of the genus Culex were taken from dredged material disposal sites during the study. *Culex salinarius* was found to be a major mosquito species associated with disposal areas. A total of 472 larvae of this species were identified during this study from 14 different disposal areas, including Morris Island, Drum Island, Hog Island, Ashe Island, S-11, S-7, N-22, Clouter Creek site, N-7, N-5, N-5A, A-6, A-5, and E-2 (see Figures 4 and 5). Larvae were consistantly collected from discharge pools,

seepage locations, and outfall areas. The largest collections were located near the Morris Island Disposal site (see Figure 4) where construction of a disposal area dike had blocked the normal tidal drainage of the marsh. Collection dates ranged from 14 March to 16 September 1976. It is interesting to note that this species was not observed to utilize the more common larval habitats used by the other species in any significant numbers, but was frequently encountered in specific locations in almost pure culture. *C. salinarius* was never located in either the dike or borrow pit swale habitats. Mixed collections of *C. salinarius* were infrequently observed around sump sites in late July of 1976. At that time *C. salinarius* was collected on three occasions in association with *Aedes sollicitans* and *A. taeniorhynchus*. Discharge pools (see Figure 15) were the most common sources of small numbers of *C. salinarius*. Because of its restricted habitat, *C. salinarius* is regarded as a minor species that may become numerous under certain conditions. Despite its name, *C. salinarius* is not thought to exhibit a preference for brackish water larval habitats. It is more frequently encountered in freshwater environments. *C. salinarius* is generally considered a lesser pest species than the more common salt marsh *Aedes* spp.

147. A single collection of 15 larvae of *Culex restuans* was made from Drum Island on 24 March 1976. This widely distributed species is not considered a major mosquito species associated with dredged material disposal areas. The site was a polluted borrow pit swale habitat (see Figure 15).

148. *Psorophora* spp. Two species of the genus *Psorophora* were collected during the study. A total of 15 larvae of *Psorophora howardii* were collected on a single occasion from site S-11 on 27 May 1976. This site was an older disposal area that had not received any fresh dredged material for almost 10 years and was considered to be in the DM-8 stage. A sample of the vegetation revealed mainly freshwater upland plants. While only a small number of larvae were

collected, the investigators believe that this species may occur in larger numbers than the collection data would appear to indicate. Other workers report (Personal Communication, 24 July 1977, Lt. Joseph Vorgetts, Jr., The Citadel, Charleston, S. C., 29409) that *Psorophora horrida* has been found within dredged material disposal sites near Topsail Beach, N. C. in significant numbers. The psorophorans are severe biters whose larvae are normally associated with transient pools of water in woodlands, pastures, and other temporary pool conditions. Like the *Aedes* mosquitoes to whom they are closely related, the psorophoran eggs are adapted for withstanding long periods of drying conditions, but tend to develop quickly in warm temperatures upon flooding. For these reasons, the investigators believe that older disposal sites (DM-8 conditions) should be carefully monitored for the possibility of larger populations than are indicated by this study.

149. Other possible species. While not encountered during this study, several additional species of mosquitoes may be capable of utilizing dredged material disposal sites for larval development. These include *Anopheles crucians*, *Coquillettidia (=Mansonia) perturbans*, *Culiseta melanrua*, *Culex territans*, *Aedes triseriatus*, *Aedes trivittatus*, and *Aedes tormentor*.

Summary

150. In summary, the following factors related to the presence of mosquito larvae developing within dredged material disposal sites have been considered.

a. An intensive survey for mosquito larvae was conducted during the entire year of 1976.

b. A total of 11 mosquito species were collected as larvae from various habitats within dredged material disposal sites.

c. An additional eight species were considered as possible mosquitoes that might be associated with older dredged material disposal sites.

d. A total of 210 separate larval collections were made from 58 different dredged material disposal sites.

e. The weathered soil subsurface fissure was identified as a potential microhabitat for mosquito larvae that may be frequently overlooked during routine survey trips.

f. *Aedes sollicitans* and *Aedes taeniorhynchus* were the major species of mosquitoes developing within the dredged material disposal sites during this study.

g. *Culex salinarius* larvae were located frequently from certain restricted habitats.

h. Other species of mosquitoes may be more or less numerous than indicated by this study due to changing environmental conditions.

i. Prolonged dry periods tended to produce larger larval broods of mosquitoes than did periods of alternate wet and dry conditions.

j. The habit of *Aedes* mosquitoes for seeking moist soil (as opposed to standing water for *Culex* mosquitoes) for oviposition sites tends to render dredged material disposal areas favorable for *Aedes* spp. larval development.

Chemical Characteristics of Water from Larval Habitats Within Dredged Material Disposal Areas

Rationale and literature review

151. From the previous sections one can see that mosquito breeding within dredged material disposal areas is totally dependent upon the presence of water. From Figure 15, it can be further determined that these water habitats may occur in a wide variety of locations. From the outset of the study, it was considered desirable to study the chemical characteristics of water from known sources of mosquito larvae. Only those habitats that had produced the dominant species of mosquitoes (*Aedes sollicitans* and *Aedes taeniorhynchus*) were studied.

152. To date no studies have been made of the chemical characteristics of mosquito larval habitats within dredged material

disposal sites. A few workers have studied the chemical characteristics of mosquito larval habitats in marsh locations similar to disposal areas. Cory and Crosthwait (1939) were among the first workers who considered the nature of mosquito aquatic habitats. Darsie and Springer (1957) studied water associated with the larvae of several species of mosquitoes, including *Aedes sollicitans* and *Aedes taeniorhynchus*, in natural and impounded salt marshes in Delaware. Chapman (1959) conducted observations of the effects of salinity on natural and impounded salt marshes. Petersen and Chapman (1969) investigated chemical factors that affected mosquito larvae within tree holes and related habitats. Finally, Petersen and Chapman (1970a) also considered the chemical characteristics that affected the larval habitats of *Aedes sollicitans*, *Aedes taeniorhynchus*, and *Psorophora columbiae*.

Materials and methods

153. Chemical tests and procedures similar to those of Petersen and Chapman (1969, 1970a) were followed. Certain changes were made to accomodate some of the unusual properties of dredged material. The samples were collected from September 1975 to April 1976. A total of 34 water samples from 10 different disposal sites were collected for analysis. In some cases, only a single water sample was collected while in other instances up to 12 samples were taken from a single site over an extended period of time. All sites contained larvae when water samples were collected or they had supported larval populations of mosquitoes in the recent past (i.e. within three months). Water samples were collected from small pools associated with fissured soil (normally under DM-4 or DM-5 conditions, see Figure 14) that exhibited a maximum depth of 6 to 8 cm. These habitats were lentic in nature and not subject to any drainage movement at the time of the collection. At the sample site the following analyses were made:

a. Dissolved oxygen (DO) by the modified Winkler micromethod.

b. Carbon dioxide (CO_2) by the sodium hydroxide titration method.

c. Total alkalinity (TA) by the bromcresol green-methyl red indicator method.

d. Temperature by mercury thermometer.

154. One additional liter of water was removed from the site and returned to the lab for further analysis. These samples were placed in sealed jars and stored at a temperature of 4°C. All water samples were analyzed within 24 hours of sample time. Conductivity was measured with a Hach conductivity meter that was temperature compensated. The cell constant was approximately 2.0. The measurements were recorded as micromhos per centimeter. Measurements of pH were studied on a Leeds-Northrup pH meter with a pH scale of 0 to 14. This meter was considered accurate within $\pm$0.1 and was manually temperature compensated. The remainder of the analyses were conducted on a Hach Dr/2 Spectrophotometer. The wavelength of this apparatus was adjustable between the range of 400 and 700 nanometers with an accuracy of $\pm$ 2.5 nanometers. Other laboratory analyses were run following standard analysis procedures (Hach Chemical Company 1975). These water tests included:

a. Suspended solids by photometry.

b. Sulfides by the methylene blue method.

c. Turbidity by absorptometric methods as formazin turbidity units (FTU's).

d. Total inorganic phosphates by hydrolysis methods.

e. Tannin and lignin concentrations by the tyrosine method.

f. Total iron by the ferrozine methods.

g. Ammonia nitrogen by the Nessler method.

h. Nitrate nitrogen by the cadmium reduction method.

i. Sulfates by the Sulfa-Ver IV sulfate method.

j. Nitrate nitrogen by the diazotization method.

k. Orthophosphates by the ascorbic acid method.

1. Organic phosphates by the orthophosphate oxidation method.

Results and discussion

155. General observations. A summary of the average chemical values obtained for this section of the report is presented as Table 8. In general, the mosquito larval habitat was found to consist of alkaline water with a high concentration of various salts. Larvae were observed to tolerate a wide range of chemical and turbidity conditions. The data collected illustrate these chemical variations. While not included in this study, the investigators on several occasions were able to observe the rapid chemical changes that occurred within larval habitats following a period of sudden rain. Larvae were never observed to be adversely affected by these rapid changes in the chemical environment. Temperatures were observed to range from a high of 98° F to a low of 28° F during the study period. During the summer months, it was common to observe a 15% temperature differential between the ambient temperature and the temperature within the dredged material fissures. Water temperatures were generally > 75% F during the summer months.

156. Salinity. Salinity levels within dredged material disposal areas are subject to rapid and drastic fluctuations. This changing saline environment limits the number of mosquito species which can survive in such a habitat. Unlike marine ecosystems where salinity usually remains constant, dredged material disposal sites present a picture of constantly changing salinity values caused by rainfall, evaporation, and soil leaching. In some instances, mosquito larvae were located in disposal site habitats with higher salinity levels than that of seawater. These larvae (*Aedes sollicitans* and *Aedes taeniorhynchus*), however, were able to complete their life cycles despite these harsh conditions. The conductivity of the water samples from disposal sites ranged from a low of 10.6 g/l of NaCl to a high of 43.6 g/l (i.e., conductivity values of 18,400

Table 8

Chemical Characteristics (Avg Values) of Water Samples from Typical Mosquito Habitats within Dredged Material Disposal Sites, Charleston, S. C., 1976

		Chemical Characteristic				
Location	No. of Samples	Conductivity Micromhos/cm	Suspended Solids mg/l	Sulfide mg/l	Turbidity FTU	pH
Albemarle Island	4	22500	20.0	0.020	27.0	8.50
Clouter Creek Island	2	18400	0.0	0.020	85.0	7.75
Daniel Island	4	46300	20.0	0.026	45.5	8.00
Drum Island	2	41000	20.0	0.031	20.0	9.10
N-9	4	38600	20.0	0.022	32.0	7.91
N-15	3	49600	20.0	0.020	20.0	7.43
N-16	1	48000	0.0	0.025	20.0	7.40
N-20	1	70400	0.0	0.020	70.0	8.30
N-21	1	75800	20.0	0.020	85.0	7.80
N-22	12	55700	20.0	0.022	42.0	8.00

(continued)

(Sheet 1 of 4)

Table 8 (continued)

Location	No. of Samples	Chemical Characteristic: Phosphate, Total Inorganic mg/l	Tannin-Lignin mg/l Tannic Acid	Iron, Total mg/l	Oxygen ppm
Albemarle Island	4	1.39	5.48	0.165	7.70
Clouter Creek Island	2	2.10	6.18	2.16	7.70
Daniel Island	4	1.16	6.58	0.23	6.60
Drum Island	2	5.47	5.00	0.20	9.60
N-9	4	0.81	4.21	1.04	9.10
N-15	3	0.21	5.80	0.39	5.20
N-16	1	0.05	4.60	0.10	2.80
N-20	1	3.20	10.0	2.75	6.80
N-21	1	0.85	9.60	0.84	8.30
N-22	12	1.60	8.23	0.30	5.30

(continued)

(Sheet 2 of 4)

Table 8 (continued)

Location	No. of Samples	Chemical Characteristic: Nitrogen Ammonia mg/1	Sulfate mg/1	Phosphate Ortho mg/1	Phosphate Organic mg/1	Alkalinity ppm
Albemarle Island	4	2.40	406	5.30	2.34	94.0
Clouter Creek Island	2	4.58	220	0.87	2.85	560.0
Daniel Island	4	2.76	1720	19.10	2.63	203.0
Drum Island	2	2.10	1600	9.40	2.20	95.0
N-9	4	2.38	1725	11.80	0.32	218.0
N-15	3	5.37	2470	0.78	0.20	143.0
N-16	1	2.60	1600	12.60	0.05	240.0
N-20	1	10.80	3000	2.70	2.40	300.0
N-21	1	2.30	3000	0.10	1.05	180.0
N-22	12	3.07	3060	2.31	1.21	195.0

(continued)

(Sheet 3 of 4)

Table 8 (concluded)

		Chemical Characteristic		
Location	No. of Samples	Carbon Dioxide ppm	Nitrogen, Nitrate High Range mg/1	Nitrogen, Nitrate Low Range mg/1
Albemarle Island	4	1.50	0.85	0.033
Clouter Creek Island	2	35.00	1.05	0.035
Daniel Island	4	5.00	2.85	0.033
Drum Island	2	0.0	1.00	0.033
N-9	4	17.00	1.15	0.033
N-15	3	23.00	1.67	0.033
N-16	1	37.50	1.20	0.033
N-20	1	0.0	1.90	0.0
N-21	1	5.00	1.00	0.0
N-22	12	7.10	1.90	0.26

(Sheet 4 of 4)

to 75,800 micromhos/cm, respectively). The lowest values were obtained from water samples taken from the Clouter Creek disposal site (see Figure 4), a location that was considerably inland from all other sites. The highest salinity values came from coastal site N-22 (see Figure 5) along the AIWW. Site N-22 was considered to be under DM-4 and DM-5 conditions during the sampling period. The low values from Clouter Creek disposal area were attributable to the location of this site while the high values of the N-22 site were probably attributable to the elevation of this sampling site: a low area which received saline runoff waters from other parts of the disposal area. The cycle of alternate wet and dry periods combined with the leaching of salt from soil particles into rainwater tends to make the DM-4 and DM-5 conditions (at least in low areas and sump locations) considerably more saline than the other stages. Petersen and Chapman (1970a) reported similar variations in their work, but their conductivity values were generally lower (due to the marsh habitat patterns as opposed to disposal site patterns).

157. Suspended solids. Values for suspended solids were generally low due to the lentic nature of the habitats sampled. These values ranged from a high of 20 mg/l from several locations to undetectable levels from water samples taken from Clouter Creek disposal site. It should be recalled at this juncture, that the tests were conducted on water samples from known mosquito larval habitats and that such habitats normally do not occur until after DM-3 conditions (see Figure 14). For this reason, low suspended solid values were expected.

158. Sulfides. The sulfide analyses were not very conclusive, because of the difficulty in preventing the loss of H_2S from the water samples during transport. The investigators believe that the data presented on sulfides may be lower than actual field conditions.

159. Turbidity. For turbidity testing, the water samples

were allowed to settle for two hours to allow the sands and silts to settle out of suspension. The turbidity measurements ranged from a high of 85.0 FTU's from two sites (Clouter Creek and Site N-21) to a low reading of 20.0 FTU's from several disposal areas (see Table 8). Formazin turbidity units are comparable to the more familiar Jackson turbidity units (JTU).

160. Values of pH and Tannin-Lignin concentrations. Measurements of acid-base relations were remarkable constant. All pH values for water from larval habitats were within a pH range of 7.4 to 8.5 with the exception of the Drum Island samples which had an average pH value of 9.1. These alkaline water conditions were undoubtedly caused by the presence of calcium compounds from both the soil and water components of dredged material. Table 8 indicates that all pH values were in excess of 7.0. Petersen and Chapman (1970a) reported similiar results, but generally lower pH ranges (6.0 to 8.4). Their higher ranges were probably due to the well-known fact that tidal marshes (unlike disposal sites) are subject to frequent changes in many chemical parameters caused by tidal action. The tannin-lignin tests ran from a low of 4.21 mg/l to a high value of 10.0 mg/l tannic acid. As expected, higher tannin-lignin values were obtained from those disposal sites that were vegetated (i.e. DM-5 conditions) than from locations that were free of vegetation (i.e. DM-4 conditions, see Figure 14). Despite changes in tannin-lignin concentrations, mosquitoes could be located from all sites. While not done for this study, the investigators believe that additional work should be considered for tannin-lignin concentrations in the earlier stages of succession. For example, the absence of mosquito larvae from DM-3 conditions might be related to tannin-lignin concentration.

161. Iron and DO. The iron analyses were conducted to determine if iron concentrations negatively affected developing mosquito larvae. Throughout the season, mosquito larvae were found in both high and low concentrations of iron. Iron values obtained during

this study ranged from a high of 2.75 to a low of 0.10 mg/l of total iron. It was assumed that the concentrations of iron encountered during this study did not significantly affect mosquito larval production under field conditions. Mosquito larvae utilize atmospheric oxygen and are not dependent on DO for their survival. The measurement of DO, however, is important in habitat studies as it provides an index to the environmental conditions of the mosquito's food chain organisms. Low measurements of DO may indicate the presence of aquatic organisms that serve as larval food sources, while high DO measurements may indicate a lack of food organism activity. DO measurements ranged from a high of 9.10 to a low of 2.80 ppm O_2. DO conditions were not observed during this study that appeared to influence mosquito larval concentrations under field conditions. Clements (1963) has discussed the concept that a decrease in DO tends to stimulate the hatching of mosquito eggs.

162. Nitrogen relationships. The phosphates and nitrogenous compounds provide a quantitative evaluation of an environment's ability to supply the necessary nutrients for the maintenance of plant life (the basis for all food chains). These data provide the means for studying the chemical basis for algae and other plant life associated with dredged material aquatic habitats. Thom (1955) noted that high mosquito larval populations were frequently preceded by the appearance of a "green scum" within disposal sites. The presence of ammoniated nitrogen normally results from microbial decay of plant and animal protein. Ammoniated nitrogen is a relative index of the organic fertility of some aquatic ecosystems. Nitrate nitrogen represents the oxidized state of nitrogen that is commonly encountered in aquatic systems. Nitrates also encourage the growth of algae and other plant life. Nitrate nitrogen is the intermediate stage of biological decomposition of compounds that contain organic nitrogen. Data regarding the various types of nitrogen compounds encountered in disposal area water samples are presented in Table 8.

163. Phosphate and sulfate relationships. Three phosphate tests were conducted during the study. These included total inorganic phosphates, organically bound phosphates, and orthophosphates. While phosphates are essential to most plant life, excessive quantities may bring about eutrophic conditions (algal blooms, etc.), leading to an abundance of plant forms that may destroy other life forms and lower the DO. A range of the three types of phosphates considered in this report may be seen in Table 8. Sulfates occur in natural waters as a result of various oxidative reactions. As expected, high sulfate values were obtained from disposal area water samples, ranging from a high of 3060 to a low of 220 mg/l SO_4. Sulfate concentrations did not appear to influence mosquito larval concentrations under field observation conditions, as larvae were collected from both high and low sulfate conditions.

164. Alkalinity and CO_2. Wide variations were observed in CO_2 concentrations during this study, ranging from a low value in the nondetectable range to a high of 37.5 ppm CO_2. It was necessary to conduct the alkalinity measurements at the sample sites because certain analyses were affected by high alkalinities and this value was needed before the other tests could be started. Alkalinity is one measure of the "hardness" of water. In almost every test $CaCO_3$ hardness was indicated. This had been expected due to the high shell content of most marine dredged material. Hardness values ranged from a high of 560 to a low of 94.0 ppm.

Summary

165. In summary, the following factors relating to the chemical characteristics of mosquito larval habitats within dredged material disposal sites have been considered.

- a. Water samples were obtained from a variety of disposal sites and subjected to a battery of chemical tests.
- b. The major chemical parameters of mosquito larval habitats within dredged material disposal areas were characterized.

c. No chemical factors were observed that appeared to limit mosquito utilization of disposal areas.

d. Mosquitoes were observed to develop through their life cycles in disposal area habitats with salinities above that of seawater.

e. The greatest change in chemical parameters occurred following periods of heavy rainfall.

f. Dredged material disposal area mosquito habitats are characterized by high salinity, mildly alkaline pH conditions, generally clear water, with variable DO conditions. In many disposal sites, lentic water samples were rich in phosphates, sulfates, calcium carbonate, nitrogenous compounds, and tannin-lignin compounds.

Adult Mosquito Surveys within Dredged Material Disposal Areas

Rationale and literature review

166. Concurrent with the larval portion of this study, a survey of adult mosquito populations was initiated. The finding of adult mosquitoes within a given disposal site did not incriminate that species as a disposal site breeder unless the female mosquitoes were actually observed to oviposit or large numbers of adults could be seen emerging from one of the many larval habitats (see Figure 15). In spite of these reservations, it was considered important to monitor adult mosquito populations by light traps within three dredged materail disposal sites. No studies were located in the literature regarding the monitoring of adult mosquito populations within disposal areas. A number of mosquito abatement programs in various parts of the United States use a mechanical light-suction trap to sample adult mosquito populations. This trap and various modifications of the original design are popularly known as "the New Jersey light trap." The development of the New Jersey light trap has been reviewed by Mulhern (1953). Since these traps normally require a source of 110-v electricity, the sampling of adult

mosquitoes from disposal sites in the past has been limited to locations that were frequently remote from the actual source of the mosquitoes. It was the goal of this portion of the study to sample adult mosquitoes that were active within dredged material disposal sites per se.

167. Mosquitoes were collected by two methods. Individual collections of feeding adult mosquitoes were collected by aspiration techniques as they attempted to feed upon the collectors. Larger samples were taken during the evening from three disposal sites through the use of New Jersey light traps.

168. Trap one. Three dredged material disposal areas were selected for the adult mosquito light trap surveys. All of the sites had a history of producing larval mosquitoes. Trap one was located near a large bird rookery (see also Part XII) within the Drum Island disposal area (see Figure 4). Drum Island is located in Charleston Harbor and is less than 1/4 mile from the city of Charleston. The location for this trap was picked to provide an index of the mosquitoes that might feed on the resident bird population and perhaps subsequently on the nearby human population. Two sources of larval mosquitoes were located near trap one. One source was due to dike seepage, while the second habitat consisted of a large dike swale with fissured soil in the DM-4 stage. The site had received fresh dredged material several months prior to the installation of the light trap.

169. Trap two. A second trap was installed within a dredged material disposal area known as site N-20 (see Figure 5) along the AIWW near the town of Isle of Palms, S. C. This disposal site was the oldest of the series and had not received dredged material for approximately 4 to 5 years. The trap was located near a fissured soil larval habitat in the DM-5 stage. A second larval source consisted of a dike failure habitat (see Figure 15, item 8). The light trap was placed in a small thicket of protective vegetation to afford

the adult mosquitoes protection from wind.

170. Trap three. The third light trap in the test series was located within a disposal area known as site N-22 (see Figure 5) along the AIWW near the town of Sullivan's Island, S. C. The major larval habitat near this trap consisted of a long dike swale with dredged material in DM-4 and DM-5 stages. Birds were not significant on either site N-20 or N-22.

171. Modification of the New Jersey light trap. In recent years a number of light-weight light traps (Sudia and Chamberlain 1962) have been developed for field use in remote areas. Despite the convenience of these smaller traps, it was decided to modify the New Jersey trap for remote field use. Since the New Jersey trap is commonly used by many mosquito abatement districts in the United States, the investigators wished the results of this survey to be comparable to standard survey techniques. A standard New Jersey light trap was modified for operation with a 12v automobile battery and a D.C. electric engine. A photoelectric cell circuit was designed to operate the trap during the evening hours only. Battery life afforded slightly more than a single night of operation. For this reason it was necessary to recharge the batteries between trap operations. The batteries were placed in steel boxes and locked for security reasons. All traps were operated at heights of 4 ft above the ground. Mosquitoes and other insect specimens were recovered following a night of operation in a small collection jar containing a small strip of an insecticide.

172. Specimen processing. All light trap specimens were processed by a bulk of sorting procedure to separate the adult mosquitoes from other insect species. Following this procedure male and female mosquitoes were separated. Female specimens were used for the construction of mosquito activity graphs. Male specimens were not recorded in the graphs that follow, but increases in the catch of male specimens were noted immediately following a major emergence.

Specimens were collected in some cases through the courtesy of the Charleston County Mosquito Abatement Program.

173. Trap operation. Light traps were operated on Tuesday and Thursday evenings from 6 June to 28 October 1976. Batteries and insects were collected on Wednesday and Friday mornings. One day was needed for battery charging during trapping interims.

Results and discussion

174. Aspiration. Very limited numbers of the dominant mosquito fauna were collected by aspiration. These included *Aedes sollicitans, Aedes taeniorhynchus, and Anopheles bradleyi* which were attracted to the investigators during field trips. Large numbers were not collected by these methods as these species could be field identified and the samples were not objective.

175. Collection data. The modified light traps operated without failure during the entire 1976 season. Graphs for the major species collected from the three light traps are presented as Figures 22-24. A grand total of 3562 female specimens, representing six species of mosquitoes were collected during the study period. Of these only one species, *Uranotaenia sapphirina*, was collected from the light trap survey that was not collected in the larval state. Grand totals for all traps in all locations included:

a. *Aedes sollicitans* 668
b. *Aedes taeniorhynchus*. 2485
c. *Culex salinarius*. 244
d. *Anopheles bradleyi*. 122
e. *Anopheles atropos* 40
f. *Uranotaenia sapphirina*. 3

Aedes taeniorhynchus was much more common in the light trap collections than had been the case with the larval collections (where *Aedes sollicitans* had been more common). Several reasons might be offered for this difference. The larval samples were collected from a wide variety of habitats, while the adult light trap survey had been

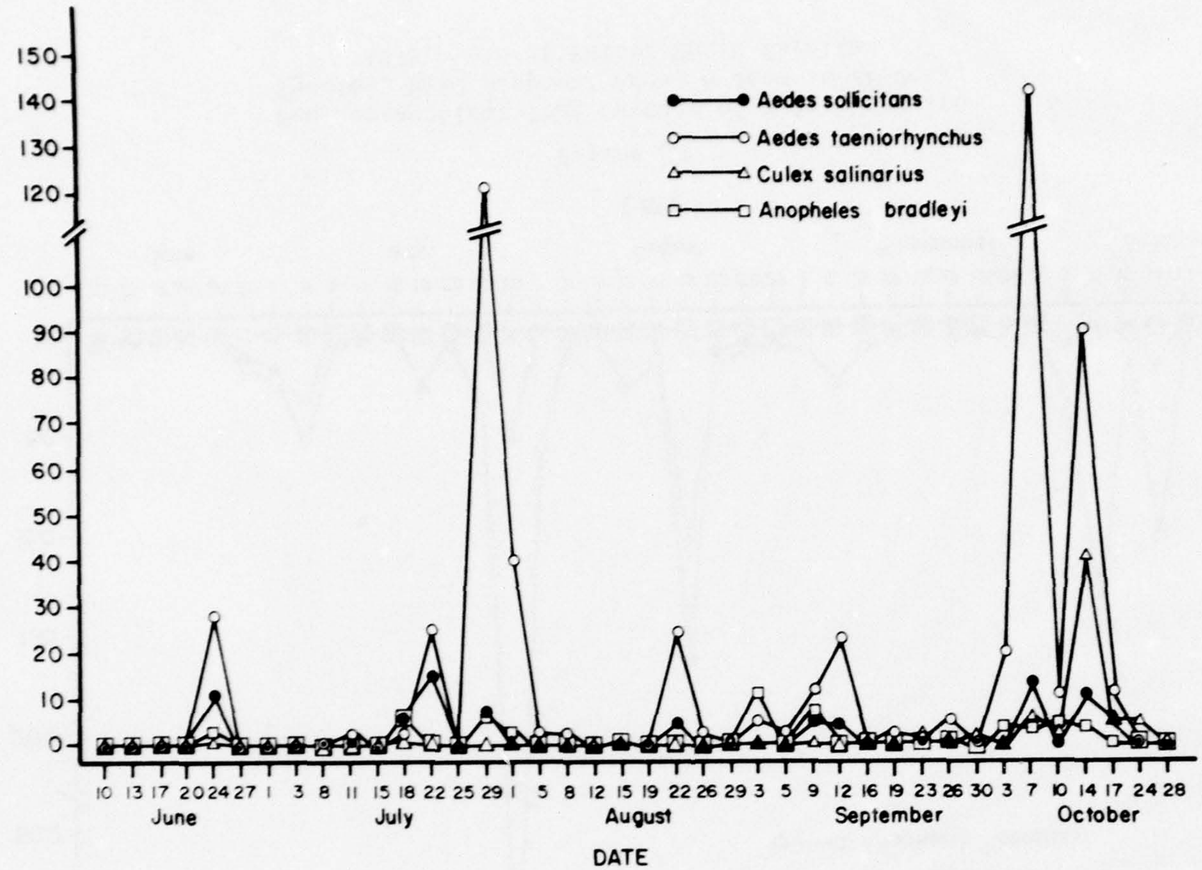

Figure 22

New Jersey Light Trap Catches of Major Mosquito Species, Drum Island Disposal Area, 10 June - 28 Oct., 1976, Charleston Harbor, South Carolina

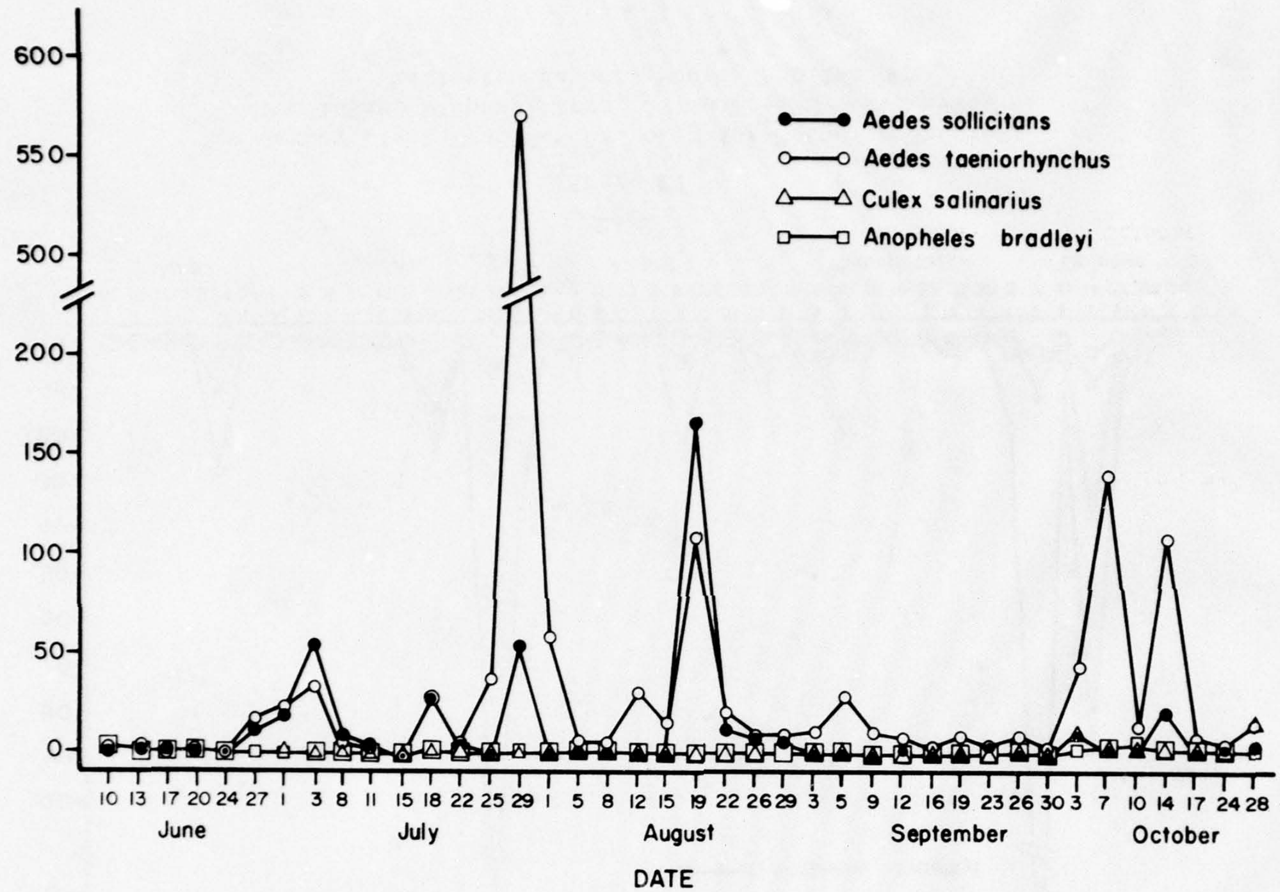

Figure 23

New Jersey Light Trap Catches of Major Mosquito Species, N-20 Disposal Area, 6 June to 28 Oct., 1976, Isle of Palms, South Carolina

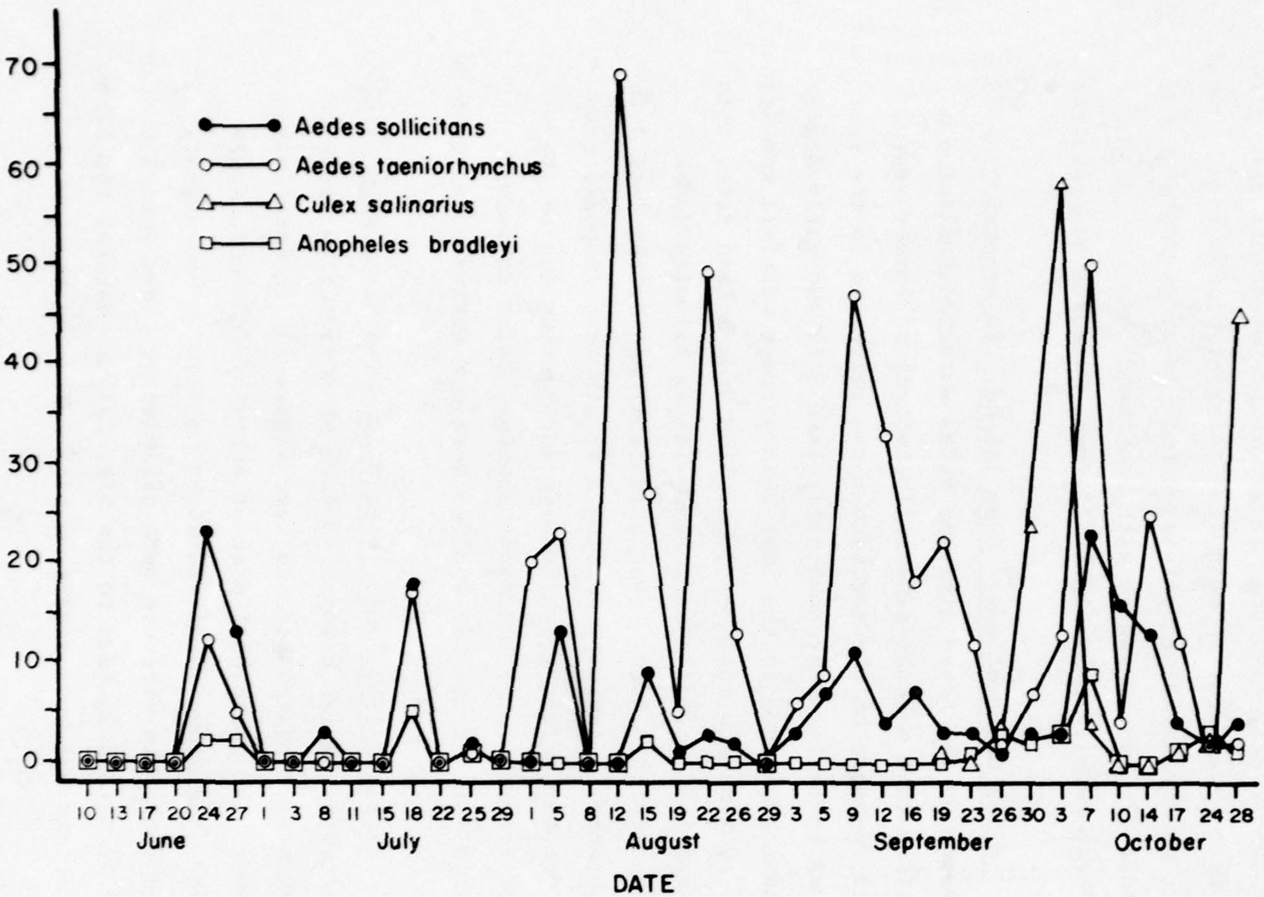

Figure 24

New Jersey Light Trap Catches of Major Mosquito Species, N-22 Disposal Area, 6 June-28 Oct., 1976 restricted to only three disposal areas. The static location of the light traps may have been such that *Aedes taeniorhynchus* larval habitats were inadvertently favored. It should be noted that all collections were made under routine mosquito abatement procedures. Normal larviciding and adulticiding operations were in effect during the survey period. It can be stated with assurance that the graphs would have been considerably higher if these measures had not been in effect.

176. Graph observations: Drum Island. In general, the 1976 mosquito season on the three disposal sites surveyed reflected a delayed pattern that was not especially typical of former years. This delayed response of the mosquitoes was reflected in the fact that the catch was generally depressed until late July and early August. This was undoubtedly due to the less than average rainfall conditions that existed during the month of June. The Drum Island site, trap one, illustrated a bimodal pattern (see Figure 22) with *Aedes taeniorhynchus* catches being especially prominent during late July and late September. Activity continued within this disposal site until late October. This graph is also interesting due to the activity patterns shown by two minor species, *Culex salinarius* and *Anopheles bradleyi*. These two species were not active on sites N-20 and N-22.

177. Graph observations: site N-20. The older AIWW site, N-20, exhibited a similar bimodal pattern of activity by *Aedes taeniorhynchus* with peaks observed (see Figure 23) in late July and late September. An additional peak of activity from both *Aedes taeniorhynchus* and *Aedes sollicitans* can be seen in mid-August. It was believed that this site was more affected by tidal activity than Drum Island or site N-22 (due to the dike failure habitat for larvae). *Aedes sollicitans* was more active on site N-20 than the Drum Island location.

178. Graph observations: site N-22. Site N-22 was perhaps

the most interesting graph produced by the light trap catches (see Figure 24). The protected nature of the nearby larval habitat (a sike swale under DM-4 and DM-5 conditions) may have contributed to the continued activity of mosquitoes on this site despite the chemical control measures that were being continuously applied. *Aedes sollicitans* exhibited a pattern of sustained activity with catches generally below 25 specimens. Continuous activity by *Aedes taeniorhynchus* can be seen from late June until mid-October. All three graphs indicate activity by *Culex salinarius* during October.

Summary

179. In summary, the following factors relating to adult mosquito activity within dredged material disposal sites have been noted.

- a. New Jersey light traps were modified for D.C. operation by automobile batteries.
- b. All traps were furnished with a photoelectric cell that limited operation to evening hours.
- c. Three disposal sites with a history of producing mosquitoes were selected for the light trap survey.
- d. Normal mosquito control operations were in effect during the survey.
- e. The sites varied in age and types of larval habitats available.
- f. The dominant species collected during the larval survey were also collected by the light traps. One additional species, *Uranotaenia sapphirina*, was collected that had not been previously collected in the larval state.
- g. The dominant species collected by the light traps was *Aedes taeniorhynchus*.
- h. Graphs illustrating the activity patterns of the major species collected were prepared.

Influence of Weather on Adult Mosquito Light Trap Collections from Dredged Material Disposal Areas

Rationale and literature review

180. Adult mosquito sampling data (presented in the previous section) were compared with daily weather conditions during the 4-month duration of the sampling period. The decision to analyze weather efforts was made because temperature, moisture, and other weather phenomena are important factors influencing the population size of many insect species including those mosquito species which were the object of this study. When making an analysis of this type, it is necessary to take into account extraneous factors not related to weather which influence light trap catches. These factors include differences in the attractance of a light source to different species of mosquitoes (i.e., some species are more readily attracted to light than others). Pratt (1948) and Provost (1959) have described one aspect of this problem: the relationship of fluctuations of light trap collections to changes in lunar light intensity associated with the phases of the moon. Bidlingmayer (1974) and Ebsary and Crans (1977) have described other environmental factors and physiological changes occuring during the adult life of mosquitoes that influence the catch of several different types of mosquito traps. Despite these factors, light traps were considered to be a valid and useful tool for this phase of the study because:

a. The nature of the confounding factors described above are understood. Therefore, the limits imposed by these factors can be compensated for in the interpretation of results (see the next section for a discussion of the relevance of these factors to this study).

b. The New Jersey light trap is a standard tool used for mosquito research and control work throughout the world for more than 50 years. Therefore, data acquired with light traps can more accurately be compared with results from similar surveys made for other mosquito studies.

c. Light traps can be generated without continuous supervision, so they are ideal for studies in isolated locations such as dredged material disposal areas.

Materials and methods

181. Light trap collections. Results of light trap collections are presented in Figures 22-24 (see previous section). Again, it should be recalled that the light traps (because of logistical factors) were operated on only two evenings per week. One problem encountered with analysis of light trap data is the fact that older mosquitoes are not attracted to light traps to the same degree as younger individuals. Therefore, for some species a disproportionately large number of young mosquitoes can be expected in light trap conditions. Thus, light trap collections may not always reflect the age structure of a population. This tendency is exhibited by *Aedes sollicitans* and *Aedes taeniorhynchus*. In the case of mosquito sampling within disposal sites, however, this factor can be considered an advantage, because the youngest mosquitoes in a population are most likely to be found near their larval habitats. Therefore, collections obtained in this study should indicate the presence (or absence) of mosquito breeding habitats within the immediate trap vicinity.

182. Analysis techniques. The relationships of light trap counts to weather variables were estimated using the cross-covariance function as applied by Hacker et al. (1973). This method enables the investigator to ascertain the degree of correspondence between two variables which occurs in a time series, even when the effect of the independent variable on the dependent variable is a delayed effect. When such a delayed effect is detected, an estimate of the length of the delay can be obtained. This is usually termed a lag time. A series of analyses were made using this technique. The total number of mosquitoes (all species) collected at each sampling location was studied to determine if the effect of each weather

variable on mosquito counts was the same at each location. Mosquito counts were also divided up by species and by sampling locations to determine if each weather variable had different effects on some species and/or on some locations than on others. In summary, the analysis used considered the cumulative effects (for the entire season) of weather against light trap collections; as a functional relationship between dependent variables (mosquito species) on independent variables (weather factors).

183. Weather data records. Weather records were obtained from Local Climatological Data (LCD) sheets at the Charleston Office of the National Weather Service. Temperature and wind data were recorded at the weather station of the Charleston Office of the National Weather Service. This site was approximately 1 mile from the Drum Island site and 4 miles from sites N-20 and N-22. Rainfall was recorded with a rain gauge located at each sampling site.

Results and discussion

184. Mosquitoes analyzed. The numbers of mosquitoes have been reported in the previous section. Slightly more than half of the total number of mosquitoes were collected from site N-20. The remainder were evenly divided between site N-22 and Drum Island. As indicated in Figures 22-24, the predominant species collected during the survey was *Aedes taeniorhynchus*, followed by *Aedes sollicitans*. *Culex salinarius* was the third most common species. The salt marsh anopheline, *Anopheles bradleyi*, was also present during parts of the 1976 season. The lesser species, *Anopheles atropos* and *Uranotaenia sapphirina*, were not caught in sufficient numbers (less than 2 percent) to justify analysis.

185. *Anopheles bradleyi* complex. The investigators noted that *Anopheles bradleyi* is a member of a species complex that also includes *Anopheles crucians* and *A. georgianus*. All three species are virtually indistinguishable as adults from each other. However, all specimens captured in this study were assumed to be *A. bradleyi*

because of the preferred larval habitat of this species for brackish water and salt marshes.

186. Rainfall effects. Perhaps the most important weather variable to affect mosquito egg populations and subsequent larval numbers is the amount of rainfall. Rainfall also influences light trap catches following a time lag for larval development. Figure 25 indicates that rainfall was followed by higher trap collections approximately 9 to 12 days after the precipitation occurred. The two floodwater species (i.e., *Aedes taeniorhynchus* and *Aedes sollicitans*) exhibited the highest degree of correlation with rainfall. This observation is consistent with the normal development time for these two species.

187. This consistency of the data indicates that the trapped mosquitoes originated near the collecting point (i.e., within the disposal sites per se). Such a conclusion is indicated because both of these two species tend to migrate and disperse approximately 3 to 4 days following emergence. Prior to that time they remain in the immediate vicinity of their larval habitats. Therefore, if trapped adult mosquitoes had completed their development stages at another locations, a longer lag time would be expected.

188. Rainfall was also closely correlated with increases in mosquito trap collections 3 days after precipitation (see Figure 25). This observation is more difficult to explain than the previously discussed rainfall effects. However, since the 3 day lag period was also closely associated with the *Aedes* species, it may indicate that some floodwater pools evaporate and dry so quickly that larvae developing in these pools do not have sufficient time to complete their development unless a second rainfall augments the water level. Additional data from other studies would be needed to substantiate this theory. If this condition is indeed necessary for the survival of developing larvae within dredged material disposal areas, then additional rainfall a few days before the completion of the

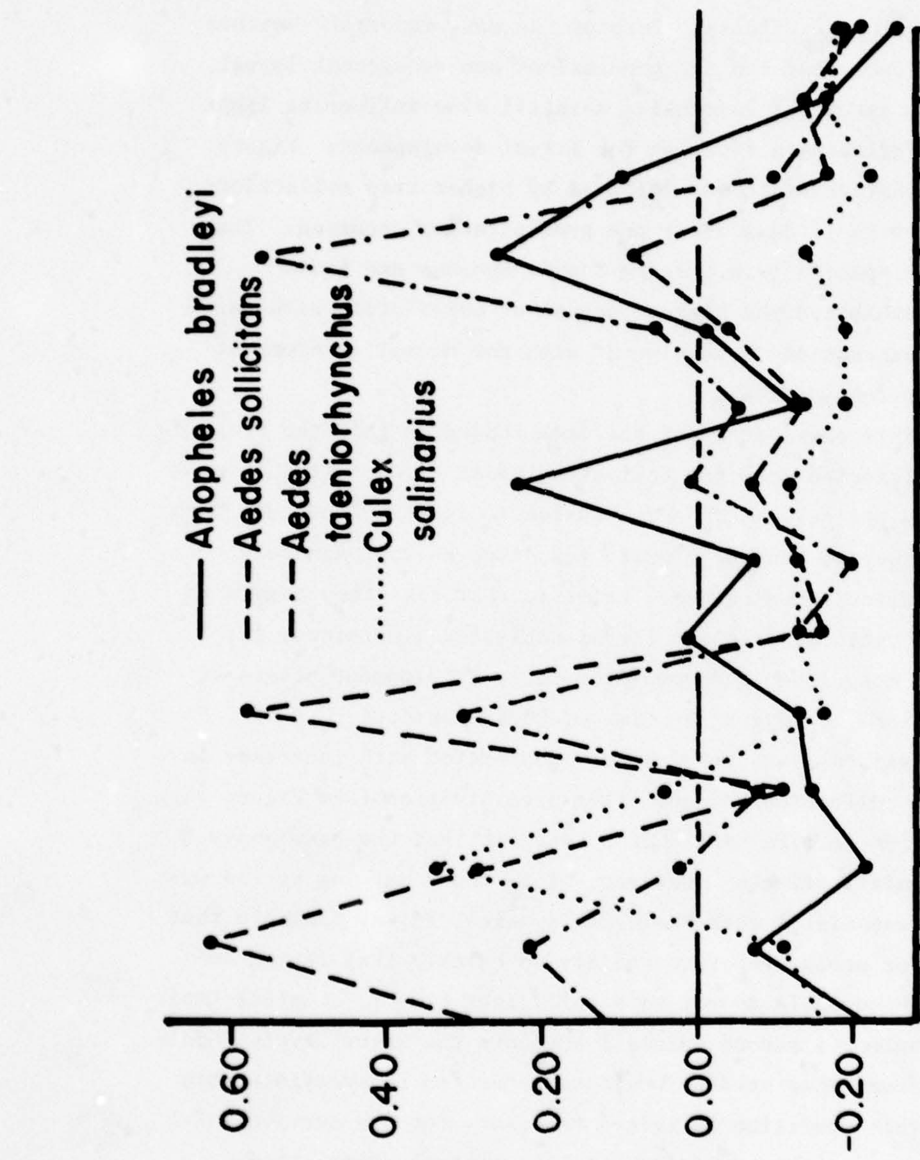

Figure 25

Cross-covariance Functions for Four Species of Mosquitoes with Respect to Rain in Charleston, South Carolina, June to Oct., 1976 development period would certainly tend to increase light trap catches.

189. Temperature. Trap collections were also influenced by temperature. All species included in the analysis were compared with daily maximum and minimum temperatures. Since both of these parameters appeared to have approximately equal effects on trap collections and because these two factors often tend to correlate with each other, the two variables were combined into a single variable, the average temperature.

190. Figure 26 indicates that the two floodwater species exhibit less of a response to temperature (within the summer ranges included in the analysis) than either *Anopheles bradleyi* or *Culex salinarius*. Some caution is necessary in the interpretation of these data, however, since the latter two species may be more prevalent on disposal sites near the end of the mosquito season. Rainfall during September and October was above normal on the sites in 1976. This fact may have allowed for cooler temperatures and more permanent pools of water needed for the breeding habitat of *A. bradleyi* and *C. salinarius*. The data indicate that *Culex salinarius* is more successful during cooler weather than the two dominant *Aedes* spp. This conclusion agrees with the findings of Hacker et al. (1973) for *C. salinarius* in Houston, Texas. *Anopheles bradleyi* exhibited a response similar (but of lesser magnitude) to that of *C. salinarius*.

191. Differences among locations. Figure 27 shows that the response of mosquitoes to light traps tended to vary among the three locations. A positive response in light trap counts to lower average temperatures was evident among those locations with a well-developed vegetative cover (site N-22 and Drum Lsland). Thus, the vegetation may have an insulating effect which offsets possible adverse effects of lowered temperatures. The *Aedes sollicitans* results appeared to reflect this more than the results for the other species. Figure 28 provides a comparison of the effect of average temperature on the

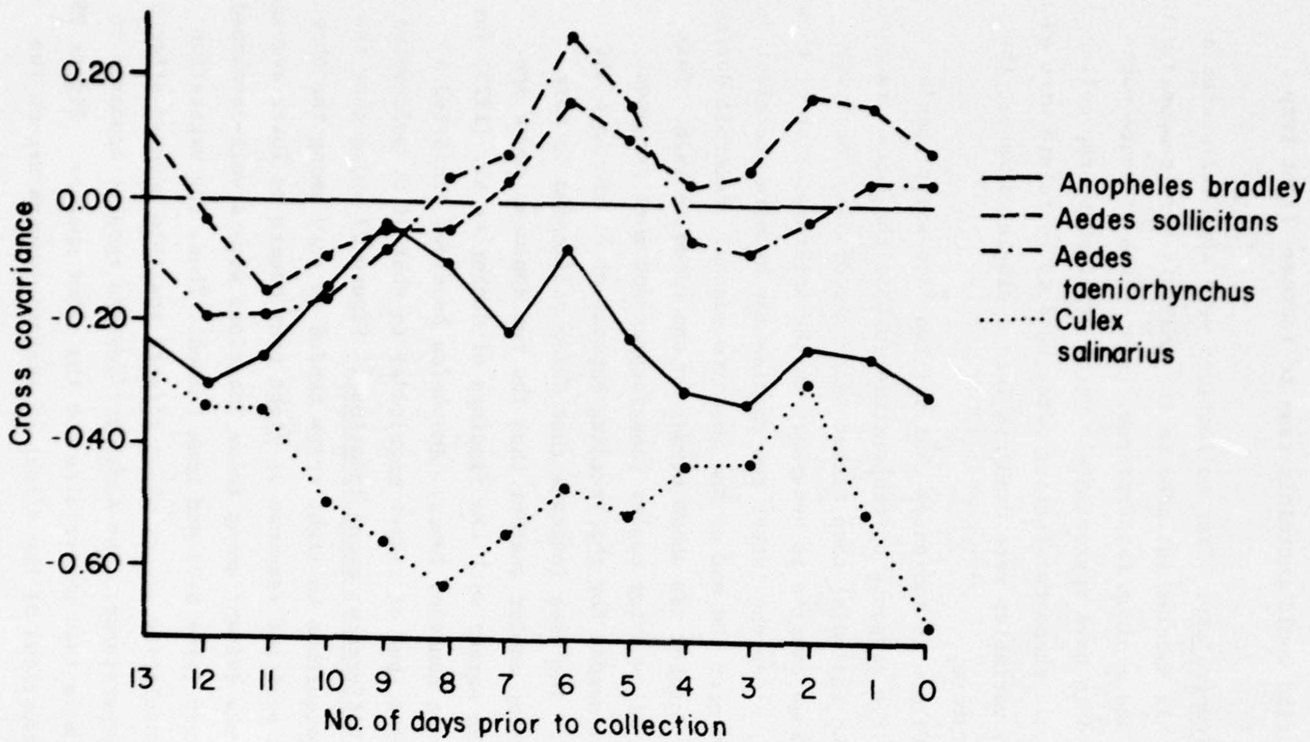

Figure 26

Cross-covariance Functions for Four Species of Mosquitoes with Respect to Average Temperature in Charleston, South Carolina, June-Oct., 1976

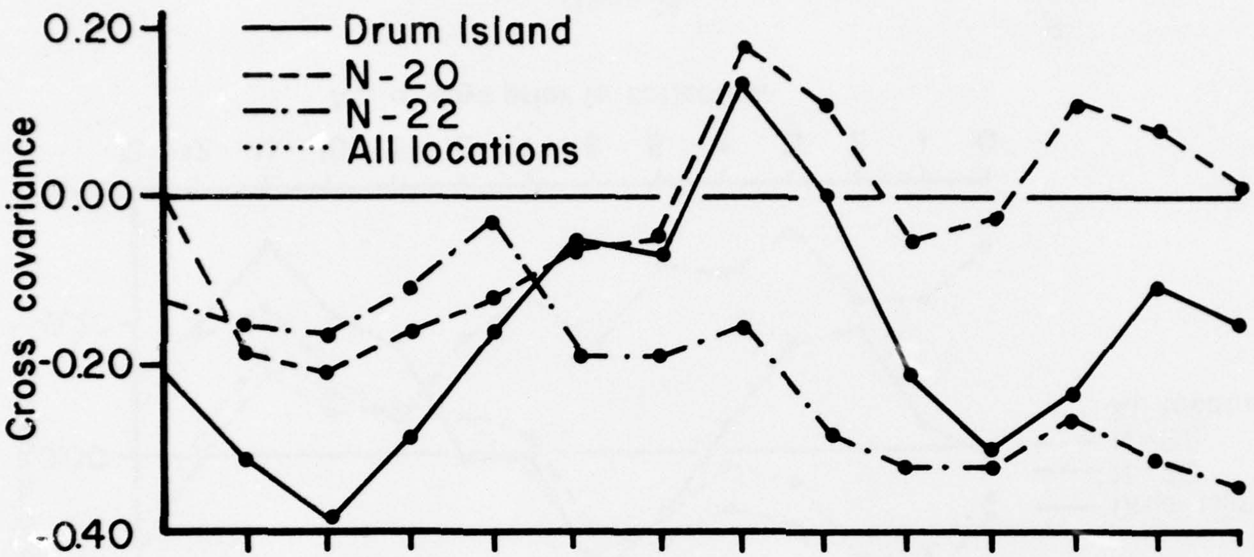

Figure 27

Cross-covariance Functions for Total Mosquitoes with Respect to Average Temperature at Three Locations in Charleston, South Carolina, June-Oct., 1976

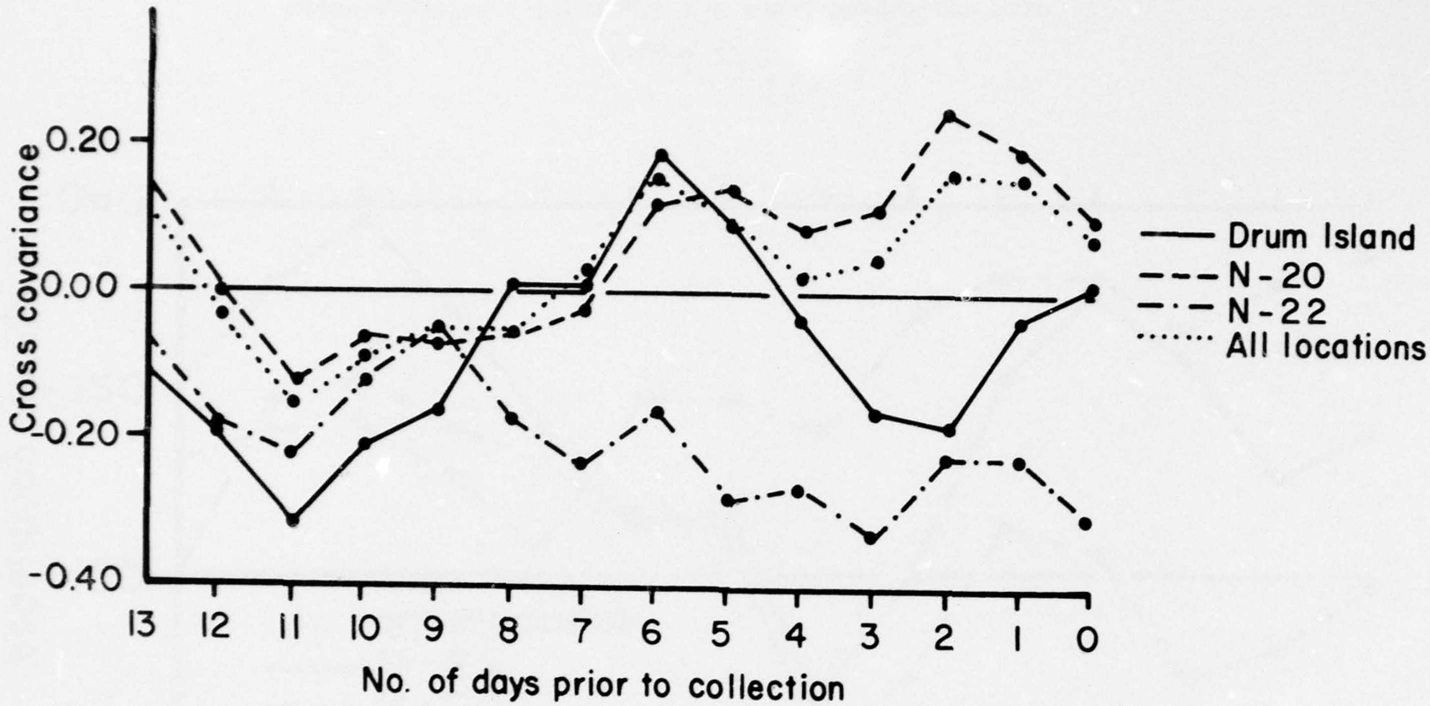

Figure 28

Cross-covariance Functions for *Aedes sollicitans* with Respect to Average Temperature at Three Locations in Charleston, South Carolina, June-Oct., 1976

A. sollicitans counts from the three collection sites and the pooled data.

192. Wind conditions. Windy conditions tend to adversely affect mosquito flight activity and therefore reduce trap catches. As illustrated in Figure 29, higher average wind speeds on the day of collection (i.e. day 0) tended to reduce the catch of all species, except *C. salinarius*. Figure 29 provides a comparison of total mosquitoes caught with respect to wind speed for all locations. Figures 30 and 31 illustrate how this relationship appeared for *Aedes sollicitans* and *A. taeniorhynchus* at each of the three test sites. Wind at those sites (N-22 and Drum Island) with the greatest amount of vegetation cover appeared to have less of an effect on reducing the *A. sollicitans* and *A. taeniorhynchus* counts.

193. Limits of the data discussed. Due to the short-term nature of this report, the investigators were unable to fully separate weather effects from the longer term temporal distribution effects. A longer study would further elucidate the exact nature of the temporal distribution of the various mosquitoes developing within disposal sites. The temporal distribution of the dominant species may be identical to their respective breeding patterns within sites other than disposal areas (i.e. the natural marsh), but some evidence gathered during field observations would suggest otherwise. In many cases, harsh winter and fall weather conditions are mitigated within dredged material disposal sites (as opposed to marsh habitats). For example, strong storm tides of winter usually do not reach larval mosquito habitats within disposal areas. The temperature within fissured soil, especially in the DM-4, DM-5, or DM-7 stages (see Figure 14), may average several degrees warmer than the ambient temperature during the fall and winter months. The height of the disposal area dike relative to the surface of the dredged material may affect the rate of evaporation. Strong autumn winds that might tend to destroy natural marsh and upland larval habitats may have

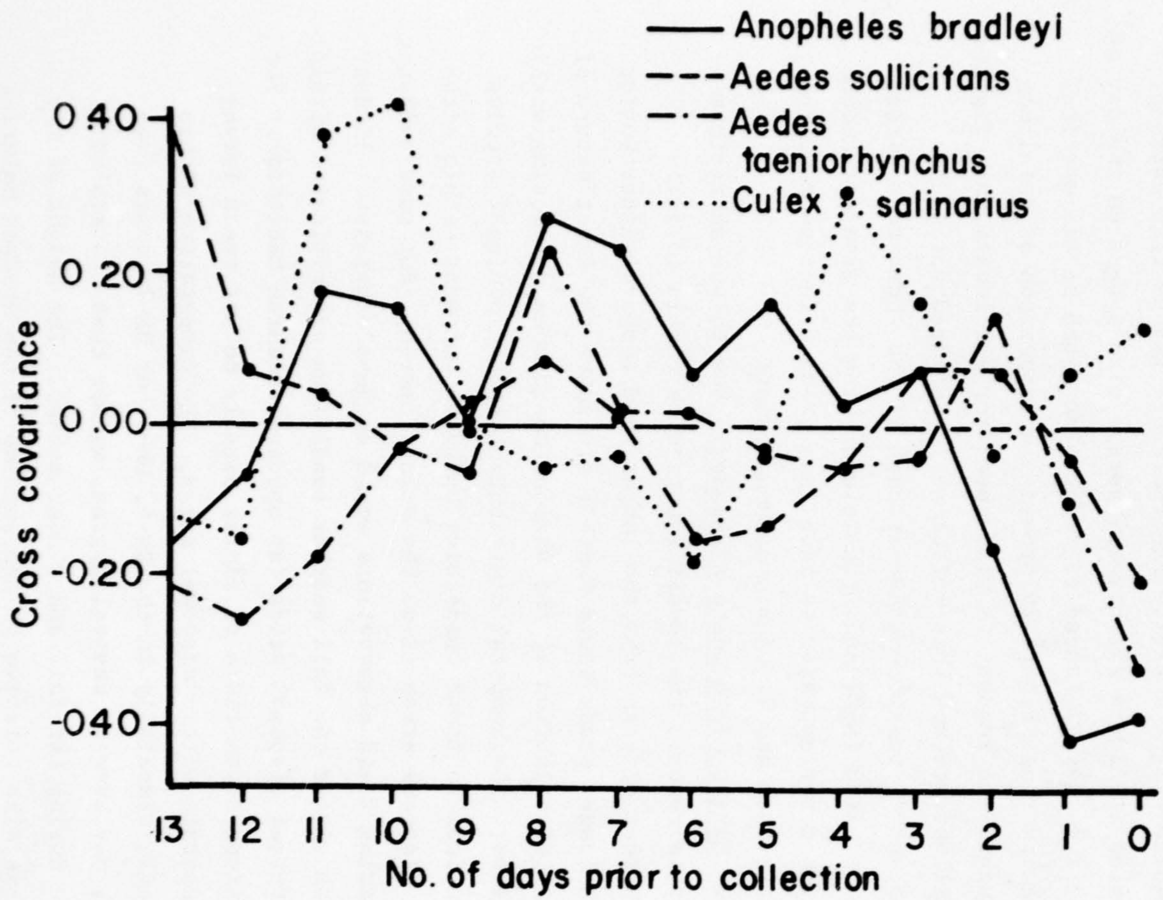

Figure 29

Cross-covariance Functions for Four Species of Mosquitoes with Respect to Wind Speed in Charleston, South Carolina June-Oct., 1976

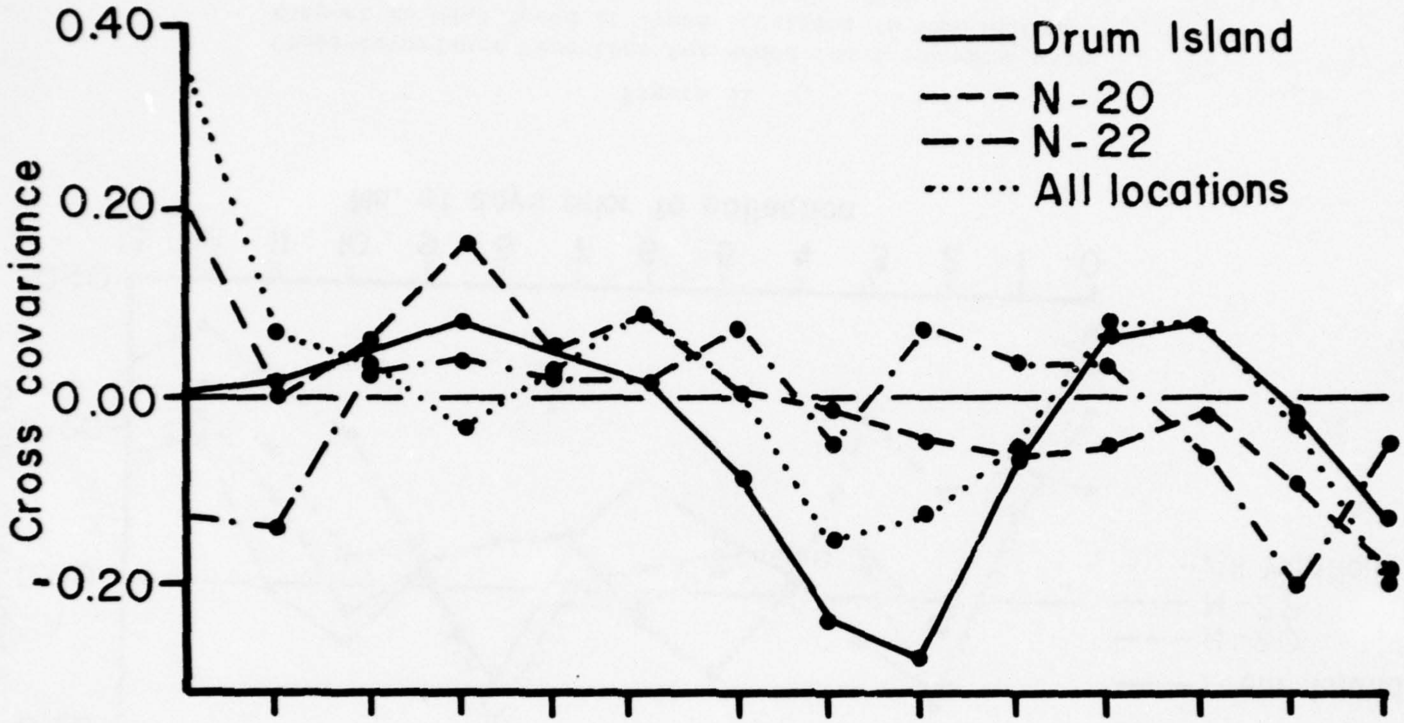

Figure 30

Cross-covariance Functions for *Aedes sollicitans* with Respect to Wind Speed at Three Locations in Charleston, South Carolina, June-Oct., 1976

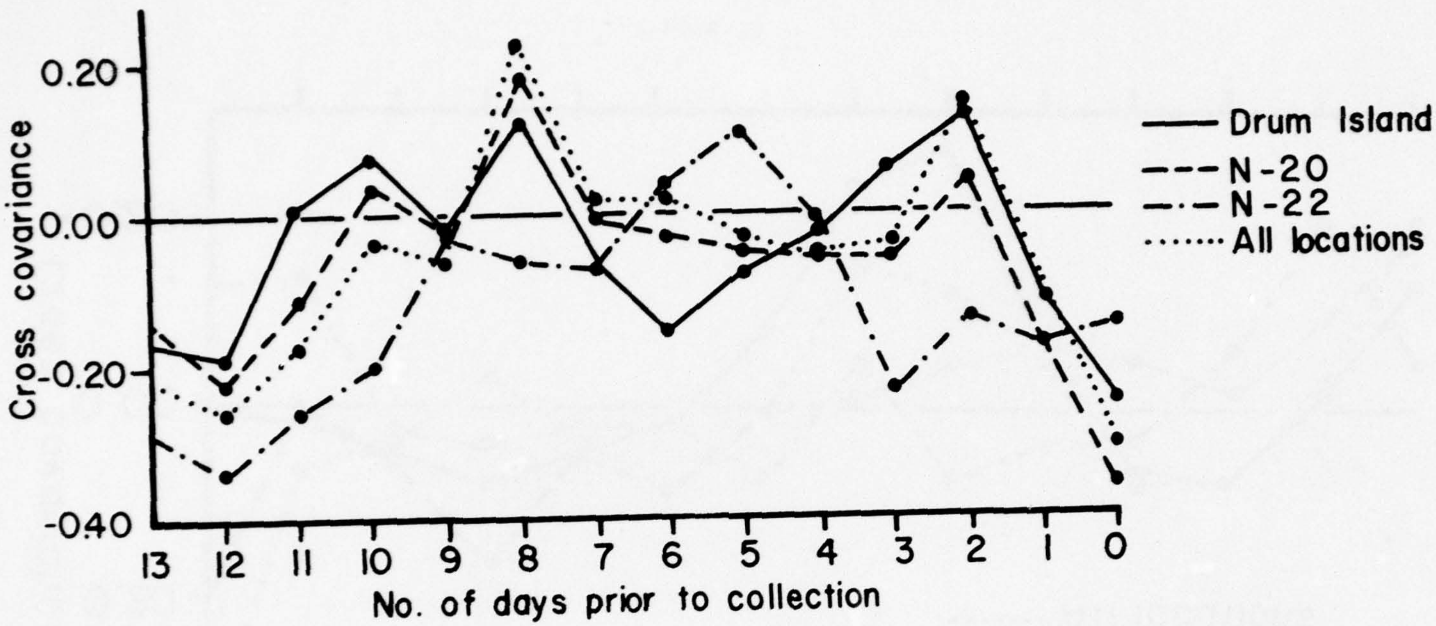

Figure 31

Cross-covariance Functions for *Aedes taeniorhynchus* with Respect to Wind Speed at Three Locations in Charleston, South Carolina, June-Oct., 1976 little (or no) effect deep within the fissured soil larval habitats of mosquitoes associated with dredged material disposal sites. Further long-term studies will be needed to determine if the mosquitoes associated with dredged material disposal sites exhibit the exact same temporal distribution patterns as their counterparts in the natural marsh and other locations. The investigators of this report believe that disposal area mosquitoes probably become active earlier in the spring and retain adult and larval activity longer during the fall and winter months than other mosquitoes from nearby sources. These observations are supported by the fact that larval mosquitoes of *Aedes sollicitans* were readily collected in early February of 1976 from disposal sites (see larval survey section). At that time, larvae could not be readily located from usually productive natural marsh sites that had been visited during the previous summer. Again, further detailed studies will be needed to confirm this hypothesis.

Summary

194. In summary, the following factors were considered relating dredged material disposal sites and weather patterns.

- a. Daily weather records (except rainfall) from the Charleston, S. C. Office of the National Weather Service were recorded for the 1976 mosquito season.
- b. Results of the adult mosquito survey were compared with the weather records.
- c. Weather variables were compared with light trap counts using the cross-covariance function as described by Hacker et al. (1973).
- d. Among the more important weather variables noted in the analysis were rainfall (especially for the *Aedes* spp.), average temperature, and average daily wind speed.
- e. Longer term studies are needed to further elucidate separate seasonal effects from weather variables.

PART VI: SUMMARY OF SITE VISITATIONS TO SELECTED CE DISTRICTS

Introduction

195. At the outset of this study it was decided that a detailed survey of mosquito problems associated with the disposal of dredged material would be made in a number of CE Districts other than the primary study sites of Charleston District. Districts were selected for geographic location and/or a known history of mosquito breeding within disposal sites.

Materials and Methods

196. Eight CE Districts were selected for detailed site visitations, field trips, and interviews. These Districts included:

Galveston	Philadelphia
Jacksonville	Sacramento
New Orleans	San Francisco
Norfolk	Savannah

Prior to each visit contact was established with the local CE District office and the offices of local mosquito abatement programs within that District. In order to gain as broad a view as possible interviews were scheduled with managerial, operational, and environmental personnel from both agencies. In almost all cases, joint meetings were scheduled (following initial contacts) between mosquito abatement representatives and CE personnel. These joint meetings allowed for a mutual exchange of ideas regarding the respective roles of the two groups. During field trips to various disposal sites within the Districts, plant and insect collections were made. All field observations, collections, interviews, and joint meetings were recorded with portable tape recorders. In some cases, time and season limited the amount of collecting. These field notes were then compiled for each

District and studied for differences and similarities.

Results and Discussion

197. Detailed observations, collections, and notes of special interest are presented in Appendix D. A list of all contact personnel is also presented as Table D1. As a result of these site visitations a number of new mosquito species associated with dredged material disposal sites were added to the previously constructed list from the primary study locations of Charleston District. A summary listing of all mosquito species known or reported to be associated with disposal sites is presented as Appendix C.

198. Many mosquito sources and problems were encountered that were similar (if not identical) to those located in Charleston District. In the interest of space a summary of those mosquito abatement problems that were not detected in Charleston District is presented below.

199. A total of seven disposal sites were visited in the Galveston CE District. A major new problem observed at several locations concerned the operation of recreational vehicles within dredged material disposal sites with the resultant creation of mosquito larval habitats within the vehicular tracks. The collection of larval *Culiseta inornata*, from this habitat added additional interest to this problem in Galveston District (see paragraph 14, Appendix D). Other salient problems in the Galveston area disposal sites included sand mining, and resistance to some chemical pesticides (see also Part II, paragraph 34). All of the successional seres proposed in Figure 14 and the habitats proposed in Figure 15 were observed in the Galveston District.

200. *Aedes taeniorhynchus* was reported to be a greater problem than *Aedes sollicitans* in the Jacksonville area. This observation was expected when the known ranges of the two species were considered. In Part V of this report, it was reported that both of these species were

common within the disposal sites of Charleston District. In northern States *Aedes sollicitans* is the more common marsh species; while *Aedes taeniorhynchus* (as a problem species) begins with Virginia and continues down for the entire state of Florida and much of the gulf coast. Other problems observed or reported from the Jacksonville District were habitats created by dike wall erosion at discharge pipe locations. While these problems were observed in the primary study areas; they were cited more commonly in the Jacksonville area.

201. Larvae were readily collected from many disposal area locations in small numbers during the site visitation to the New Orleans CE District. With the exception of *Aedes taeniorhynchus* not being considered a problem species (in the immediate New Orleans area), dredged material disposal sites in this District were similar to those of the Charleston District study areas. A detailed account of this visit is presented in Appendix D.

Norfolk District

202. The mosquito fauna of the Norfolk District was essentially the same as that of the Charleston District. A common plant species reported to cause some difficulty in mosquito control operations was *Phragmites communis*. The dense foliage of this plant is known to prevent proper penetration of pesticides into mosquito larval habitats within dredged material disposal sites. The most unusual mosquito larval habitat encounted in the Norfolk District was a dredged material disposal site that had received a deposit of sewage sludge. This site was noted as a source of *Culex* spp. mosquitoes (see paragraph 46, Appendix D).

Philadelphia District

203. Many conditions encountered in this District were similar to the other Districts previously visited with the exception that *Phragmites communis* was regarded as a more serious plant pest than was the case in the Norfolk District. Many large disposal sites in the Philadelphia District were covered with a monoculture of this plant that rendered mosquito control and/or inspection procedures difficult,

if not impossible. Some residents also reported this plant as a fire hazard in the Fall and Winter. *Aedes sollicitans* was the salient mosquito pest species.

San Francisco and Sacramento Districts

204. Dredged material disposal sites on the west coast were not regarded as major sources of mosquitoes in most cases. The habitats were similar and the DM stages of fissured soil were frequently observed. Many species of plants and mosquitoes collected from the east and gulf coasts were not present, but "equivalent species" were usually located. A major difference noted on the west coast disposal sites was the presence of the winter mosquito *Aedes squamiger.* This univoltine species was cited as a significant pest under special conditions. *Aedes dorsalis* was considered as the principal pest species associated with disposal sites. Dredged material successional seres (the DM stages of Part IV) were observed to be similar to their counterparts in the east, but the mature fissure stage (DM-4) was observed to be consistently deeper. The lack of rainfall during much of the warmer months in California probably accounts for the low production of mosquitoes from west coast disposal sites. See Appendix D for an account of other conditions from these two Districts.

Savannah District

205. Without exception, all dredged material sites visited in the Savannah CE District were similar to those of the Charleston District. All larval habitats and successional seres noted in Figures 14 and 15 were also readily located in the Savannah District.

Summary

206. In conclusion, a total of eight site visitations were conducted to observe mosquito problems associated with the disposal of dredged material. These studies were made to compare and contrast different conditions within disposal areas in different CE Districts. Most of the conditions were similar to conditions encountered in the

primary study sites in the Charleston District. A summary of all mosquitoes from all areas is presented as Appendix C and details of each site visitation are presented in Appendix D.

PART VII: POSSIBILITIES FOR BIOLOGICAL CONTROL OF MOSQUITOES WITHIN DREDGED MATERIAL DISPOSAL SITES

Rationale

207. Professional mosquito control agencies have long known that control by chemical pesticides in and around disposal areas is often inadequate. A number of efficient chemical pesticides are available for use against mosquitoes as adulticides or larvicides. However, because of the increased cost of bringing a new chemical pesticide to the consumer and its unknown life span, fewer and fewer chemical pesticides are being developed. Furthermore, the costs of chemical pesticides have greatly increased due to inflation. In addition, mosquitoes are continually developing resistance to chemical pesticides and more interest is developing towards reducing pollution of the environment by any and all chemicals, etc.

208. This section will examine various methods of biological control that are available now or might be available in the future. Therefore, it is mandatory to examine very critically other avenues of curtailing mosquito populations in disposal sites. It should not be expected that other approaches will necessarily be substitutes for chemical pesticides, but that it is realistically possible to expect nonchemical substitutes to reduce the use of chemical pesticides. Therefore, it is practical to look closely at what is available now or what may be available in the near future that might provide control of mosquitoes in this unusual habitat.

A Survey of Biological Control Agents

209. Classically, biological control agents are composed of diseases (pathogens and parasites) and predators. The principal and

important groups of pathogens and parasites are nematodes, bacteria, fungi, viruses, and protozoa. The main predators are either vertebrates, invertebrates, or plants. Chapman (1974) and Jenkins (1964) have recently reviewed a large portion of the literature concerned with the biological control of mosquito larvae.

210. Four round worms or nematodes are presently available in culture, *in vivo*, and all belong to the family Mermithidae.

211. *Romanomermis culicivorax* (Petersen et al. 1968 and Petersen and Chapman 1970b) is a nematode that infects over 60 species of mosquitoes, including all of those mentioned that breed in dredged material disposal sites. *R. culicivorax* is being produced in laboratories in substantial numbers using a host mosquito and it is possible that it will be marketed in several years. The preparasite (the infective stage) can be sprayed on mosquito producing areas or eggs (in media) can be easily distributed. However, this nematode as well as *Diximermis peterseni* which infects only anopheline larvae, will not tolerate brackish or saline waters, and hence would be ineffective in most disposal areas. Another species, *Octomyomermis muspratti*, is being cultured which possess a greater tolerance to alkaline waters and it is possible that this nematode could be eventually used. Several years of research, involving mastering its mass culturing; sensitivity to temperatures, salts, etc.; and host range and many other studies remain to be done with this new nematode.

212. The nematode, *Perutilimermis culicis*, which emerges from adult mosquitoes rather than from larvae as do the other previously mentioned nematodes, is species specific to *Aedes sollicitans* (Petersen et al. 1967). Since *A. Sollicitans* is one of the most important pest species produced in disposal sites, such specificity would not rule out this nematode as a possible control agent. However, because *P. culicis* emerges from adults, its culture is more complicated. It does have the added advantage of being disseminated by adult mosquitoes and thus does not have to rely on man to be spread from area to area. Excellent to complete parasitism of larval broods

in specific breeding sites has been observed although collections of adult females of *A. sollicitans* from large areas over a long period of time have indicated an overall level of insufficient parasitism. Some mosquito broods have excellent parasitism, which indicates that no eggs will be added to the habitat from those females, but often the following broods occur too soon with low parasitism resulting.

213. Nematodes undoubtedly occur that will tolerate saline waters, and if such organisms could be found and cultured, they would provide a good tool for control in dredged material disposal sites. The nematodes (as a group) are very persistent (9 years in some pools) and readily tolerate droughts and the absence of hosts. Current field information indicates that nematodes have an excellent potential for becoming established (recycling) in a site after their release in mosquito habitats and that they then continue to parasitize (sometimes completely) future mosquito broods.

Fungi

214. At least three different fungi are being intensively studied as biological agents of mosquitoes (*Coelomomyces* spp., *Metarrhizium anisophliae*, and *Lagenidium giganteum*).

215. The life cycle of *Coelomomyces*, after more than 50 years, has finally been resolved to the extent that a secondary host (a copepod) is now known to be involved. This breakthrough should stimulate researchers to determine whether the infective agent to mosquitoes that occurs in the copepod can be disseminated rather than sporangia from the mosquito. More than 40 species from 11 genera of *Coelomomyces* are known from many mosquito species. All of the principal mosquitoes occurring in disposal sites have been reported as hosts of this fungus. Species of *Coelomomyces* are very persistent in nature and survive well during periods of drought and absence of hosts. Specific sites have continued to produce infected mosquitoes after 9 years. Several small successful releases have been made against mosquitoes. Apparent disadvantages of *Coelomomyces* are that many species are apparently species specific or have a limited host range, they can

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only be cultured *in vivo*, and no mammalian or nontarget safety data are available. Since most *Coelomomyces* species are restricted to larvae, thus infecting and killing this stage in the same body of water, it is necessary that man disseminate the fungus to uninfected habitats. It appears that species of *Coelomomyces* are at least 5 years from being used in mosquito control programs, even though three or four substantial grants are now being funded for research on the fungus.

216. *Lagenidium giganteum* is an attractive biological agent of mosquitoes since it infects mosquito species of many genera, it can be produced in the laboratory both *in vivo* and *in vitro*, and it is a facultative parasite which can exist in nature in organisms other than mosquitoes. Also, preliminary studies show that it has the ability to recycle and infect subsequent mosquito broods as well as being noninfective to most nontarget organisms. Unfortunately, the present strains of *Lagenidium* now being studied are infective only in relatively fresh water and will not tolerate saline, alkaline, or polluted waters. This trait pretty well eliminates their use in dredged material disposal sites. See also the work of Umphlett and Huang (1972).

217. The World Health Organization has been active in the development and safety testing of the ubiquitous imperfect fungus *Metarrhizium anisophliae*. See also the works of Roberts (1967, 1970). This pathogen differs from the other two fungi in that it is incapable of recycling in mosquito populations because mosquitoes are not a natural host and the fungus does not produce conidia in the mosquito. Thus, this fungus must be applied to each mosquito brood as are chemical pesticides. *M. anisophliae* kills a wide variety of mosquito species and seems to tolerate diverse environments. Safety testing remains to be done, both on mammals and nontargets. Though the dosage for mosquitoes seems to be rather high, the development of more lethal strains or better formulations might make this a good biological agent since it can be mass produced quite economically *in vitro*. This agent might have eventual use in mosquito control in disposal areas if such shortcomings can be overcome.

Bacteria

218. Only species of *Bacillus* seem to offer promise among the bacteria. This group is of particular interest because it is easily mass produced via fermentation processes. At present, two species are being investigated, *Bacillus thuringiensis* and *B. sphaericus*, with the World Health Organization particularly interested in the development of the latter species.

219. A strain of *Bacillus thuringiensis* called BA-068 has elicited considerable past interest because of laboratory studies and one small field release (Reeves and Garcia 1970, 1971). The strain infected species of both *Culex* and *Aedes* mosquitoes but the dosage seemed to be fairly high. A plus for this organism would seem to be that it might easily be registered for use since *Bacillus thuringiensis* is the only biological agent that has achieved complete pesticide registration (for use in agriculture). Regardless, no safety data have been attained for this strain and further field studies are needed before the full potential of *Bacillus thuringiensis* against mosquitoes will be known. The effect of environmental factors on this strain of *Bacillus thuringiensis* is also known. Nothing is known as to the recycling of this biological agent but it would probably have to be applied against each brood of mosquitoes. Its manufacturing low costs would make it a likely candidate for eventual use in disposal sites.

220. The *B. sphaericus* (SSII-I) strain has looked promising in the laboratory against a variety of mosquitoes. It also can be easily mass produced, and preliminary safety data on mammals and other nontarget organisms will soon be completed. Field tests are needed to see how this bacterium will survive in nature. Again, such an agent that can be mass produced would probably work well in disposal sites but it appears that the use of such an agent is 3 to 5 years from being operational, if indeed it survives all of the testing. Kellen et al. (1965) and Singer et al. (1966) have provided contrasting views of the efficiency of this microbe against mosquitoes.

Protozoa

221. Although a great variety of protozoans attack mosquitoes, relatively few of these biological agents look promising at this point in time. Most of the research effort has been with the Microsporidia (Kudo 1925, 1960) and their greatest potential drawback has been the inability of the researchers to perorally infect healthy larvae in the laboratory with all but a handful of species. Hence most species cannot be maintained in the laboratory to do preliminary research and provide inoculum for field studies. A promising microsporidium is *Nosema algerae* (Savage and Lowe, 1970) since it is effective against anopheline mosquitoes. However, safety data against mammals and other nontarget organisms are not yet available, and it cannot as yet be produced *in vitro* although it can be produced *in vivo* in large lepidopteran larvae. A negative feature of *Nosema algerae* is its lack of effectiveness against *Aedes* and *Culex* mosquitoes. In addition, recycling ability of this pathogen is unknown. All of this negative information indicates that it would probably not be a good organism for use in dredged material disposal sites.

Viruses

222. As promising biological agents, viruses are actually only of academic interest at present. Although irido viruses, cytoplasmic, nuclear polyhedrosis, and other strange viruses have been located in mosquitoes, none are near field testing. Problems such as low transmission levels in the laboratory, no development of *in vitro* cultures, lack of safety testing, and limited host range of most viruses continue to plague researchers. Nuclear polyhedrosis of *Aedes sollicitans* (Clark et al. 1969, Clark and Fukuda 1971, Federici and Anthony 1972, and Federici and Lowe 1972) still seems to be the best virus that has been observed in three epizootics in larval broods in salt marshes that approached a 70 percent level of infection. Thus it is evident that viruses cannot be considered for biological control in disposal sites even in the near future.

Invertebrate predators

223. Probably insufficient credit has been given to the benefits derived from many invertebrate predators, particularly on mosquitoes breeding in permanent waters. Many beetle species (adults and larvae), Odonata naiads (dragon and damsel flies), hemipteran nymphs (nepids, belostomatids, notonectids, and corixids), certain mosquito larvae, and even planaria are efficient predators of many mosquito species. The papers of Washino (1969) and Trpis (1973) should be consulted for recent research on the control of mosquito larvae by invertebrate predators. Unfortunately, few of these species can be mass produced for release against mosquitoes. Also, timing the release of such predators against larval broods of floodwater mosquitoes is very difficult. At present no invertebrate predators can be produced in sufficient numbers for use in dredged material disposal sites. This is not to say that one could not take advantage of the natural populations of insect predators such as by providing them a reservoir ditch or pond or rim ditch where they could increase their numbers during periods of low water. Such populations could then be naturally disseminated by high waters' rainfall or tidal action to other parts of the disposal sites.

Vertebrate predators

224. The most common predators in this group are larvivorous fish, particularly *Gambusia affinis*, the top water minnow. Also many other minnows and fish such as killifish, sunfish, and carp have demonstrated their ability to control mosquitoes or vegetation that supports mosquitoes in specific situations. Again in such areas as disposal sites, reservoirs would have to be provided for the fish to recede to and survive in during periods of drought or absence of tides. See also the papers of Bay (1967) and Gerberich and Laird (1968).

Predative and larvicidal plants

225. Such plants or their seeds or extracts are only mentioned in passing since some grants are in effect at the present time for various studies against mosquitoes. Bladderworts do eat mosquitoes,

some stoneworts do exude chemicals into breeding areas that are said to discourage mosquito breeding or kill larvae, and various Cruciferae seeds are mucilaginous when wetted and do entrap mosquitoes, at least in the laboratory (Reeves and Garcia, 1969). None of these, at least at this time, seem to offer much promise in controlling mosquitoes in dredged material disposal sites.

Other Biological Control Methods

226. The use or release of sterile, incompatible, or those male mosquitoes with adverse genetic translocations is generally referred to as genetic control.

227. This genetic approach, particularly the release of sterilized males, has shown excellent promise in areas that are isolated from other breeding areas. At present there is nothing in this approach that would contribute to the control of mosquitoes within disposal sites.

Summary

228. In summary, the following factors relating to the potential of biological control methods against mosquitoes developing within dredged material disposal sites have been considered.

a. The life span or longevity of certain of today's chemical pesticides may be limited due to environmental considerations and resistance in mosquitoes. Alternative methods, such as biological control, are needed.

b. Biological control agents have been historically successful against certain insect pests following sufficient research.

c. The development of mass rearing techniques and the ability to infect host organisms are important considerations in the development of a successful biological control agent.

d. Classically, biological control agents have been considered as diseases (pathogens and parasites) and predators.

e. Among the nematodes, the inability to survive in saline and alkaline waters is a major limiting factor preventing successful propagation and release of species that might act against disposal site mosquitoes. One nematode species, *Reesimermis muspratti*, is said to be tolerant of alkaline waters.

f. Further research is needed before the fungi, bacteria, and viruses will be effective biological control agents against disposal area mosquitoes.

g. The role of invertebrate predators has been greatly underestimated in the past and further research is needed to understand and develop techniques that would tend to maintain these predators under field conditions.

h. The present state of the art of biological control is such that most potential control organisms cannot yet survive and/or be released into disposal sites. The future for biological control, however, remains promising.

PART VIII: TEMPORARY (CHEMICAL) CONTROL STUDIES WITHIN DREDGED MATERIAL DISPOSAL SITES

Rationale

229. A number of efficient chemical pesticides are presently available for the control of larval and adult mosquitoes that develop within dredged material disposal sites. In theory, all phases of the mosquito's life cycle can be affected by the action of chemical toxins. In practice, however, most chemical materials are applied against mosquito adults and larvae. The pupal period for most mosquito species is often short and the organisms do not feed during this time. At the present time, there are no effective ovicides.

230. All chemical control of mosquitoes must be regarded as essentially temporary in that the toxin eventually will become ineffective or diluted, allowing the target organism to return to its previous population levels. Chemical control of mosquitoes may take the form of larviciding measures that are applied within or on mosquito larval habitats. Larviciding treatments have the advantage of limited application to specific known sources of mosquito larvae. Control of adult mosquitoes by chemicals is generally termed adulticiding. Adulticiding operations are directed against flying mosquitoes over widespread areas and must be applied by truck or aircraft. The frequency and effectiveness of these measures is frequently a function of materials and operational and labor costs.

231. A good example of increased material costs can be cited in the case of a common larvicide, Flit MLO.® This common larvicidal oil is a petroleum product whose prices have risen sharply in recent years due to the overall shortage of petroleum products and its use in other areas (i.e. nonmosquito control). Larvicidal oils affect mosquito larvae and pupae through two actions: penetration of the trachea as a toxin and by suffocation through mechanical interference

of breathing mechanisms.

232. A number of organic poisons are available for action against both mosquito larvae and adults. Some newer commercial formulations are presently available as controlled release (CR) formulations. These encapsulated materials are designed to release toxic materials at a slow controlled rate over an extended period of time. Cautions regarding the use of organic poisons within mosquito breeding habitats have been previously discussed (see Part II, paragraph 34).

Insect Growth Regulator Field Tests

Introduction

233. Since the applications of chemical control measures against both larval and adult mosquitoes are well established and operational procedures are employed in hundreds of mosquito abatement programs in the United States, no further studies were conducted for this project. A recent new development in the control of insect pests by chemical measures concerns the use of insect growth regulators (IGR's). Insect growth regulators have added new dimensions and possbilities to the field of mosquito control. Two materials, Altosid® and Dimilin,® are presently available. While these materials have been found to have some promise against many species of mosquitoes, even the IGR's are not immune to the threat of genetic resistance. Both of the following IGR's have shown promise as practical mosquito control agents.

234. Altosid. Altosid SR-10 (active ingredient is methoprene) is effective against 2nd, 3rd, and 4th larval stages only. With this product there is a delayed effect (i.e. the larvae will not be killed), but the pupae will die or the adult mosquitoes will not emerge normally. Methoprene breaks down in water fairly rapidly and about half is lost in 2 days. It reportedly is relatively nontoxic to birds, fish, and wildlife. Several coastal mosquito abatement districts in Florida and Georgia have started using this IGR to control their salt

marsh mosquitoes.

235. Dimilin. Dimilin (TH 6040) is molting inhibitor (Tamaki and Turner 1974) which acts to inhibit chitin synthesis during molting (Post and Vincent 1973). It is effective against all instars of mosquito larvae. There may be a delayed effect. The chemical seems to break down fairly rapidly (in a few days) in water.

236. Nontarget organisms. The apparent success of these IGR's to control mosquitoes and their possible widespread use has caused several researchers to study their effects on different nontarget organisms (Steelman and Schilling 1972; Darlington et al., 1972; Miura and Takahashi 1973, 1974a, 1974b, 1975; Schafer et al. 1974; Norland and Mulla et al. 1975; Steelman et al. 1975; Mulla et al. 1975; and Gradoni et al. 1976). Their consensus conclusion was that there is a sufficiently high margin of safety to allow the use of these two IGR's as mosquito control agents. Cunningham (1976), however, cautions that the possible effects of Dimilin on nontarget arthropods has not yet been directed toward commercially valuable species, especially shrimp, lobsters, and crabs. Cunningham feels that large-scale treatment of salt marshes adjacent to estuaries with Dimilin may have a detrimental effect on both the adult crustaceans during molting periods and the larval crustaceans which use estuaries as nurseries during their development. However, with appropriate caution, it may be useful on dredged material disposal sites.

237. Axtell (Personal Communication, R. C. Axtell, 20 July 1977, Department of Entomology, N. C. State University, Raleigh, N. C.) compared Flit, Altosid and Dimilin in ground ("hand" applied) applications on diked disposal sites in North Carolina. In the only published aerial field test of these IGR's against salt marsh mosquitoes, Rogers et al. (1976) found that Altosid and Dimilin formulated on sand gave good penetration of the dense canopies of mangrove trees and picklewee[illegible] nd resulted in effective control. There was no indication in their [illegible] at the sand formulation of either of these IGR's gave suffic[illegible] idual activity to control later broods of

Aedes mosquitoes. But they observed that even with overtreatment these IGR's did not adversely affect fishes present in their experimental plots.

238. During the summer of 1976, tests were conducted with aerial and ground applications of several formulations of Altosid to determine possible use to control mosquito larvae within diked dredged material disposal sites. Two locations, in Charleston and Georgetown counties, South Carolina, were selected. Both sites were with the Charleston District of the Corps of Engineers.

Charleston county tests: Trial 1

239. Materials and Methods. In July and August of 1976 tests on two formulations of Altosid® (Altosid SR-10 sand mixture and Altosid 0.4% sand granules) were performed. Application sites were selected through the courtesy of the Charleston County Mosquito Abatement Program. The aircraft used was a Rockwell Thrush Commander® available from a commercial pesticide applicator. The aircraft was equipped with a Transland® seeder which was modified to allow for the low rates of application that are needed for granular materials.

240. The Altosid SR-10 sand mixture was prepared on 27 July and applied on 1 August 1976. Six hundred pounds of the material were prepared. During the interim, the mixture was stored in sealed buckets. The mixture was applied at the rate of 10 to 12 lb/acre (0.02 lb of active ingredient/acre) to a heavily vegetated dredged material disposal site known locally as S-10 (see Figure 5). The vegetative covering was predominantly dense stands of salt marsh aster, *Aster tenuifolius*, which had grown to a height of 5 to 6 feet. This vegetation covered two stages of dredged material. Some parts of the site were considered as stage D-6, while other habitats were considered as D-5 conditions.

241. A control site known locally as N-21 disposal site (see Figure 5) was selected as a check area for untreated larval sampling. Control collections from the same site were used in all chemical tests.

242. A pretreatment survey showed that there were 86 to 205 mosquito larvae per dipper. The majority of the larvae were *Aedes taeniorhynchus*, but some *Psorophora howardii* and *Anopheles* spp. were also present. The larvae were late third or early fourth instar when the material was applied. Following the test application, larvae and pupae were brought back to the laboratory and held in emergence cages at room temperature. Untreated check areas were, likewise monitored for both larval and pupal collections.

243. Trial 1: results and discussion. A visit to the test site on the afternoon following the test application revealed excellent penetration of the vegetative canopy. During the period 11 August to 20 August 1977, approximately 3.6 in. of rainfall was recorded on both the test and control disposal area.

244. Results were not encouraging. Pupae and late fourth instar larvae were collected on 24 August. From five different locations (i.e. samples) a total of 434 pupae were collected. From these samples, 379 adult mosquitoes emerged, with 54 pupae and only 1 larvae noted as dead, giving a percent mortality of 12.5 percent. Larvae (late fourth instars) were also collected and separated during this time. From four samples totaling 118 larvae, 104 adult mosquitoes emerged, with 9 pupae and 5 larvae recorded as dead, giving a percent mortality of 11.9 percent.

245. Two days later, on 26 August 1977, an all pupal collection consisting of five samples was made from the test site. A total of 571 pupae were collected. From these samples, 467 adult mosquitoes emerged, with 104 pupae and no larvae recorded as dead, giving a percent mortality of 18.2 percent.

246. While the mortality observed in these initial tests was low, it was observed in the laboratory that the size of the adults appeared to be somewhat reduced, with the emerged adults appearing to be somewhat smaller than the control samples. This observation, however, was not statistically verified. Possible reasons for the failure to obtain better control are that the water depth (approximately

5 in. during the test) was sufficient to allow the chemical to become diluted. It is also possible that the chemical did not diffuse throughout the water rapidly enough (resulting in a sublethal dosage level). The investigators believe that the latter explanation is more realistic as later tests were more successful.

247. Control collections (from site N-21) were the same for all the Charleston County tests. Since the test applications of Altosid were within days of one another only one control site was utilized. When four samples, totaling 791 pupae, were collected from the control site on 1 August 1976, only four pupae failed to emerge as adult mosquitoes giving a natural mortality of 0.5 percent. During other control areas sampling (23 August), a total of 38 second instar larvae were collected from five samples. Of these, 13 pupae were recorded as dead, representing a natural mortality of 34.2 percent. The investigators believe that this natural mortality was due in part to the early stages that were collected. The final control site collections were collected on 27 August. These collections, from the same site and possibly the same brood as the previous collection, exhibited only a 4 percent mortality. A total of 25 fourth instar larvae were collected, with only 1 larval death noted.

Charleston County tests: Trial 2

248. Introduction. A major problem confronting mosquito control personnel is the inability to "pretreat" a potential larval habitat prior to the onset of rainfall that will convert the dry habitat into a mosquito source. This problem is especially acute with *Aedes* and other floodwater mosquito species. This section of the study was concerned with pilot studies that might lead to the development of "pretreatment techniques." Altosid 0.4% sand granules are a premixed, encapsulated, slow release formulation of Altosid.

249. Material and methods. A heavily vegetated disposal site, known locally as S-8 (see Figure 5) was selected for this trial. This dredged material disposal area had a history of producing large concentrations of mosquitoes (Personal Communication, 22 April 1976,

Max M. Askey, Jr., Entomologist, Charleston County Mosquito Abatement Program, 4370 Azalea Ave., Charleston, S. C., 29405). Due to the lack of rainfall, the disposal site had become quite dry and a large concentration of mosquito eggs was suspected. On the day of application (1 August) no water was located within the disposal site with the sole exception of the discharge site habitat (see Figure 15, item 9). Twenty-five acres of dredged material were treated at a rate of 8 to 10 lb/acre (0.04 lb of active ingredient/acre) by aircraft. On 2 August, the site was inspected and good uniform coverage was observed. Excellent canopy penetration was achieved and the black granules were easily seen against the grey, weathered appearance of the dredged material.

250. On 2-3 August the site received 2.4 in. of rainfall. This extensive rainfall started the first *Aedes* mosquito brood. An average of 150 to 300 larvae per dip could be observed almost at random within the disposal site. Two collections were made from the site during this brood. The first collection consisted of 15 samples from a variety of locations. The total of these five samples was 326 larvae (mostly third and fourth instars). Laboratory observations revealed that 37 specimens died as larvae and 222 pupae were recorded as dead, representing an observed mortality of 79.4 percent. Several days later, a second collection, representing five samples was made that totaled 598 pupae. Of these specimens, 597 were observed to die in the laboratory, representing an observed mortality of 99.9 percent. Thus, it was felt that excellent control was obtained from this pretreatment of a previously dry disposal site.

251. The next question to be considered was the residual life of the encapsulated material. On 10-11 August, the test site received 2.6 in. of rainfall which perpetrated the second observed larval brood during the test. Within 12 hr, larvae were again observed and estimated at greater than 150 larvae per dip. For the second collection, only pupae were collected (on 21 August) and retained in the laboratory. A total of 386 pupae from three samples were collected. From

sample, the observed mortality was 88.6 percent.

252. The third and final collection that was obtained from the test of encapsulated Altosid followed approximately 1 in. of rainfall that occurred on 20 August on the test site. A total of 489 late fourth instar larvae, representing eight sample locations were collected on 27 August. This rapid rainfall within a short period caused some overlapping of the second and third broods, but again greater than 150 larvae per dip were observed (the third brood was recognized due to the presence of earlier instars). Due to lower ambient temperatures, this third larval brood developed slower than had been the case with broods one and two. A total of 489 late fourth instar larvae, representing eight sample locations, were returned to the laboratory for observation. An observed mortality of 59.9 percent was recorded for the third brood.

253. As previously cited, the control collections revealed naturally high emergence with almost no mortality, provided later instars were collected. Laboratory emergence was therefore in all cases (treatment and control) based on larvae that were at least third or fourth instars.

Georgetown County tests

254. Introduction. During August, two additional formulations of Altosid were tested in Georgetown County, South Carolina. These tests were conducted with the cooperation of the Georgetown County Mosquito Control Program. The Georgetown County tests were designed to test two formulations of Altosid under disposal area conditions. Different portions of a disposal area known locally as "Little Crow Island" or A-5 (see Figure 5) was selected for both tests.

255. Materials and methods. Two formulations were used, the Altosid "Briquet" and Altosid SR-10 liquid formulation. Both formulations were applied on 6 August. The briquet is designed to treat approximately 100 sq ft of water surface up to 2 ft deep. A total of thirty 100-sq ft plots were marked within the disposal site with stakes. Each plot received one briquet. On the morning of 9 August

pupal collections were conducted within the plots. Collections were made from the centers (nearer to the briquets) and from the edges of the plots.

256. The second formulation, Altosid SR-10 liquid, was tested on the opposite side of the disposal site from the briquet tests. This test involved a ground application of Altosid with a 2-gal hand sprayer. The desired rate of application was achieved by mixing 0.6 fluid oz of the 10 percent Altosid SR-10 to 1 gal of water. Five gallons of the final solution were sprayed per acre or 0.02 lb of active ingredient per acre. To attain the desired coverage, the applicator walked approximately 1 mph and sprayed a swath of 15 ft. One hour and five minutes were required to cover the 2 acres that received the treatment. Several days after treatment pupal collections were made and held for emergence in the laboratory.

257. In the case of both tests, an unusually high wind-driven tide was noted just prior to the collection time. This tide entered the test disposal site through dike weirs and may have diluted the material. A third portion of Little Crow Island was utilized as a control area for both tests.

258. Results and discussion. The briquet test collections were taken from both the centers and edges of the test plots. In general pupae were noted to be more concentrated near the edges of the test plots, while larvae were scattered throughout. A total of 403 pupae, representing two sample locations, were collected from the centers of the test plots. Upon observation in the laboratory, a total of 195 pupae from this sample died, representing an observed mortality of 48.4 percent. A total of 1114 pupae were collected, representing three sample locations, from the edges of the test plots. From this sample, 608 pupae died, representing an observed mortality of 54.6 percent.

259. Five sample locations were chosen for a collection that totaled 1044 pupae from the Altosid SR-10 test site. Of these pupae, 1006 died, representing an observed mortality of 96.4 percent. A

total of 535 pupae, representing four sample locations, were collected from the control area. The observed natural mortality among the control group was 9.2 percent.

260. The briquets did not give the apparent level of control that was observed with the Altosid SR-10 formulation. It should be recalled at this point that the sand SR-10 formulation did not offer good results in the Charleston County tests as was the case in Georgetown County. The most encouraging tests were associated with the encapsulated material that was employed within disposal site S-8. This formulation indicated promise as a pretreatment material within disposal sites. All tests conducted during this section were considered as pilot studies conducted under field conditions. Additional replications and tests will be needed before it is fully known if insect growth regulators will be able to offer mosquito control within disposal sites.

Summary

261. In summary, the following points were considered during chemical control studies conducted within dredged material disposal sites.

- a. Limited pilot studies were initiated to determine if certain compounds, commonly known as insect growth regulators (IGR's), could be employed against mosquitoes developing within dredged material disposal sites.
- b. Several formulations of one growth regulator, Altosid, were tested within disposal areas that had a history of producing mosquitoes.
- c. Mortality was observed in larval and pupal collections that were returned to the laboratory several days after treatment.
- d. The application of Altosid 0.4 percent sand granules as a pretreatment to a dry disposal site was the most successful experiment of the series.

e. **Insect growth regulators were found to offer promise as mosquito control agents within dredged material disposal sites.**

PART IX: PHYSICAL CONTROL OF MOSQUITOES DEVELOPING WITHIN DREDGED MATERIAL DISPOSAL SITES

The Rim-Ditch as a Physical Control Measure

Rationale

262. Mosquitoes are present in large numbers within disposal sites for two reasons: the absence of effective predators and the presence of lentic water within fissured soil in low swales. Any physical control measure that might enhance predators or increase water flow would tend to be detrimental to the present mosquito larval habitats that are common within most disposal sites in the eastern United States.

Materials and Methods

263. A number of field trips were made to a large number of disposal sites in an effort to determine or elucidate any natural factors that might be used to eliminate or reduce mosquitoes. During these trips, extensive field notes were recorded on any factors that might appear significant to mosquito control. One natural site was located that did not produce mosquitoes at any time during the study period. This site, known locally as N-15 (see Figure 5), was studied and analyzed for possible duplication as a mosquito control measure. The principal "natural" feature controlling mosquitoes within site N-15 was the presence of a "rim-ditch" which allowed for the access of natural larval predators. The site had not received a large amount of dredged material, but an intact dike separated the location from the surrounding marsh. Water entered the disposal site freely with each tide and a "tidal flushing action" was effected. An artist's conception of the rim-ditch concept is presented as Figure 32. An aerial and ground-level photograph of site N-15 are presented as Figures 33 and 34,

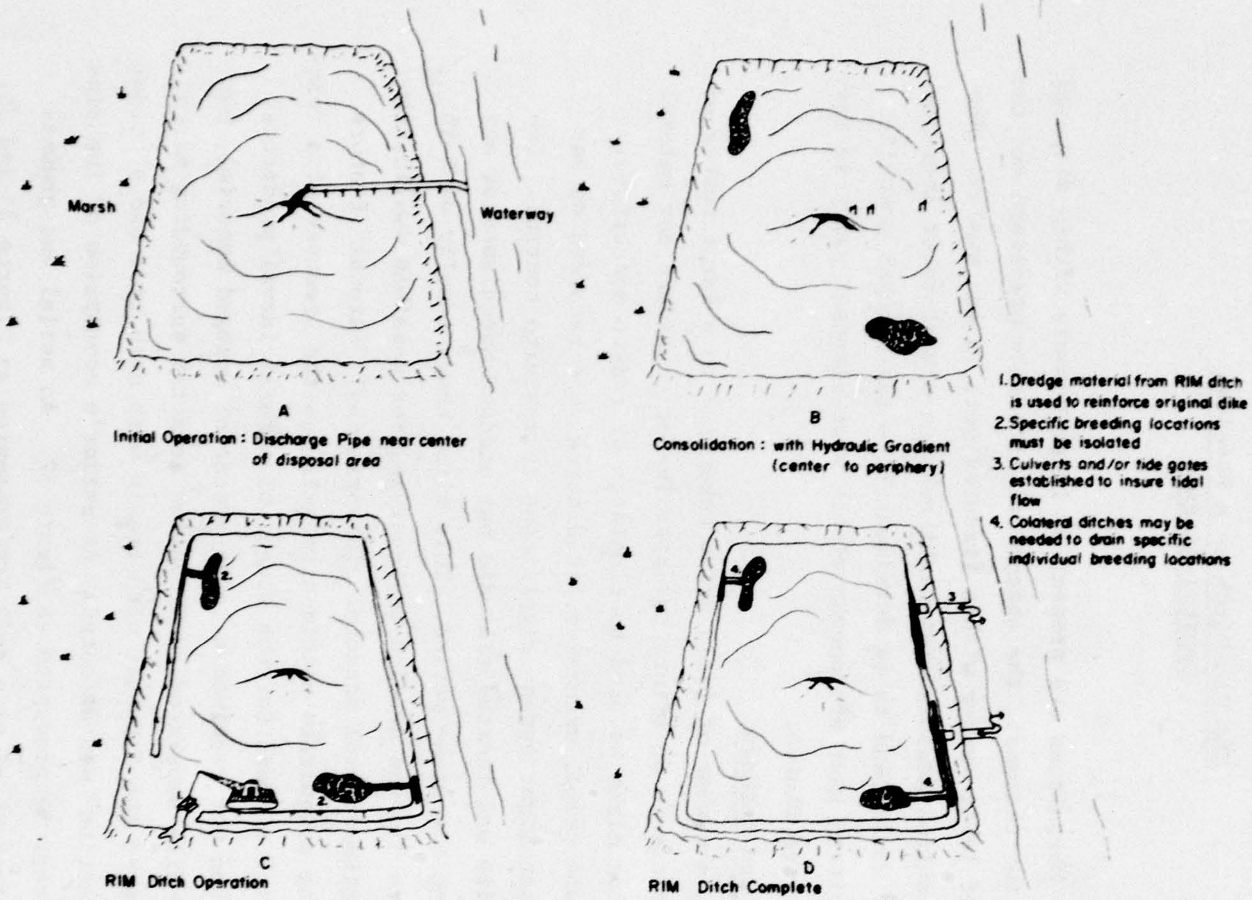

Figure 32

Artist's Conception of Rim-Ditching Pattern for Mosquito Control within Dredged Material Disposal Sites

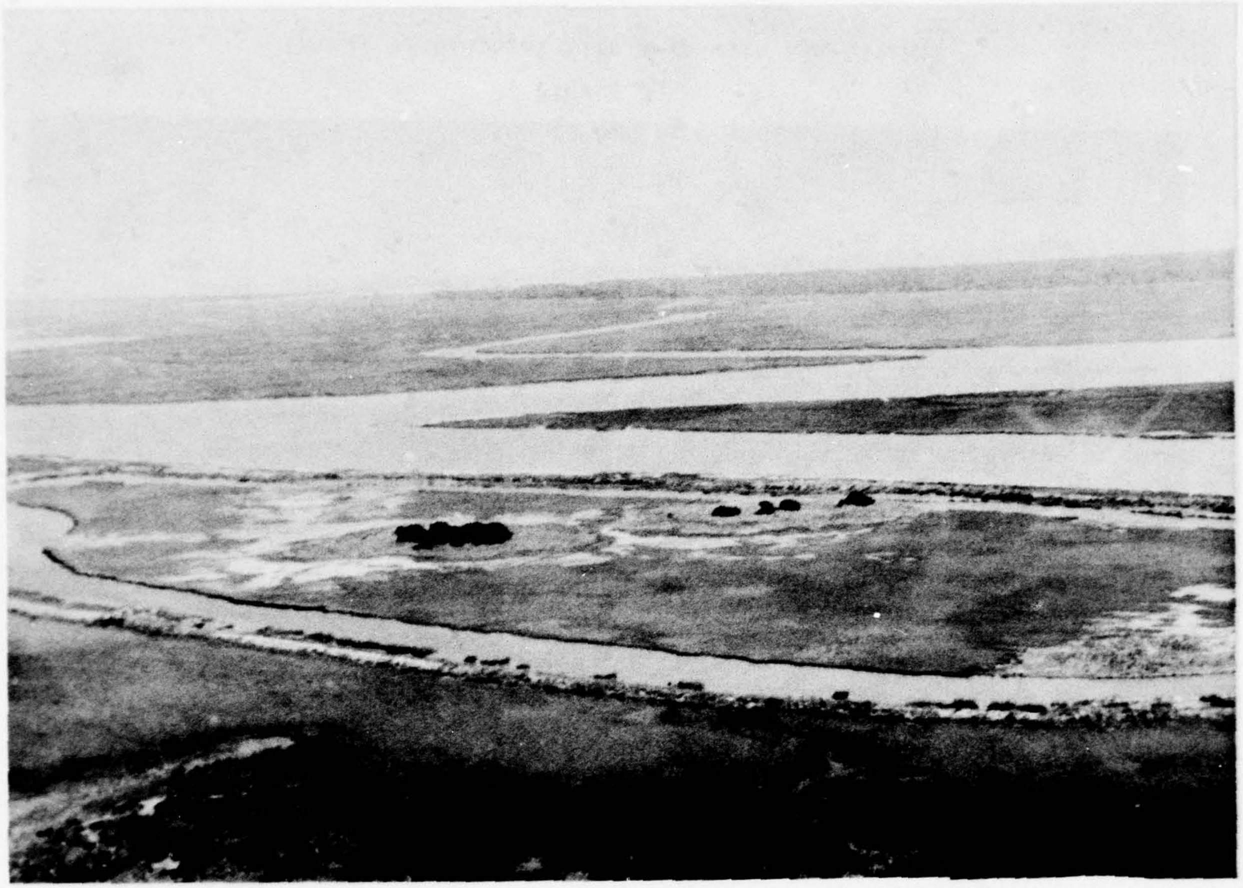

Figure 33

Aerial View of Disposal Site N-15 with Encircling Rim-Ditch

Figure 34

Detail of Disposal Site N-15 with Rim-Ditch respectively.

264. The site. Through the courtesy of the Charleston District of the Corps of Engineers, arrangements were made to attempt to duplicate rim-ditch conditions on an active mosquito source. This site known locally as site N-22 (see Figure 5) had been a major source of mosquitoes for the nearby towns of Sullivan's Island and Isle of Palms, South Carolina, during the 2 years prior to the onset of the study. Most of the active larval habitats were considered as being under DM-4 or DM-5 conditions (see Figure 14). The most common sources of larvae within the site were dike swales, borrow pit swales, protective volunteer vegetation sites, and sump sites (see Figure 15 for an explanation of these sites).

265. Rim-ditching techniques. In order to compare the effects of the rim-ditch with a nonrim-ditched area, it was decided to divide the disposal site into approximately equal halves by the construction of a cross dike (Figure 35). A rim-ditch was then dug within the western end of the divided disposal site. Materials from the rim-ditch were used to strengthen the western dikes. The rim-ditch was dug as a rough perimeter approximately 12 to 15 ft from the dike, 3 ft wide and 6 to 18 in. deep. A "weep hole" connected the rim-ditch with the AIWW in the northern dike.

Results and discussion

266. Observations on the rim-ditch construction. In early August of 1976, construction began on the proposed rim-ditch for site N-22. Construction was completed on 25 August and observations on the effectiveness of the concept began immediately. From the outset, several engineering difficulties were encountered that had not been anticipated. It is now apparent that a good rim-ditch must be at least 6 to 8 ft wide, 12 to 24 in. deep, and allow for free water movement. Within the N-22 site the ditch frequently did not allow water to move freely. This problem was the result of making separate lateral "passes" with the dragline as opposed to

Figure 35

Rim-Ditch and Cross Dike Construction within Disposal Site N-22, Charleston CE District (note cross dike on left and "weep hole" in background dike) longitudinal passes that are in line with the proposed ditch. An example of this type of digging and the broken pattern created is shown in Figure 36. In this figure, notice that the separate "passes" by the dragline operator were not connected in such a manner as to create a smooth ditch that would allow for water passage. If a ditch is to be dug for mosquito control (as opposed to diking), it is essential that all turn around areas be graded in such a manner that swales and depressions do not remain in the area. Surface alteration of dredged material disposal sites frequently creates additional mosquito larval habitats. These conditions have been previously illustrated as Figure 19 and in diagram form in Figure 15 (as item 12). Numerous areas of surface alterations from dragline operations were observed within the N-22 site following the construction of the rim-ditch.

267. Successful construction features. The addition of the weep hole in the southern dike was successful and substantial drainage did occur. The area was observed to flood at high tides and the site did drain rapidly along those portions of the rim-ditch that were properly constructed. The western end (rim-ditched) tended to dry much faster than was the case with the eastern end (nonrim-ditched). Predatory organisms were able to enter the weep hole and colonize the rim-ditch. Plant growth and succession seemed to be retarded by the rim-ditch. Perhaps the introduction of salt water or the rapid drying prevented plant forms from growing rapidly. The eastern end of the site (nonrim-ditched) obviously sustained better plant life.

268. Biological observations. The following fish species rapidly colonized the rim-ditch (within 3 weeks), but were usually confined to the deeper sections:

a. *Gambusia holbrooki*, the top minnow.

b. *Cyprinodon variegatus*, the broad killifish.

c. *Fundulus heteroclitus*, the common killifish.

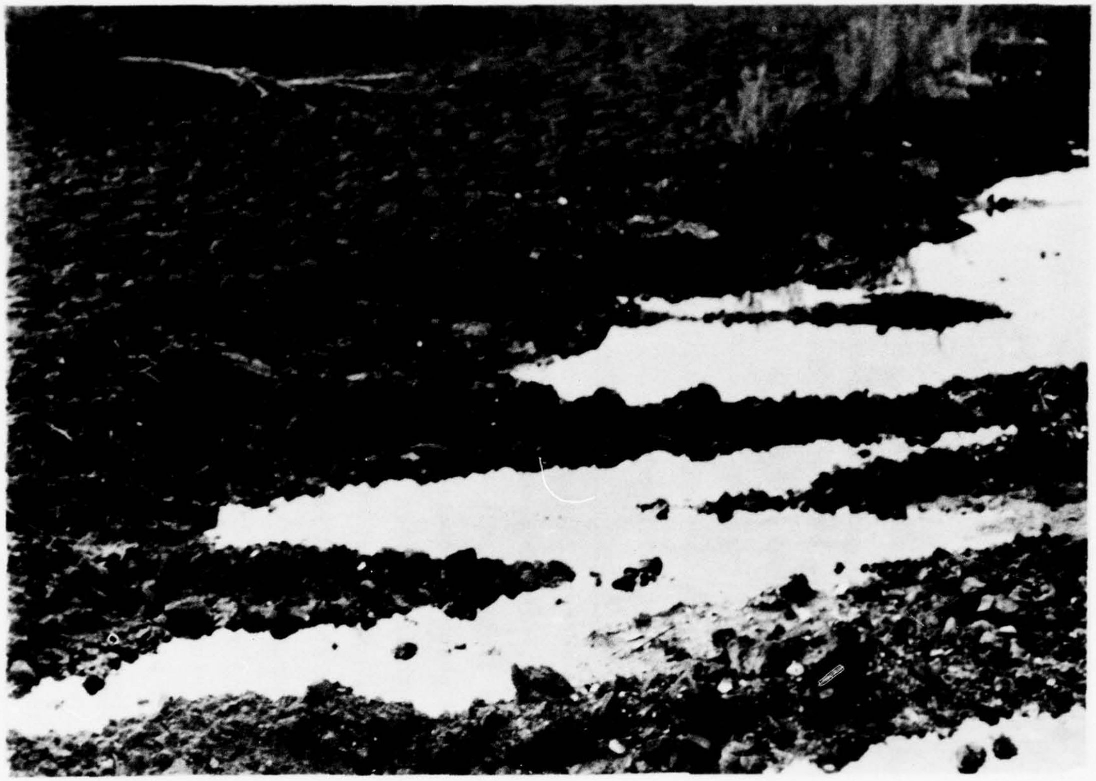

Figure 36

Detail of Poor Ditch Construction (note that water is separated in compartments and does not circulate)

All of these fish species are known to be useful in mosquito control, with *Gambusia* perhaps the strongest predator of larvae. Mallars and Fowler (1970) have summarized a number of important features concerning the control of mosquitoes by fish. Other organisms that were collected from the rim-ditch included shrimp (*Palaemonetes pugio*) and crabs (*Callinectes sapidus*). It is important to note that none of these species were introduced into the disposal site and that none occur in diked disposal sites that do not have a rim-ditch and weep hole through the dike.

269. Mosquito observations. Mosquito observations were not as encouraging as had been anticipated. The disposal site was very dry during the ditching operation and it was suspected that mosquito eggs had reached a high potential prior to the first flooding. Shortly, after the first major rainfall on the test site, larvae were located readily on both sides of the disposal area. Large concentrations of larvae, however, were always in protected sites that afforded protection from predators. It was felt that if the rim-ditch had freely communicated to all parts of the site that many of these larvae would have been destroyed by predatory fish.

270. Borrow pit swale. The rim-ditch, despite its poor construction, did eliminate major portions of the borrow pit swale larval habitat in the ditched side of the test site. Larvae continued to breed within the borrow pit swale on the unditched portion of the disposal site. One of the better portions of the ditch that did eliminate the borrow pit swale larval habitat is shown as Figure 37. In addition, the dike swale habitats appeared considerably drier and likewise did not produce mosquitoes after the rim-ditch was installed on the western side of the test location.

271. Mosquito collections. Prior to the construction of the cross dike and rim-ditch, a number of larval samples were taken from both sides of the intact disposal site. These larval counts were deliberately taken during high larval populations. These

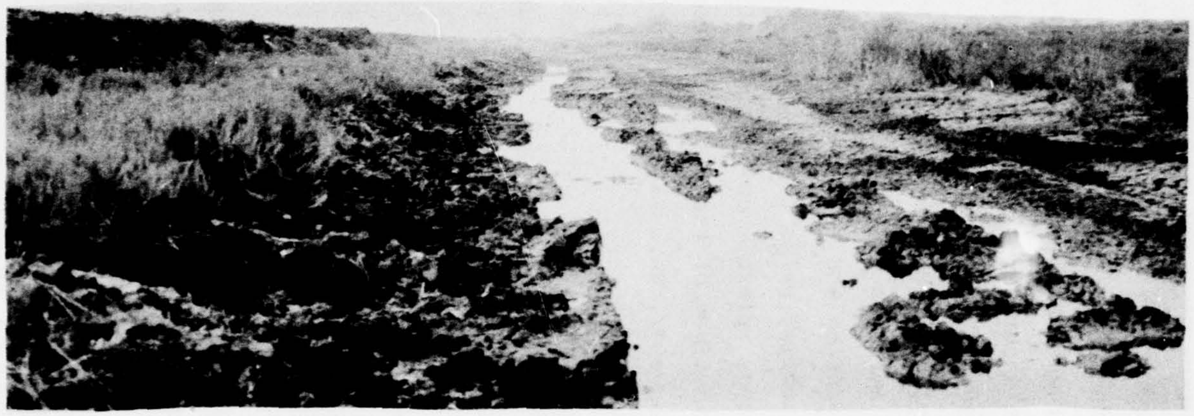

Figure 37

Rim-Ditch Construction for the Elimination of the Borrow Pit Swale Habitat pre-construction counts totaled 7,866 mosquito larvae, representing 43 samples with an average larvae/dip count of 182.9 from the western end of the site (to be rim-ditched). Another sample was collected from the control area (western end) which totaled 3,303 larvae, representing 16 samples with an average larvae/dip count of 206.4. Following the construction of the cross dike and rim-ditch, both sides were sampled during periods of suspected high larval activity. The rim-ditched collections totaled 1,014 specimens, representing 45 collections with an average larvae/dip count of 22.5. The control collections yielded 1,392 individuals, representing 30 samples with an average larvae/dip count of 46.4.

272. Future considerations. The investigators of this report are convinced that the rim-ditching techniques proposed in Figure 32 will reduce larval counts even more if careful attention to proper ditch construction is observed. The ability to employ water management practices within dredged material disposal sites is obviously the key to the successful physical control of mosquitoes breeding within such sites.

Summary

273. In summary, the following considerations regarding rim-ditching have been considered in this section.

a. The only disposal areas that were located during field surveys that did not have the potential for supporting larval mosquitoes were observed to have a rim-ditch.

b. Physical alterations that introduce predators and/or the flow of water will tend to eliminate larval mosquitoes from disposal sites.

c. Through the cooperation and courtesy of Charleston District of the Corps of Engineers an experimental rim-ditch was constructed.

d. The rim-ditch communicated with the AIWW through a "weep hole" in the dike.

e. Following construction of the rim-ditch, mosquito predators were readily collected from aquatic habitats.

f. The rim-ditch was not as successful as anticipated, but new design techniques were learned and some larval habitats were successfully eliminated.

g. Overall larval counts in the rim-ditched area were lower than the control section.

h. Surface alteration of the disposal site by heavy equipment tended to generate new mosquito habitats in some cases.

i. It was proven that the rim-ditch could eliminate a major mosquito habitat (the borrow pit swale) from disposal areas.

Mechanical Drainage Equipment

Rationale

274. Source reduction. For a number of years, various types of heavy equipment have been employed in drainage and fill projects to eliminate mosquito larval habitats. Such projects are generally termed source reduction. These methods have the advantage (over chemical control methods) of permanently eliminating or at least reducing mosquito larval habitats without additional treatments. Throughout the United States, one can locate older source reduction mosquito control structures that are still functioning with minimal maintenance. Source reduction methods have the disadvantage of high costs at the outset. The literature on source reduction is large, but a number of source reduction techniques have been summarized in a recent report by the World Health Organization (1973).

275. Use of the RUC. Through the courtesy of Charleston District of the Corps of Engineers and the Dredged Material Research Program, a number of observations were made on a special vehicle constructed by the U. S. Navy, popularly known as the "RUC" (Riverine Utility Craft). A summary of the abilities of this vehicle have appeared in a publication by the U. S. Army Engineer Waterways Experiment Station (1975). The RUC has been extensively

tested within dredged material disposal sites in the Mobile District. A photograph of the RUC in operation is shown in Figure 38.

Materials and methods

276. Since the RUC was to be tested within a number of dredged material disposal sites in Charleston District in conjunction with other engineering studies, it was convenient to make certain observations regarding the potential of the machine for mosquito control. Most of the observations were made on Drum Island disposal site (see Figure 4).

Results and discussion

277. Capability. The RUC was observed to operate on a wide variety of different substrates. It was especially interesting to observe that the RUC was capable of movement through dredged material stages DM-4 and DM-5 (see Figure 14). It will be recalled that these stages tend to be associated with high larval populations of mosquitoes. The RUC moves through soft substrates or water by means of twin helical screws powered by interior engines. The craft is 20 ft long and weighs 6 tons. A detail of the helical screw mechanism is shown as Figure 39.

278. The RUC is of interest to mosquito control personnel because of its ability to enter dredged material disposal sites several months before a conventional dragline could function. As the RUC moves through a disposal site, the twin helical screws leave behind a pair of shallow ditches. A photograph of these ditches may be seen in Figure 38 and in greater detail in Figure 40. During the Charleston studies, the RUC was operated for approximately 1/2 day within the Drum Island disposal site. During this time a number of parallel ditches were constructed from the disposal site proper to various drainage weirs. These ditches did appear to affect water movement and promote the dewatering of the site in affected areas.

279. Limitations for mosquito control. The only limitation to the use of the RUC as a drainage tool for mosquito control is the inability of the machine to create drainage ditches in fluid-like dredged

Figure 38

Riverine Utility Craft (RUC) Underway in Dredged Material,
Drum Island Disposal Site, Charleston, South Carolina

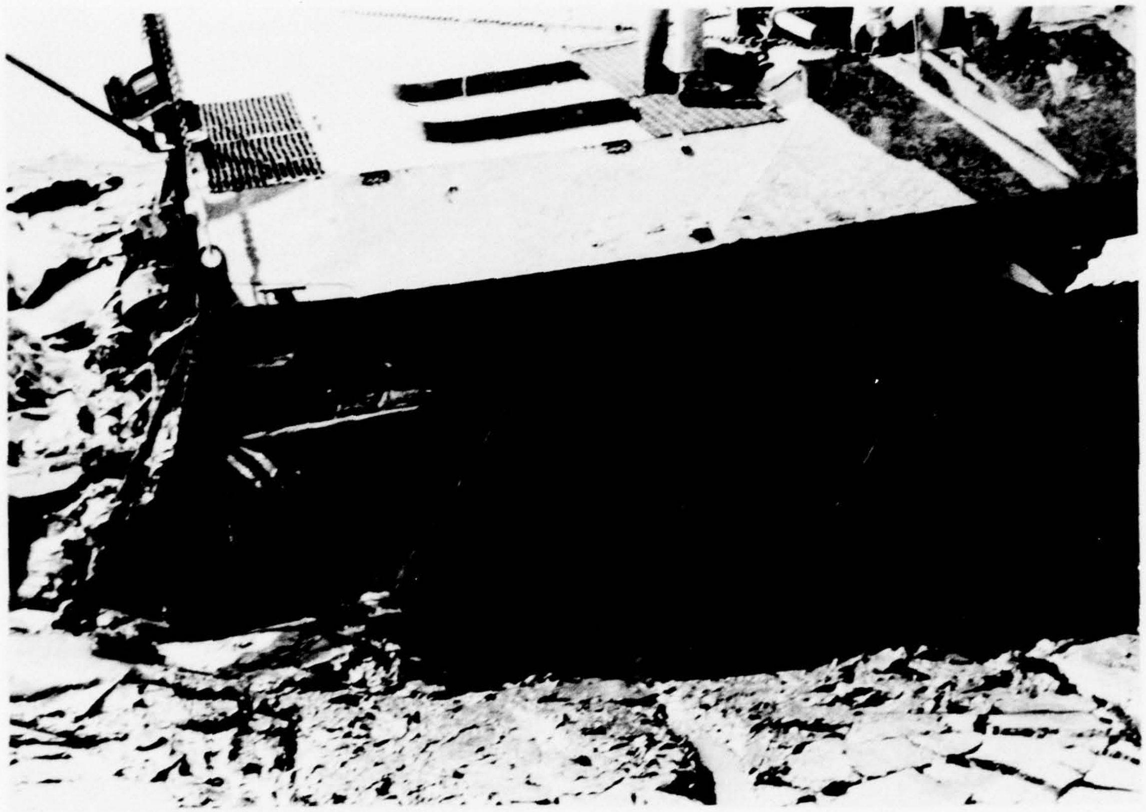

Figure 39

Detail of RUC Helical Drive Screw

Figure 40

Twin Ditches Produced by RUC Operation in Dredged Material

material usually found around sump sites. These areas will often require additional visits by the RUC after additional dredging has occurred. The breakdown of RUC ditches near sump sites is shown in Figure 41. Another minor disadvantage is the shape of the ditch per se. The helical screws of the RUC leave behind depressions in the ditch that were later observed to breed mosquitoes. This habitat, however, is quite small compared to the overall fissured soil environments. The RUC during its Charleston visit did not employ any implement (such as a plow) that might have created a cleaner ditch.

280. Future uses. There is a need for future research on the use of the RUC in mosquito control. The investigators of this study feel that its potential in dewatering certain areas and the possible creation of rim-ditches within dredged material disposal sites should be carefully studied. Present physical control measures of mosquitoes within disposal sites are limited by equipment which may not be able to operate during mosquito producing conditions or vehicles which create additional mosquito habitats by the nature of their operation.

Summary

281. In summary, the following items have been considered regarding the use of the RUC for mosquito control.

a. The RUC is capable of operating within dredged material disposal sites at times when other equipment cannot function.

b. The RUC has the ability to dig twin ditches through a variety of substrates.

c. Some limited mosquito breeding was observed within RUC tracks, but this disadvantage was countered by the ability of the RUC to effect dewatering of larger areas of mosquito larval habitats.

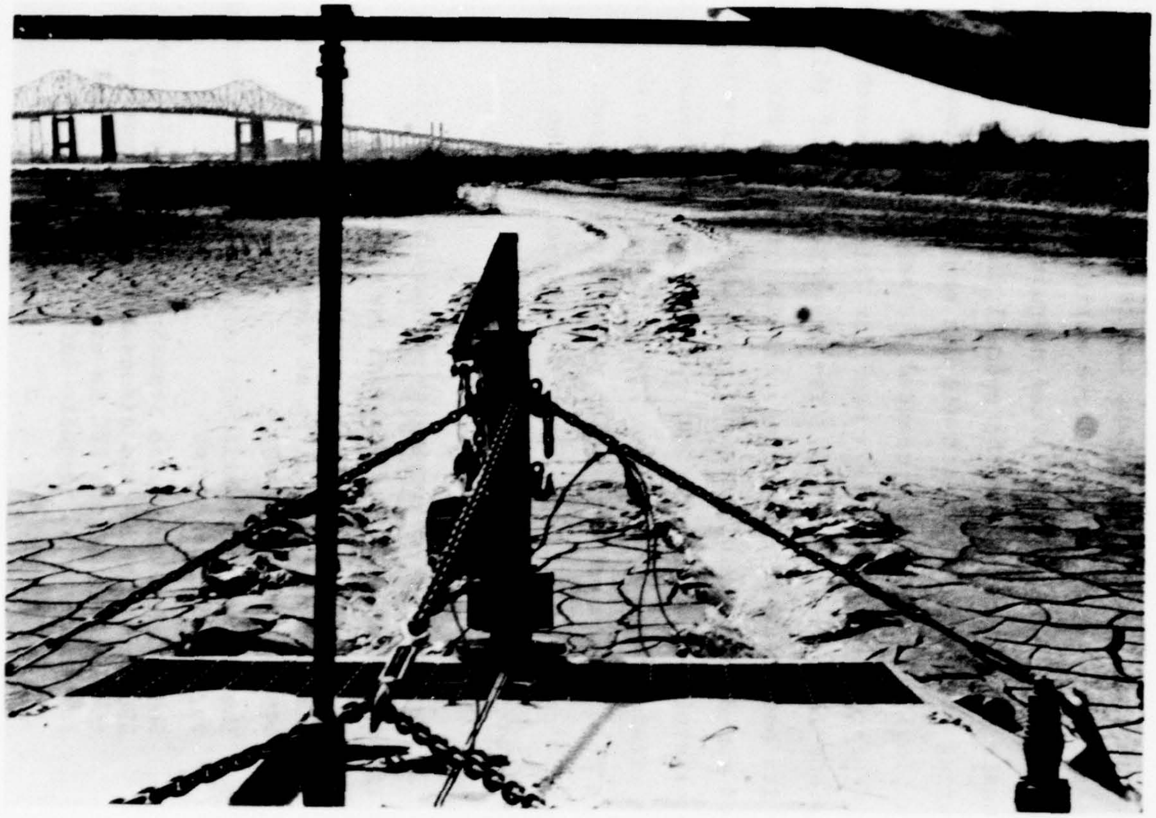

Figure 41

Result of RUC Operation through a Sump Habitat, Drum Island Disposal Site, Charleston CE District *d*. Future experiments should be designed to study the use of the RUC with additional ditching tools, such as backhoes and draglines.

e. It is possible that the RUC could be used to construct disposal area rim-ditches.

Use of Soil Amendments

Rationale

282. As noted in the section on mosquito larval ecology (see Parts IV and V), the presence of mosquito larvae is often associated with the appearance of some form of fissured soil. In those areas that do not have fissured soil (i.e. sandy disposal sites), larvae are scanty or absent. Since most dredged material consists of fine-grained material that will invariably form soil fissures, some pilot studies were initiated to investigate the possible use of soil amendments to prevent the formation of the fissured soil mosquito habitat. It was reasoned that if the soil fissures could be eliminated or at least reduced, then the mosquito threat would be likewise reduced in proportion.

283. The prevention of the formation of soil fissures can be accomplished by one of two ways. The first procedure involves the use of a covering material to keep the surface of the dredged material at a water content slightly above the water content at which the formation of the soil fissures begins. The second procedure requires the addition of coarse-grained particles to the dredged material to prevent fissure formation. This latter method would require the addition of large amounts of additives that would reduce the holding capacity of the disposal site. Therefore, this study considered only the use of covering materials.

284. Capillary action in the covering material is required in order to keep the surface of the dredged material at a high water content. As shown in Figure 42, soil moisture is divided into

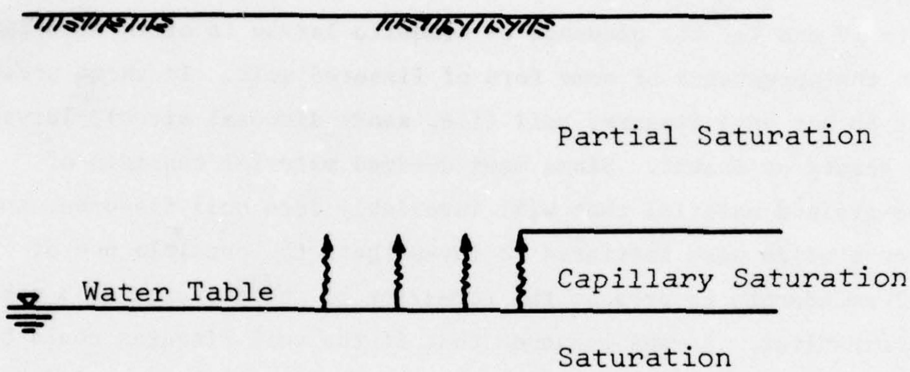

Figure 42

Diagram of Dredged Material Saturation Zones

three zones. Soil lying below the water table is assumed to be completely saturated, and a portion of the soil above the water table is also assumed to be saturated due to capillary action. Therefore, if the covering material is applied to the disposal area soon after the supernatant surface water disappears, the capillary action of the cover material will draw moisture above the surface of the dredged material. Once the moisture is in the cover material, evaporation can take place without the formation of soil fissures because the surface of the dredged material remains saturated as shown in Figure 43.

285. The height of capillary rise depends to a large extent on the particle size of the cover material with larger capillary rises occurring in the smaller grained material. Therefore, the particles in the cover material should be as small as practicable in order to get the maximum capillary action. Since the drying and consolidation of the dredged material are of prime importance, the covering material must be porous enough to allow evaporation once the moisture has ascended.

Materials and methods

286. Four substances were tested as cover materials for dredged material, including sawdust, an asphaltic binder*, a mixture of sawdust and asphaltic binder, and primary sludge waste (a by product of paper manufacturing). Tests of the cover material were carried out in 10-ft sq plots at The Citadel disposal site (C-1) and in 3-1/2 ft by 5-1/2 by 1-1/2 ft fiberglass tanks. At the disposal site five field plots were delineated by the use of 1- by 8-in. boards. Four of the plots were used to test the cover materials and the fifth plot was used as a control and had no cover material. Dredged material from the disposal site was placed in each of the four fiberglass tanks to a depth of 8 in. This dredged

* Petroset, a registered trademark of the Phillips Petroleum Co.

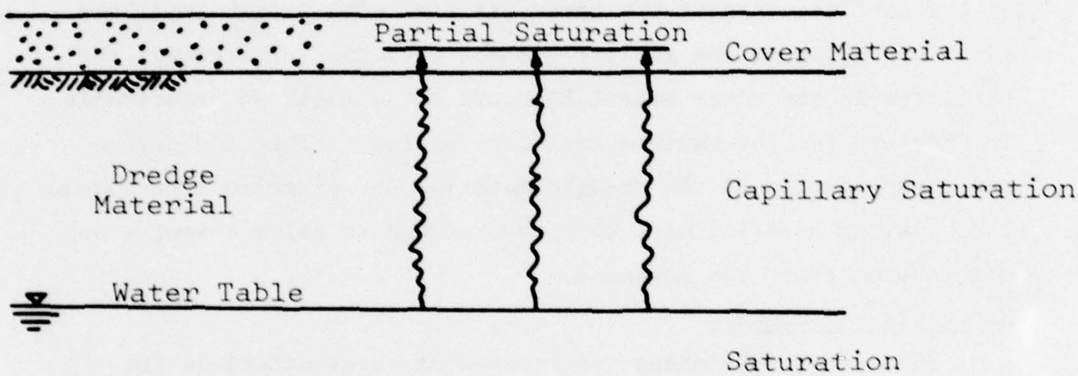

Figure 43
Diagram of the Saturation of the Interface Between
Dredged Material and Cover Material

material was taken from the same general location in the disposal site as the field plots. Three of the tanks contained test cover materials, and the fourth tank was used as a control. At the time testing was started, the supernatant liquid in the disposal site had been removed and the dredged material in the site had dried to a consistency that would support the cover material (DM-2 stage) but the formation of incipient fissures (DM-4) had not begun. Except for the asphalt binder, which was applied in a liquid state, the cover materials were applied to the field and tank tests to a depth of 1/2 in.

287. Testing consisted of moisture content determinations made at the surface of the dredged material and observation of the amount of fissure formation at both test locations. Comparison of the data obtained from these tests gives an indication of the cover material that will be most effective in reducing fissures, while at the same time, allowing the dredged material to dry and consolidate.

Results and discussion

288. Disposal site field tests. Tests of the cover materials (sawdust, asphalt binder, asphalt binder with sawdust, and primary sludge) were conducted at the disposal site over a 32-day period. Water content tests were made on samples of the dredged material in each of the field plots, and the results are shown in Table 9. The wide scattering of the data in Table 9 was caused by rain during the test period. These data were plotted as composite curves of water content versus time and are shown in Figure 44.

289. Examination of the curves indicates that overall drying of the dredged material occurred in all the plots during the test period. On-site inspection of the plots during the test period showed that the dredged material formed soil fissures to some degree in all test plots, but that fissure formation was negligible in the plots containing sawdust or the mixture of sawdust and asphaltic

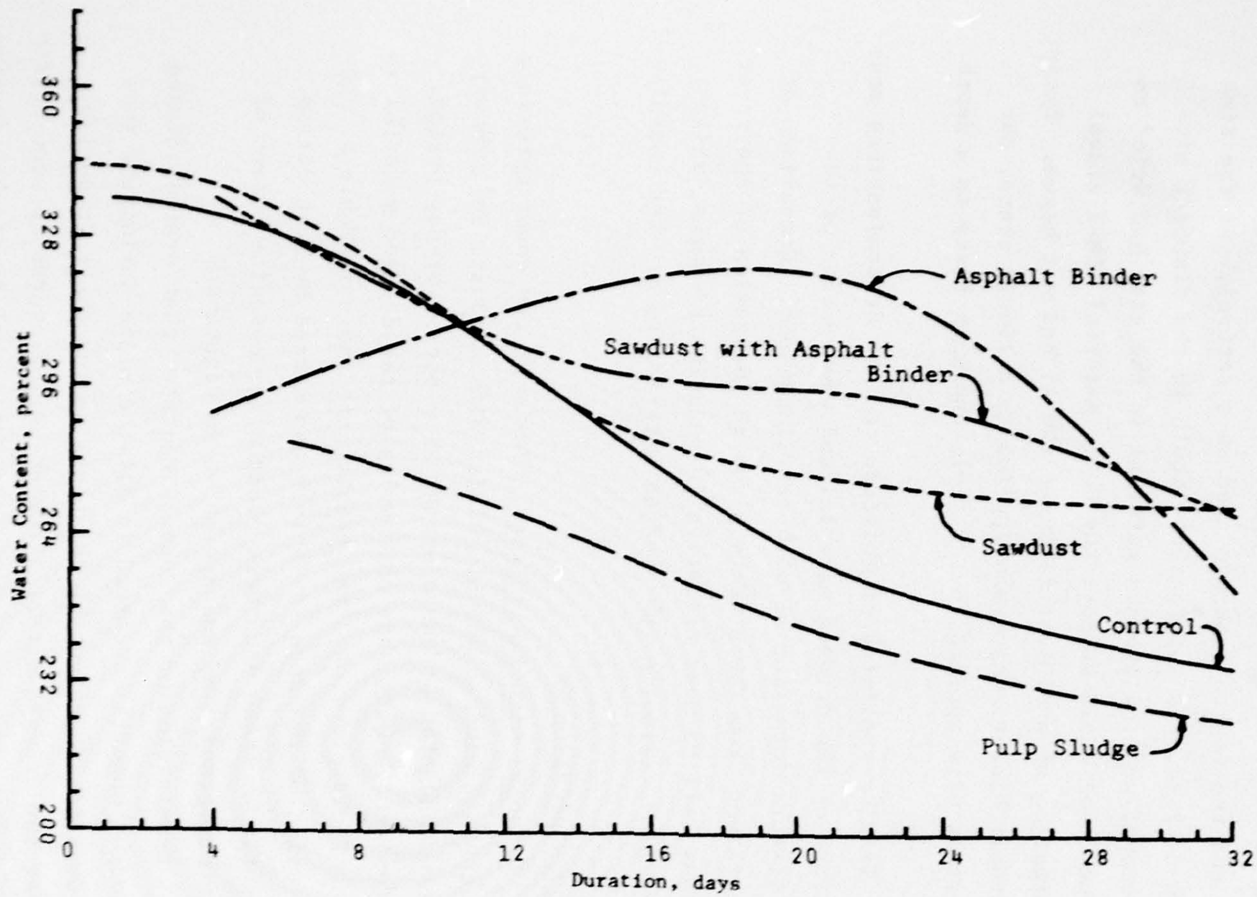

Figure 44

Composite Comparison of Water Content Curves from Dredged Material Field Plot Tests binder. When the curves for the sawdust and the mixture of sawdust and asphaltic binder are compared to the curve for the dredged material alone, it is seen that neither of the two covering materials appreciably slow the drying of the dredged material. The effectiveness of the sawdust as a covering material is shown in Figure 45. This picture was made 22 days after the testing began at the field site. The smaller fissures in the test area are the result of the washing of the test plot by rainfall.

290. Fiberglass tank tests. Testing of the dredged material was also done in fiberglass tanks so that test conditions could be more closely controlled. This testing was done over a 29-day period. Unfortunately, the rain covers over the tanks were not completely effective, and rainwater entered the tanks causing the moisture content of the dredged material to fluctuate. Results of these tests are shown in Table 10 and Figure 45.

291. Tests in the tanks used sawdust, a mixture of sawdust and asphaltic binder, and sludge as covering materials. A fourth tank with no cover was used as a control. Observation of the material in the tanks showed that cracking occurred only in the tank with no cover material.

292. Comparison of the composite curves in Figures 44 and 46 shows that the moisture content of the dredged material in the tanks was somewhat lower than the moisture content of the material in the disposal site at the beginning of the test period. However, there was little difference in the moisture contents at the end of the test periods (tank versus field).

Summary

293. In summary, the following items have been considered regarding the use of soil amendments with dredged material to prevent the formation of soil fissures.

- a. The formation of soil fissures in test plots can be controlled by the addition of cover materials.

Table 9

Soil Moisture Content of Field Plot Samples

Date	Days after Testing Began	Water Content (Percent) Plot 1 (Sawdust)	Plot 2 (Asphalt Binder)	Plot 3 (Asphalt Binder w/Sawdust)	Plot 4 (Primary Sludge)	Plot 5 (Control)
9-24-76	0	341	-	-	-	326
9-28-76	4	343	303	343	-	-
9-30-76	6	323	266	314	278	333
10-1-76	7	337	306	334	218	333
10-4-76	11	303	235	293	295	262
10-5-76	12	280	255	267	212	280
10-6-76	13	293	325	297	237	317
10-7-76	14	285	290	313	284	316
10-8-76	15	300	306	310	263	270
10-12-76	19	270	343	269	229	249
10-13-76	20	301	324	317	280	271
10-14-76	21	267	316	300	241	247
10-19-76	26	284	210	298	239	263
10-23-76	30	265	283	283	219	253
10-25-76	32	276	246	247	228	218

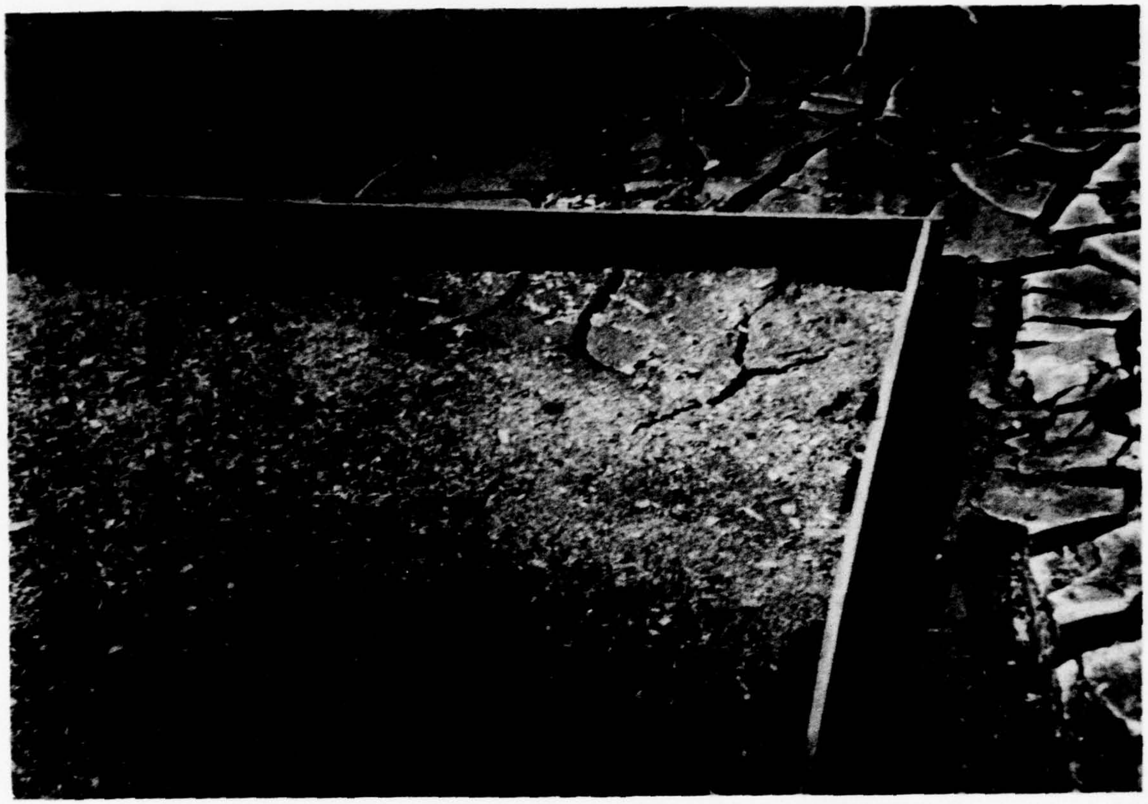

Figure 45

Comparison of Sawdust as a Cover Material (within plot) against Untreated Dredged Material

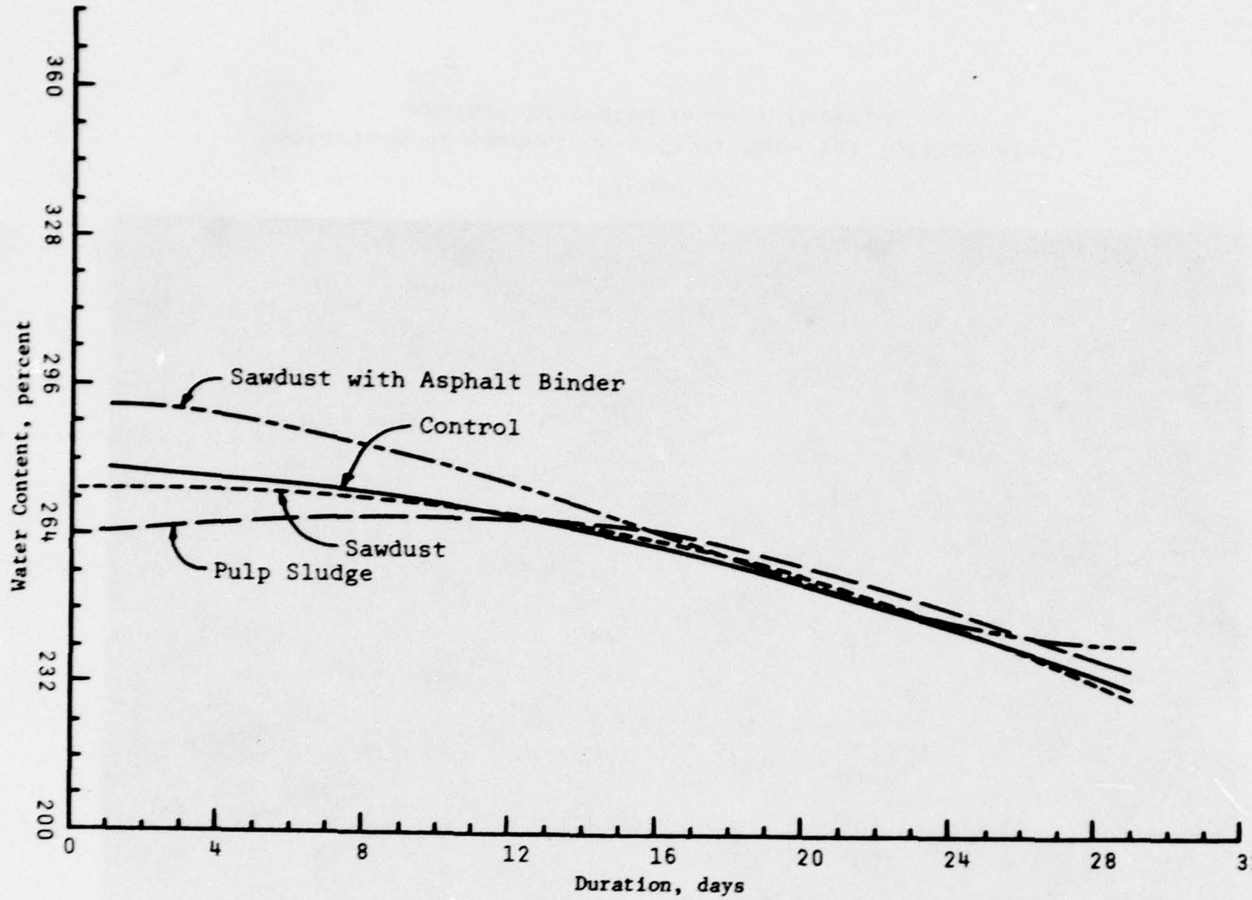

Figure 46

Composite Comparison of Water Content Curves from Dredged Material Tank Tests

Table 10

Soil Moisture Content of Fiberglass Tank Samples

		Water Content (Percent)			
Date	Days after Testing Began	Tank 1 (Sawdust)	Tank 2 (Asphalt Binder w/Sawdust)	Tank 3 (Control)	Tank 4 (Primary Sludge)
10-5-76	0	280	280	-	-
10-6-76	1	-	-	317	317
10-7-76	2	264	263	381	205
10-8-76	3	277	244	268	284
10-13-76	9	263	246	271	265
10-16-76	11	177	197	166	182
10-18-76	13	272	286	268	268
10-19-76	14	256	190	246	286
10-20-76	15	307	292	264	279
10-21-76	16	242	262	260	253
10-23-76	18	277	238	326	204
10-25-76	20	262	214	235	240
10-27-76	22	220	310	193	271
10-28-76	23	246	241	253	232
10-29-76	24	252	264	253	265
11-1-76	27	240	219	233	254

(continued)

Table 10 (concluded)

		Water Content (Percent)			
Date	Days after Testing Began	Tank 1 (Sawdust)	Tank 2 (Asphalt Binder w/Sawdust)	Tank 3 (Control)	Tank 4 (Primary Sludge)
11-2-76	28	232	238	228	231
11-3-76	29	228	256	264	262

b. Field and tank studies were conducted to study the effects of cover materials on dredged material fissure formation.

c. A good cover material should be porous enough to allow for evaporation and yet absorbent enough to hold a high mositure content at the surface of the dredged material.

d. The major problem encountered was holding the cover material in place during periods of rainfall in the field plots.

e. Even when fissure formation occurred, the amount of fissuring was strikingly reduced.

f. The use of soil amendments constitutes a novel, although untried, approach to mosquito control within disposal sites.

g. The use of cover materials for mosquito control did not appear to substancially affect the dewatering of dredged material.

h. Further research is needed on distribution techniques for cover materials in large scale operations.

PART X: SUMMARY OF VEGETATION ANALYSIS OF DIKED DREDGED MATERIAL DISPOSAL SITES

Introduction

293. Mosquito-plant relationships, plant successional patterns, and plant indicator species within dredged material disposal sites have received little attention prior to this study. For these reasons, a number of plant studies and collections were made throughout the study period. It was suspected at the outset of the study that plant relationships within disposal sites would not necessarily be the same as plant relationships in the nearby marsh. A detailed account of these studies is presented in Appendix E.

Purposes

294. The purpose of this section of the study was to gather qualitative baseline data regarding the species composition of various plant species associated with dredged material disposal sites. Since few studies were located in the literature concerning plant species within diked dredged material disposal areas the approach was qualitative (covering a wide variety of disposal sites) as opposed to more intense quantitative surveys utilizing a few locations. A second purpose centered around the development of a proposed plant successional pattern within disposal sites. If plant successional seres could be related to arthropod successional patterns, a basis could then be established for more accurate surveillance techniques. A third reason for plant investigations involved the possible use of plants as indicator species (of mosquito larval conditions). Finally, a few plant species were selected for an estimate of standing crop values.

Materials and Methods

Habitat descriptions

295. Extensive field trips were made to numerous disposal sites within the Charleston District (see Figures 4 and 5). During each field trip field notes and plant collections were made. After initial work, a total of five habitats appeared to be common or possible within most dredged material disposal sites. Plant species lists were then compiled for each of the five habitats.

Indicator species

296. As a routine part of the mosquito investigations (Part V) a listing of all plant species that were observed to be associated with significant numbers of larval mosquitoes was kept. In most cases a species was not recorded on the list unless larvae were collected on several occasions.

Plant successional patterns

297. Following several initial trips into disposal sites of varying ages, a successional pattern was proposed. Plant species were then collected from the proposed successional stages and related to the arthropod successional patterns reported in Part IV (see Figure 14).

Standing crop studies

298. A total of five disposal site plant species were located in sufficient "pure stands" to conduct standing crop biomass determinations. These species were *Aster subulatus*, *Borrichia frutescens*, *Salicornia bigelovii*, *Spartina alterniflora*, and *Suaeda linearis*. A complete description of these techniques is presented in Appendix E.

Other plant collections

299. Plant species collected from specific site visitations to the different CE Districts are listed with their respective locations in Appendix D. A composite listing of all plant species from all areas is presented as Table E6 in Appendix E.

Results and Discussion

Habitat descriptions

300. The following habitats were established for this survey:

a. Sandy areas (including sand mounds around discharge pipes, sand bars within disposal areas, and wind-deposited sand).

b. Silt (including fissured soil, bare mud deposits, and wind-deposited silt).

c. Dikes (including diked constructed from natural marsh, dredged material, and imported materials).

d. Waste areas (including natural and man-made islands).

e. Aquatic sites.

Complete listings of plant species associated with each of the above habitats are presented as Tables E1, E2, and E3 in Appendix E. A variety of herbaceous seed plants, trees, and shrubs were encountered.

Indicator species

301. A listing of all major seed plants associated frequently with mosquito larvae (primarily *Aedes sollicitans* and *Aedes taeniorhynchus*) is presented as Table E4 in Appendix E. Personnel trained to recognize these plants should be more efficient in mosquito larval surveillance. As noted more fully in Appendix E, these plants are capable of developing and maintaining fissured soil (and thereby also maintaining a mosquito larval habitat). In general, it can be stated that almost any salt tolerant plant species capable of growth on fissured soil within dredged material disposal sites will frequently be found in association with mosquito larvae. Plant species change the microhabitat of fissured soil by producing lower temperatures and reducing evaporation from fissured soil. Additional research is needed on possible specific mechanisms of plant attractiveness for various mosquito species.

Plant successional patterns

302. Four plant successional patterns or seres were documented.

Justification for this hypothesis and a proposed flow pattern are presented in Appendix E. The following stages were consistently observed within many disposal sites:

<u>a</u>. <u>Halophytic stage</u>, characterized by the development of pure and mixed stands of succulent halophytes.

<u>b</u>. <u>Forb-shrub stage</u>, characterized by intense growth of herbaceous plants mixed with young woody shrubs.

<u>c</u>. <u>Shrub stage</u>, consisting mainly of older shrubs.

<u>d</u>. <u>Climax stage</u>, dominated by larger trees tolerant of maritime conditions.

The halophytic stage tends to be the most productive plant successional stage for mosquito larvae. This stage compares with the DM-4 and DM-5 stages (see Figure 14) of Part IV. This observation can greatly aid future mosquito surveillance workers, if they are trained to recognize the dangers of large disposal sites in this stage. Mosquito species diversity tends to increase with the age of the disposal site, with the later plant successional stages producing more different microhabitats for larval mosquitoes. Later successional patterns also allow for increased organic matter in specialized locations (e.g. tree holes and swales). To summarize, the greatest numbers of mosquitoes, represented by a few species, were frequently associated with the succulent halophytic stage, but a greater variety of mosquito species, in reduced numbers, could be located from older disposal sites in the later stages of plant succession. If field workers are trained to recognize the various plant successional stages and then in turn relate these stages to the DM stages of Figure 14 and the habitats of Figure 15, the process of disposal site inspection can be greatly simplified.

303. The climax stage with regard to plant succession is not yet clearly understood and two possibilities are offered in Appendix E and noted in Figure 14. In many parts of the United States, a self-sustaining monoculture of *Phragmites communis* develops, but in other area (perhaps more saline) a mixed variety of woody shrubs and trees begins to develop under DM-8b (Figure 14) conditions. For a fuller discussion of this exception to the plant successional pattern, see

paragraph 23 of Appendix E.

<u>Standing Crop Studies</u>

304. Results of standing crop estimates from pure stands of four plant species are presented as Table E5 in Appendix E. With one exception (*Spartina alterniflora*), the values obtained for dry weight, stem heights, and numbers of stems were somewhat high for the species in question. Without question, dredged material disposal sites support many rich stands of marsh vegetation in localized habitats.

Summary

305. A wide variety of plants were collected and catalogued from dredged material disposal sites. These plants were studied by habitat preference, successional patterns, and as indicators of mosquitoes and/or fissured soil. Several species were observed to be frequently associated with mosquito larvae under disposal site conditions (see paragraph 11 of Appendix E). It should be noted, however, that these same plant species in other locations (such as the natural marsh) may not be indicators of mosquito activity. Mosquito breeding was most productive in those disposal sites that experience an interrupted successional cycle. In some localized habitats within dredged material disposal sites, standing crop estimations of some plant species were estimated and found to be high as compared to the surrounding area. A complete listing of all plant species collected from dredged material disposal sites is presented as Table E6 in Appendix E.

PART XI: SUMMARY OF STUDIES ON THE OCCURANCE OF AVIAN SPECIES WITHIN DREDGED MATERIAL DISPOSAL SITES

Introduction

306. Large mosquito populations associated with large populations of birds (as in rookeries) are of some concern to the environmental scientist for several reasons. Birds offer a source of blood and therefore may sustain the mosquito populations and, more importantly, birds may serve as reservoir hosts for a group of pathogenic viruses. These viruses are usually termed arboviruses (for arthropod-borne-viruses). It should be noted that many bird and mosquito species associated with arboviruses are located in habitats other than disposal sites. For these reasons, a portion of this study was devoted to the use of dredged material disposal sites by avian species. A fuller account of these studies is presented in Appendix F.

Materials and Methods

307. Field trips were made to three types of dredged material disposal sites during this portion of the study:

a. Inland Waterway Disposal Sites: These are a series of approximately 40 small to medium-sized sites located north and south of Charleston adjacent to the Atlantic Intra-Coastal Waterway (AIWW). S-18 (Figure 5) and N-16 (Figure 5) are examples of this type.

b. Barrier Island Disposal Sites: These consist of large disposal sites located on barrier islands between salt marshes and the Atlantic Ocean. Morris Island is the only example of this type in the Charleston area (Figure 4).

c. Estuarine Disposal Sites: These are large disposal sites situated on islands adjacent to coastal rivers. Drum, Daniel's, and Hog (Patriot's Point) islands are examples of this type (Figure 4).

During field trips to these disposal sites, notes were made on species composition, numbers of birds, habitat utilization, and behavioral activities. Aerial censuses were also conducted over most major disposal areas in conjunction with another research project. These aerial censuses were especially useful in studying the larger disposal sites and rookeries. For a complete listing of literature and methods used for this section of the study see Appendix F.

Results and Discussion

308. Approximately 164 species were noted to use dredged material disposal sites in various capacities. This total represents about 45 percent of the bird species that are known from the lower coastal plain of South Carolina. Comparative data of avian community composition and the lower coastal plain in general is presented as Table F1 in Appendix F. Disposal sites were found to be important breeding habitats for the black-necked stilt and Wilson's plover and a variety of long legged wading birds (see Table F1 in Appendix F). A listing of all bird species observed or known from the disposal sites of Charleston is presented as Table F3 in Appendix F.

Summary

309. Studies on bird utilization of dredged material disposal sites were conducted. In many cases large populations of breeding birds (i.e. rookeries) were observed to congregate within disposal areas. It was noted that large avian populations may not only sustain mosquitoes (as a source of blood), but may also harbor arboviruses. Disposal sites provided the only major breeding habitats available in the study areas for some avian species, including Wilson's plover, black-necked stilt, and a variety of long legged wading birds. Studies are needed on the possible enhancement of dredged material disposal sites as habitats for game birds.

PART XII: CONCLUSIONS AND RECOMMENDATIONS

310. Detailed summaries have been presented with each section and appendix of this report. Only major conclusions that relate specifically to recommendations are considered in this section.

Historical Aspects

311. Dredged material disposal sites were found to be a little known, but major, habitat of mosquitoes. The extent and nature of the problem was known to relatively few Corps of Engineers or mosquito abatement personnel. Most early studies were in the form of government reports or scientific notes, but no extensive quantitative studies of mosquitoes associated with dredged material could be located in the literature (Part III).

Interagency Perspectives

312. The survey of interagency perspectives on mosquito conditions within dredged material disposal sites revealed a high level of interest among those surveyed (85 percent return rate). The data indicated clear perceptual differences among the agencies surveyed as to the nature and extent of mosquito control problems developing within disposal sites. There were also clear differences of opinion regarding current and future agency responsibility for mosquito abatement within disposal areas. Travels to eight different Corps Districts confirmed these data.

313. It is recommended that each Corps of Engineers District concerned with mosquito abatement within dredged material disposal sites consider the appointment of a "District communicator" to the various mosquito abatement programs within that District. The proposed "communicator" should be completely familiar with mosquito

habitats and life cycles. The most frequent complaint voiced by mosquito abatement personnel against the Corps was the lack of communication between the two agencies. It is also recommended that the possibility of joint field inspections (Corps and mosquito abatement personnel) of disposal sites be considered by each District. The investigators of this study would favor the inclusion of local mosquito abatement programs on all of the environmental mailing lists (notices, environmental impact statements, etc.) for a given District.

314. It is strongly recommended that Corps Districts establish a policy of always notifying local and state mosquito abatement programs when various disposal sites are scheduled to receive fresh dredged material. These local and state agencies need to know site locations, dates of initial and final operations, estimated amounts of dredged material, and drainage conditions in order to better plan mosquito surveillance and control.

315. It is strongly recommended that Corps Districts consult with local and state vector control officials regarding the planning and design of new disposal sites in the future. Many mosquito abatement personnel were encountered from engineering backgrounds during the study. A number of these engineers offered suggestions and engineering solutions (i.e. source reduction) to local disposal area problems. It appears reasonable that some mosquito larval habitats could be reduced by changes in disposal area designs. Such plans should be pursued on a local basis.

316. Obviously, the failure to develop good working relationships between the Corps Districts and mosquito abatement personnel is counterproductive to both parties. Good interagency relationships are not accidental, and they develop only in an atmosphere of mutual trust and respect. Accordingly, it is also recommended that state and local mosquito abatement personnel routinely include the local Corps District in their mailing lists, environment impact

statements, etc.

317. It is recommended that local Corps Districts initiate and sponsor their own research efforts on the ecology of dredged material disposal sites. Such studies, whenever possible, should include cooperative ventures with local mosquito abatement programs.

Plant Relationships

318. The major plant species associated with several disposal area habitats were catalogued. A proposed outline of plant succession was presented. A listing of plant species positively associated with mosquito breeding was presented. Mosquito breeding was observed to be more common on disposal sites where plant successional patterns were interrupted on a regular basis (every 2 to 5 years). Such interruptions are common with many Corps projects.

319. It is recommended that the Corps consider further research on plant species that might prevent the development of DM-4 and DM-5 conditions within disposal sites. Additional work is also needed on techniques of aerial photo-reconnaissance and utilization of those plants that have been found (in this report) to be indicators of larval mosquito habitats.

Avian Relationships

320. The presence of mosquitoes and birds together in the same breeding habitat (e.g. disposal sites) may constitute a health hazard (encephalitis) to man. Disposal areas were found to be important breeding sites for coastal wading birds.

321. It is recommended that additional research be conducted on the possible presence of the encephaltide virus group within both bird and mosquito populations that occur within disposal sites. Additional studies are also needed on the importance of disposal

sites for Wilson's plover, black-necked stilt, and long legged waders.

Arthropod Succession

322. A total of seven different successional stages were isolated and described in this study. The pattern was found to be valid for a variety of disposal sites in many coastal locations with the possible exception of California. Species numbers and diversity were compared through Shannon-Wiener Indices. Stages DM-4 and DM-5 were always (except in California) found to be associated with mosquito larvae.

323. It is recommended that appropriate field personnel from both the Corps and local mosquito programs be trained to recognize the importance of the various successional patterns proposed in this study. It is especially essential that the appropriate field personnel learn to differentiate between DM-3, DM-4 and DM-5 seres as the latter two stages generally support larval mosquitoes.

324. It is strongly recommended that various Corps Districts consider formulating their dredging schedules with some consideration and regard for mosquito seasons. For example, for short periods of time, the addition of fresh dredged material onto disposal sites (perhaps in stages DM-4 or DM-5) may eliminate the need for mosquito control on that site for 6 months. Such joint approaches are possible only after a high degree of interagency cooperation has been achieved for several years.

Mosquito Larval Habitats

325. A total of 14 different and distinct larval habitats have been defined in this study (Figure 15). This vast majority of these habitats occur in disposal sites throughout the United States. Some habitats are preventable, while others are not.

326. It is recommended that the appropriate field personnel within various Corps Districts and mosquito abatement programs receive training that will enable them to recognize the likely sources of mosquitoes within various types of disposal sites. It is strongly recommended that the use of concrete splash pads near discharge points be continued.

Larval and Adult Mosquitoes

327. In most disposal areas in the East *Aedes* spp. mosquitoes were the most common pests associated with dredged material disposal sites. Other species may develop within disposal areas under specialized conditions. It is recommended that local mosquito control programs and/or Corps Districts maintain both larval and adult mosquito surveillance programs over dredged material disposal sites. Rainfall data from disposal areas are especially needed for accurate predictions of mosquito activity.

Mosquito Control

328. With the possible exception of predatory fish, biological control measures do not appear practical for disposal area mosquito control at the present time. Several promising studies are currently underway that involve the use of nematodes.

329. A number of chemical pesticides are currently available for mosquito control within dredged material disposal sites. As noted in this report, it appears that certain Insect Growth Regulators (IGR's) are equally promising for the chemical control of mosquitoes. Perhaps the most unusual approach to disposal area mosquito control is the notion of pretreatment (i.e. treating a dry disposal site with an encapsulated IGR prior to rainfall). Data presented in this report support the validity of this concept.

330. In view of rising costs for some traditional materials (larvicidal oils), it is recommended that further consideration be given to the IGR's as a practical means of disposal area mosquito control. Further research is needed on possible resistance mechanisms of mosquitoes to the IGR's. Additional research is also needed to further test pretreatment concepts and materials.

331. Data presented in this report also support the need for further research on physical control (i.e. source reduction) methods for disposal site mosquitoes. This report has tested the rim-ditch concept in a limited fashion and found it feasible as a source reduction method for borrow pit swales. It is thought that rim-ditching techniques will be most successful within those disposal sites that are low enough in elevation to allow for tidal flushing. An added benefit of rim-ditching is the natural appearance of mosquito predators following the intrusion of tidal waters. It is strongly recommended that additional research be conducted regarding use of the RUC and other marsh vehicles as tools for achieving the source reduction of disposal site mosquitoes.

332. In conclusion, dredged material disposal sites were found to be common sources of mosquitoes along the Atlantic and gulf coasts. Disposal sites on the west coast were generally not common sources of mosquitoes (except under specialized conditions) due to the low rainfall conditions during the summer months. Interagency cooperation and close surveillance for larval mosquito conditions within disposal sites by trained personnel are, without doubt, the keys to successful pest management programs. If the peculiar ecology of dredged material disposal sites is well understood, then a variety of chemical, physical, and (in the near future) biological measures can be utilized against mosquitoes. It is imperative that some form of mosquito surveillance be conducted over most disposal sites during mosquito seasons. While this report has offered many new answers, suggestions, and conclusions regarding

the control of mosquitoes associated with disposal areas, the future of this effort rests upon the development of interagency cooperation between Corps Districts and local mosquito abatement programs and new research directions.

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APPENDIX A: INTERAGENCY PERSPECTIVES ON MOSQUITO CONDITIONS AND CONTROL IN CONFINED DREDGED MATERIAL DISPOSAL SITES

Introduction

Public policy analysis as a research tool

1. Public policy, long neglected by observers of the American political system, has in recent years been the object of a wide variety of research. These efforts have revealed, among other things, the enormous complexity of the subject. In its barest outlines, public policy involves: (1) formation (both process and substance), (2) execution, and (3) impact. Each of these components is quite complex in itself and, to make overall analysis even more difficult, each is integrally intertwined with the others. For some extended discussion of these points see Froman 1967, Hofferbert 1974, Anderson 1975, and Dye 1975. Given these complications, a fairly common research approach is to concentrate on one component (such as policy formation or innovation) of a particular policy with a view toward building understanding of the policy incrementally. Good summaries of studies using this and other approaches can be found in Sindler 1973 and Hofferbert 1974. Since each part is crucial, such a research strategy can be justified as helping to clarify perceptions of the specific program selected for study. Ideally, analysis would extend to all parts of the policy under examination, and there have been a few such ambitious projects undertaken, but in many cases recognition of numerous practical limits leads to a more realistic investigation. Such studies can singly shed important light on the program being researched, and cumulatively they can perhaps ultimately be combined to give a more general understanding of the program from inception through impact. Insofar as one of the main goals of better policy understanding is policy improvement, both of these types of results of limited program analysis can be quite useful.

Application of policy
analysis to mosquito abatement

2. In light of these considerations, it was decided to include within the general research design for this project a subdesign for some limited policy analyses regarding certain aspects of mosquito control programs in confined dredged material disposal sites in the selected CE Districts. These efforts were focused mainly on some features of policy execution and responsibility rather than policy formation or impact, but as already noted, these are interrelated in many ways. No significant policy analysis studies have previously been made comparing the attitudes and opinions of government agencies concerned with mosquito abatement.

Central study focus

3. Specifically, this part of the study was concerned with the extent of interaction and cooperation among three governmental agencies which were involved in varying degrees with confined dredged material disposal sites. The agencies were:

a. Selected CE Districts.

b. Selected state vector control agencies.

c. Selected local mosquito abatement districts.

The foundation of this concern is the widely recognized fact that, in the American Federal system where many agencies representing different governmental levels may be involved in a program (as in the case with mosquito abatement efforts in diked dredged material disposal sites), successful program execution requires some minimal level of interagency cooperation. A major problem is that different agencies have different goals, different program priorities, and different policy perspectives. In short, they see things differently and, hence, approach program execution in a wide variety of ways.

4. In the context of the present study, then, a logical hypothesis would be:

> Given the different program priorities and operational responsibilities of the Army Corps of Engineers, State vector control departments, and local mosquito control districts, there will be significant inter-agency differences in the recognition and definition of mosquito problems in confined dredged material disposal sites and in attitudes on responsibility for mosquito control in such sites.

From some previous work on mosquitoes in diked dredged material disposal sites and from a review of certain communications between personnel of various agencies, it was strongly suspected that the hypothesized differences do indeed exist and may account for some of the actual and/or potential problems in the efficient execution of mosquito abatement programs in many of these areas. The absence of systematically gathered evidence to test the accuracy of this impression prompted an attempt to seek empirical data for that purpose. In the vast literature on insects and insect control, there have been very few attempts to utilize empirical attitudinal data of this sort, with the exception of Gerhardt et al. (1973). Obviously, when biological research leads to a series of policy suggestions, some attention to the attitudes involved in policy definition, responsibility, and execution is quite justified.

Methodology

Questionnaire construction

5. This hypothesis was pursued by constructing a short questionnaire for mail distribution to selected personnel of CE Districts, state vector control agencies, local health departments, and local mosquito abatement districts in the following CE Districts:

New York	Vicksburg
Philadelphia	New Orleans
Baltimore	Galveston
Norfolk	San Francisco
Wilmington	Sacramento
Charleston	Portland
Savannah	Seattle
Jacksonville	

Selection of these CE Districts was based on the scale of dredging activities as indicated in the study of Harrison and Chisolm (1974).

Questionnaire purposes

6. The questionnaire was designed to allow both descriptive and comparative analyses of these groups with respect to:

a. Their perception of the mosquito problem (extent, nature, and source) in confined dredged material disposal sites.

b. Their perception of agency responsibility for dealing with the mosquito problem in confined dredged material sites both presently and in the future.

c. Their perception of interagency communication patterns (what these patterns are and what they should be) relating to mosquito conditions in these sites.

Preliminary considerations

7. The questionnaire used in this study was prepared after a series of consultations with Corps of Engineers personnel and state and local vector control officials in South Carolina. These consultations were supplemented by periodic discussions with entomologists at The Citadel, on-site field inspections of confined dredged material

disposal sites in the Charleston District, and reference to other Corps of Engineers studies, most notably Harrison and Chisolm (1974). Two key decisions, beyond the selection of the basic topics for examination, are reflected in the questionnaire as it finally evolved through five preliminary drafts. First, it was decided to limit the length to three pages to reduce the work requested of the respondents and, thereby, to increase the likelihood that the respondents would complete the form. In the cover letter which accompanied each questionnaire, these space limitations were explained and the respondent was invited (even urged) to add any information considered to be important. Thus, it was possible to get a great deal of material beyond that requested in the questions themselves. This is fairly standard procedure in mail surveys, and it seems to have worked well in this particular instance.

Questionnaire differences

8. The second key decision concerned tailoring the wording of certain questions to the agencies involved. For the most part, this required no more than a simple change of one or two words in the question, and, whenever such changes were needed, great care was taken not to alter the basic content of the question or its fundamental tone (or connotations). Thus, three slightly different versions of the same questionnaire were constructed, one version for each of the three agencies involved in the survey. Pretests indicated that these versions were comparable. The main difference among the different versions consisted of combining the first two questions in the Corps of Engineers and state vector control questionnaires into one question for the questionnaire sent to local mosquito abatement districts (since it was evident that the very existence of local mosquito control agencies indicates the presence of a mosquito problem in the area). The other variations involved extremely minor changes in wording to make them applicable to the different agencies. For example, where question four on the Corps questionnaire asks

about mosquito breeding in the District, the corresponding question on the local officials' questionnaire asks about mosquito breeding in the locality.

Sample Corps of
Engineers Questionnaire

We are interested in your viewpoint or perspective on the topic of mosquito production in spoil areas. Please answer all of the following questions. There is, of course, no right or wrong answer as such on any question.

1. Opinions about whether or not mosquitoes are a problem vary. In your opinion, are mosquitoes a problem in all or part of your district?
   ______(a) Yes, throughout the district.
   ______(b) Yes, in parts of the district.
   ______(c) No.
   ______(d) Not sure; no opinion.

2. If mosquitoes are a problem, in your opinion which of the following most accurately describes the degree of the problem?
   ______(a) Mosquitoes are a nuisance only.
   ______(b) Mosquitoes are a minor health hazard.
   ______(c) Mosquitoes are a major health hazard.
   ______(d) Not sure; no opinion.
   ______(e) Inapplicable; mosquitoes are not a problem.

3. Are the opinions expressed in the first two questions supported by your own observation and investigation, or are they based mainly on information provided to you by some other agency such as the state or local health department or local mosquito abatement district?
   ______(a) Own observation and investigation.
   ______(b) Other agency (Please specify:________________________).

4. What are the main sources (breeding areas) of the mosquitoes in your district? (MARK MORE THAN ONE IF YOU WISH).
   ______(a) Natural domestic sources (tin cans, old tires, rain barrels, etc).
   ______(b) Natural salt water marshes.
   ______(c) Natural fresh water (ponds, lakes, puddles, etc.).
   ______(d) Confined dredged material disposal sites used by the Army Corps of Engineers.
   ______(e) Not sure; no opinion.
   ______(f) Inapplicable; there are no mosquitoes in this area.

5. In your opinion, if mosquitoes are a problem related to spoil areas, is the mosquito problem more or less serious than the following environmental conditions? (PLEASE CHECK THE APPROPRIATE BLANK BY EACH CONDITION LISTED)

	Mosquitoes are less serious	Mosquitoes are more serious	Problems are the same	One or both problems don't exist	Not sure; no opinion
Pollution from seepage or dike failures.	_____	_____	_____	_____	_____
Botulism (food poisoning).	_____	_____	_____	_____	_____
Dust.	_____	_____	_____	_____	_____
Turbidity in the surrounding water or marsh.	_____	_____	_____	_____	_____
Flies or other insects.	_____	_____	_____	_____	_____
Other organisms (rats, mice, etc.).	_____	_____	_____	_____	_____
Other (Please specify: ____________________).	_____	_____	_____	_____	_____

6. If mosquitoes are a problem in confined dredged material disposal sites (or if they become a problem in the future), which of the following agencies is mainly responsible for dealing with the problem?

_____(a) Local health department.
_____(b) Local mosquito abatement district.
_____(c) State health department.
_____(d) Army Corps of Engineers.
_____(e) Other (Please specify: ______________________________).
_____(f) Not sure; no opinion.

7. If there is an actual or potential problem with mosquitoes in confined dredged material disposal sites, in your opinion should the Army Corps of Engineers in your district assume (or be assigned) any responsibility for mosquito control there? (MAY MARK MORE THAN ONE).

_____(a) Yes.
_____(b) No, this is not what the Army Corps of Engineers is intended or designed to do.
_____(c) No, the Corps of Engineers is too occupied with its normal duties to get involved in mosquito control.
_____(d) No, other organizations should do this (please identify: _____).
_____(e) Other (Please specify: ______________________________).
_____(f) Not sure; no opinion.

8. Beyond any official responsibility, or even if the Army Corps of Engineers has no official responsibility for mosquito control in confined dredged material disposal sites at the present time, does the Corps in your district participate voluntarily with local and/or state agencies in programs designed to deal with mosquitoes?

_____(a) Yes, a great deal and on a regular basis.
_____(b) Yes, sometimes.
_____(c) No, other authorities have not requested and/or do not need Corps assistance.
_____(d) No, the Corps' normal work commitments here allow no time for mosquito work of this nature.
_____(e) Other (please specify:________________________________).
_____(f) Inapplicable, there is not a mosquito problem here.
_____(g) Not sure; no opinion.

9. In your opinion, if assistance is requested in the future, should the Corps of Engineers in this district participate in local and/or state mosquito abatement programs as they apply to confined dredged material disposal sites?

_____(a) Yes, in any way and as much as possible.
_____(b) Yes, but only on a limited basis since the Corps' normal responsibilities require the bulk of its time and resources.
_____(c) No, the Corps' normal workload prevents such participation.
_____(d) Other (please specify:________________________________).
_____(e) Not sure; no opinion.

10. Is there communication between the Army Corps of Engineers and local and/or state health departments in this area concerning actual or potential mosquito problems in confined dredged material disposal sites?

_____(a) Yes, often (an average of at least once a month).
_____(b) Yes, sometimes (an average of at least once every three months).
_____(c) Yes, but rarely (once every six months or less).
_____(d) No.
_____(e) Other (please specify:________________________________).
_____(f) Not sure; no opinion.

11. If there is such communication, please indicate which of the following in your opinion, describe the nature of the communication. (MARK MORE THAN ONE IF YOU WISH).

_____(a) An exchange of printed material (reports, bulletins, etc.).

_____(b) Letters and memos concerning present work and future plans (for dredging, spraying, etc.).
_____(c) Personal telephone calls about plans, work, and problems.
_____(d) Formal conferences involving personnel of the concerned agencies.
_____(e) Informal discussions of work and plans among personnel of the various agencies.
_____(f) Other (please specify:_______________________________).
_____(g) Inapplicable; there is no communication.
_____(h) Not sure; no opinion.

12. If there is communication, please indicate which of the following are involved.
_____(a) Both state and local health (or mosquito abatement) officials.
_____(b) Local officials only.
_____(c) State officials only.
_____(d) Other (please specify:_______________________________).
_____(e) Inapplicable, there is no communication.
_____(f) Not sure; no opinion.

13. In your opinion, would more interagency communication of this nature be worthwhile?
_____(a) Yes.
_____(b) Yes, but only if a mosquito problem develops.
_____(c) No, it is not necessary (present communication is adequate).
_____(d) Other (please specify:_______________________________).
_____(e) Not sure; no opinion.

14. If you feel that more communication of this type would be useful, which of the following should, in your opinion, be increased? (MARK MORE THAN ONE IF YOU WISH).
_____(a) An exchange of printed material.
_____(b) Letters and memos about present work and future plans.
_____(c) Personal telephone calls about plans, work, and problems.
_____(d) Formal conferences among personnel of the concerned agencies.
_____(e) Informal discussions of work and plans among personnel of the various agencies.
_____(f) Other (please specify:_______________________________).
_____(g) Inapplicable; more communication is not needed.
_____(h) Not sure; no opinion.

15. How does interagency communication about actual or potential mosquito problems compare with interagency communication about other environmental matters?

_____(a) There is more communication about mosquitoes than about other health problems.

_____(b) There is less communication about mosquitoes than about other health problems.

_____(c) Communication in both topic areas in about the same.

_____(d) Inapplicable, there is no interagency communication on other health problems.

_____(e) Not sure; no opinion.

Respondent lists

9. At the start of the survey phase of the study no complete lists of potential respondents existed for any of the three agencies. Consequently, it was necessary to construct these lists through a variety of lengthy procedures. This was probably the most difficult and time-consuming task faced in the survey.

10. It was decided to write each of the CE Districts selected for inclusion in the study requesting the names of five or six people familiar with the construction, use, and reuse of confined dredged material disposal sites in the particular District. In most Districts this request was directed to the District Engineer, but in a few cases the request was made to some other Corps official with whom there had been previous contact (during site visitations). Most of the requests were answered rather quickly, but in a few instances a follow-up telephone call was necessary to secure the names needed. Since it was left up to each District to determine the specific number of names submitted, final respondent lists varied from District to District from four to ten. This variation was not important as long as the names on the list included those designated as most knowledgeable about diked dredged material disposal sited in their Districts.

11. At the state level, an attempt was made to contact at least two people with extensive involvement in vector control programs. Again, this effort began without any preconstructed lists. A pre-

liminary list was put together through communication with Dr. L. A. Williams, Jr. (Personal Communication, 11 October 1974, L. A. Williams, Jr., South Carolina Department of Health and Environmental Control, Columbia). One name per state was obtained in this manner. Two questionnaires were then sent to each of these people with a request that they complete one and give the other to a second person in their department involved in mosquito control work (if indeed there was another person with this responsibility). In most states it was possible to get responses from two state vector control officials through this procedure; however, in several states there was only one response accompanied by notification that no other person was involved in this type of program at the state level. In calculating response rates, it was therefore assumed that only one state official was involved in vector control at the program execution level unless there was evidence of more. At the other end of the scale, in two states more than two officials were mentioned and, consequently, in the interest of getting as much input as possible, these were included (and thereby deviated a bit from the normal pattern).

12. The most difficult respondent lists to compile were those for local mosquito control officials. In a few states, state vector control officials supplied, upon request, a list of mosquito control commissions (districts) in areas where the Corps of Engineers was doing substantial dredging. In a few other states there had been some previous contact (site visitations) with some local abatement districts and these were contacted for more information in their respective states. A third measure undertaken involved contacting all local control programs in the various states as listed in <u>Mailing List of U. S. Agencies Interested in Mosquito Control</u> (Personal Communication, 1 August 1975, L. Cavey, American Mosquito Control Association, Fresno, California). Questionnaires were sent accompanied by an explanatory cover letter regarding the study and asking

for the return of the completed questionnaire if there were Corps of Engineers confined dredged material disposal sites in the particular county. Finally, a notice was put in the American Mosquito Control Association News Letter, March 1976, requesting responses from local mosquito control officials. It should also be noted that on occasion the Corps of Engineers in an area suggested a few local mosquito control or health officials to be contacted. In brief, the construction of these lists was rather laborious and involved various preliminary contacts, but it is felt that the lists finally did provide good coverage of existing mosquito control programs in the Districts surveyed.

13. At the local level, two questionnaires were usually sent to each abatement district with the request for a second completed form if there was a second person in the program familiar with the topic. In some areas there was no second official so the respondent lists for local mosquito control personnel were not completed until each locality had responded to find out about the nature of that area's specific program.

14. The primary factor involved in selecting a local mosquito abatement district (or city or county health department) for inclusion in the survey was the existence of Army Corps of Engineers confined dredged material disposal sites in the area. On a rare occasion, it was decided to include a locality which did not currently meet this criterion if the local mosquito control agency had dealt with such disposal areas in the past (and thus had some experience with mosquito conditions related to diked dredged material disposal sites) or if the Corps of Engineers had plans for future use of confined dredged material disposal sites in the area. In both types of exceptions to the standard practice, it was felt that the local agencies could add valuable information to the study, especially on such things as opinions on responsibility for mosquito control in diked disposal areas, communication patterns, etc. For the same rea-

sons, it was also decided to include responses from a very few agencies which have no confined dredged material disposal sites in their immediate areas but which do have rather extensive dealings with the Corps of Engineers in other types of operations (marshland dredging, etc.) which may be associated with mosquito production; while these agencies could not respond to the questions specifically concerned with (and limited to) confined dredged material disposal sites, they could respond to the questions on communications, theoretical responsibility for mosquito control in Corps project areas, voluntary Corps assistance in mosquito control efforts, etc. It should be emphasized, however, that over 90 percent of the agencies surveyed are in areas where there are confined dredged material sites; deviations from this were included only when it was very obvious that useful additional information would be forthcoming, and care was taken not to include such areas on items irrelevant to their actual experiences with the Corps of Engineers.

15. In the final analysis, it cannot be claimed that all agencies (and officials) that should be contacted in this part of the study were actually included on the various respondent lists given the above-mentioned complexities of obtaining the information necessary for compiling complete lists. However, it was felt that the final listings did include the vast majority (if not all) of the concerned agencies and personnel. In summary, an effort was made to obtain as much data as possible from three types of agencies in a number of selected Corps of Engineers Districts throughout the country with a view toward making a valid interagency statistical analysis. While more complete data might be possible, the data far exceed the minimum goal.

Return rates

16. The questionnaires were mailed during the period from 1 November 1975 through 15 April 1976. Care was taken to follow tested procedures for conducting a mail survey (Norman 1948, Ferris 1951,

Moser 1958, Levine and Gordon 1958-1959, Franzen and Lazersfeld 1958, Parten 1966, Selltiz et al. 1966, Linsky 1975). Consequently, it was possible to obtain good response rates of 88 percent for the Corps of Engineers, 88 percent for State vector control officials, and 82 percent for local mosquito abatement personnel. The total response rate was 85 percent. Since mail survey return rates are frequently much lower than this (not uncommonly falling below 50 percent), there was high confidence in the reliability of the data. The response rates were in themselves a testimony to the cooperation of the officials contacted in all three types of agencies.

Analytical approach

17. The analytical approach was to concentrate primarily on contingency table (percentage distribution) descriptions and comparisons of these three aggregates. The chi-square test was also used in each table to give some standardized indication of the statistical significance of any interagency differences that may be found. This indicated with some certainty whether or not differences in proportional distributions on the various questions are true indications of important aggregate disparities among these agencies. While it was recognized that there is some disagreement among statisticians about utilizing the chi-square test of significance in this manner where the data are not based on a sample of respondents in the strict statistical sense, it was believed that a strong case can be made for its use here (Blalock 1972). For those who are uncomfortable with chi-square analysis in these data, the alternative would be to use the rule of thumb of ten percentage points as representative of significant differences, an approach described in Wahlke et al. (1963).

Discussion

Recognition and definition of the mosquito problem

18. National data. The first concern in this part of the project

was to examine and compare interagency perspectives on the existence and nature of the mosquito problem in confined dredged material disposal sites. Quite obviously, congruence of control programs is not likely if there is wide disagreement among the three agencies on these basic questions: (1) Are mosquitoes a problem in the selected areas, and are they breeding significantly in Army Corps of Engineers confined dredged material disposal sites? (2) What is the degree of the mosquito problem in these areas? (3) How does the mosquito problem in diked disposal areas (if the problem does indeed exist in these sites) compare with other environmental problems sometimes associated with such areas?

19. The initial question, then, was simply: "In your opinion, are mosquitoes a problem in your district?" This was immediately followed with a question concerning the respondents' opinions of the degree of the mosquito problem in the area (contingent upon a perceived problem). Obviously, these questions deal with problem recognition, or the lack of it, a crucial factor in the development and exucution of any policy (Anderson 1976). Based on the earlier hypothesis, one might reasonably expect to find wide variations on these queries between CE personnel on the one hand and the State and local mosquito control officials on the other hand. It was something of a surprise, then, to find that at least on the first question there were only insignificantly small differences among these agencies. {Note: As indicated earlier, throughout this section of the report, the chi-square (X^2) test was used as the indicator of statistically different data distributions. Where the data are presented in tabular format, the chi-square values and the level of significance will be included; otherwise, references will be included to the significance level in the text. It was decided to use the 0.05 level (or lower) as the statistical line indicating significant differences. That is, anytime the significance level was 0.05 or less ($p < 0.05$), this was taken as an indication of true differences

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in the data since the probability of the specific distribution occurring by chance would be less than 5 percent. If chi-square was even lower, this was an indication of an even lower possibility of a chance data distribution (for example, if $p < 0.001$, there was less than one chance in a thousand that the data show a chance distribution). Conversely, if chi-square was above 0.05, the probability of chance distribution of the data was high enough to prevent interpreting it as statistically significant (although it may have been, especially if it was only slightly above 0.05). This is a fairly standard approach (Roscoe 1969, Blalock 1972).} Practically all of the State and local officials saw a mosquito problem in their areas (100 percent and 98 percent, respectively), with a similar view being held by only a slightly smaller majority (89 percent) of the Corps personnel.

20. While interagency differences in the recognition of mosquitoes as a problem were apparently not large enough to be considered a source of potential or existing dispute, variations in opinions about the degree of the mosquito problem may be. As shown in Table A1, a considerably larger proportion of the CE respondents than of the State and local vector control officials felt that mosquitoes are a nuisance or simply a minor health problem although majorities of each agency saw the situation in one of these two ways. Similarly, significantly larger percentages of the control agencies saw mosquitoes as a major health problem. Clearly, these distributions identified an area of possibly serious disagreement between the Corps of Engineers and the control agencies regarding the urgency of mosquito control offorts.

Table A1

Opinions on the Degree of the Mosquito Problem in the Research Area

Problem	Corps %	State %	Local %
Mosquitoes are a nuisance	36	18	20
Mosquitoes are a minor health hazard	48	43	37
Mosquitoes are a major health hazard	5	39	41
Inapplicable	3	0	1
No opinion	8	0	1
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 43.68599$, $p < 0.0001$

Regional data

21. When the data are controlled by region —— Atlantic, Gulf, and Pacific —— this pattern of interagency variation existed in each region surveyed (see Appendix B, Table B1). (Note: A word of caution is in order on the breakdown of the national data by region. While it is believed that it is interesting and worthwhile to look at the data by region, the authors hesitate to draw firm conclusions from it in this form because the low base numbers of some of the group categories (for example, the state vector control groups in the Gulf and Pacific regions) and the low raw numbers in many of the table cells make percentage and chi-square analysis inconclusive. Moreover, the regional placement of Florida was difficult. It could be logically placed either in the Atlantic or in the Gulf groups with the decision finally going to the latter mainly because there were already more re-

spondents categorized as Atlantic than as Gulf. This problem was unavoidable, but it obviously might alter the regional breakdowns and should be taken into consideration. In short, the regional data are presented in Appendix B and it is referred to in the text discussion on occasion, but the firmer national data are the foundation of the analysis and conclusions.} It seems clear that in each region the chances for greater harmony in mosquito control programs would be enhanced if there were a greater correspondence of opinions on the degree of the mosquito problem. Whether this would in fact be the case depends upon whether or not the Corps' confined dredged material disposal sites are seen by these respective organizations as a major source of mosquito breeding. Different perceptions of the nature of the mosquito problem would logically make little difference if few or none of the respondents feel that confined dredged material disposal sites constitute a major breeding source. On the other hand, if these sites are generally seen as major mosquito breeding sources, and especially if they are seen this way by the control agencies but not by the Corps of Engineers, the difficulties involved in securing interagency cooperation in mosquito control efforts would be not only present but compounded.

Major sources of mosquito breeding

22. National data. In pursuit of this point the respondents were asked to indicate their opinions of the major mosquito breeding sources in their areas (See question 4). Table A2 presents a composite picture of the responses (that is, it lists the proportion of each of the groups mentioning the various types of breeding areas as being major mosquito producers in their area), and Tables A3-A6 present the complete distribution of opinions on each of the sources individually. The data here show wide variations among the three groups' opinions on mosquito breeding sources, but interestingly, in every case CE personnel were very close proportionally to one of the control agencies with the percentage of the remaining control agency being significantly different. For instance, almost identical per-

centages of the Corps and state vector control officials saw natural domestic areas as a major breeding source for mosquitoes while a significantly higher percentage of the local mosquito abatement personnel held this view. On the other three types of areas mentioned, including confined dredged material disposal sites, the Corps of Engineers and the local mosquito control officials were quite close proportionally while the respective percentages of state officials varied significantly. For this analysis, the views on diked dredged soil disposal sites are the most important.

Table A2

Perceived Sources of Mosquito Breeding in the Designated Areas: Composite*

Source	Corps %	State %	Local %
Natural domestic areas	45	46	69
Saltwater marshes	64	89	68
Freshwater areas	71	54	77
Confined dredged material disposal sites	35	54	43
N =	(86)	(28)	(111)

*This table shows the percentage of each group who answered that the source listed is a major area for mosquito breeding.

Table A3

Perceived Sources of Mosquito Breeding in the Designated Areas: Natural Domestic Areas

Source	Corps %	State %	Local %
Natural domestic areas are a breeding source	45	46	69
Natural domestic areas are not a breeding source	46	54	31
No opinion	9	0	0
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 22.86366$, $p < 0.0001$

Table A4

Perceived Sources of Mosquito Breeding in the Designated Areas: Saltwater Marshes

Source	Corps %	State %	Local %
Saltwater marshes are a breeding source	64	89	68
Saltwater marshes are not a breeding source	27	11	32
No opinion	9	0	0
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 18.81406$, $p < 0.0009$

Table A5

Perceived Sources of Mosquito Breeding in the Designated Areas: Fresh Water

Source	Corps %	State %	Local %
Natural Freshwater areas are a breeding source	71	54	77
Natural Freshwater areas are not a breeding source	20	46	23
No Opinion	9	0	0
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 20.81319$, $p < 0.0003$

Table A6

Perceived Sources of Mosquito Breeding in the Designated Areas: Confined Dredged Material Disposal Sites

Source	Corps %	State %	Local %
Confined dredged material disposal sites are a breeding source	35	54	43
Confined dredged material disposal sites are not a breeding source	56	43	57
No Opinion	9	3	0
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 13.29928$, $p < 0.001$

On this specific point, the Corps of Engineers was slightly less inclined than local control officials and significantly less inclined than state vector control personnel, proportionally, to see such disposal sites as major sources of mosquitoes. Of the four types of sources listed, the Corps ranked this last in importance as a mosquito source (based on the percentage mentioning it). Local mosquito abatement officials also ranked it last. State officials, in sharp contrast, ranked it second in importance as a source of mosquitoes (although it was tied for second with freshwater areas). In sum, the following points stand out. First, substantial proportions of each group saw confined dredged material disposal sites as a major mosquito source. This underscores the importance of the interagency variations in perceptions of the nature of the mosquito problem in the areas surveyed discussed in the preceding paragraph. Second, there was a clear lack of agreement among these agencies concerning the sources of mosquitoes in their areas. This was not just disagreement between the Corps of Engineers on the one hand and the control agencies on the other hand, as might be anticipated, but it involved obvious disagreement among the control agencies themselves. There is no great concern with the correct or incorrect view on mosquito breeding sources in an objective sense at this point; rather, the main interest is in the possibility of interagency misunderstandings which might well be rooted in these differential perceptions, regardless of their accuracy. It certainly seems that all three agencies would benefit from greater efforts to familiarize themselves with the objective facts about mosquito breeding sources in these areas to lessen this incongruity.

Regional data

23. When regional controls were introduced, the specific distributions changed in some ways, but the general points made above remained basically valid for each region (See Appendix B, Tables B2-B6). There was clear interagency variation in each region concerning opin-

ions about mosquito sources. It is noteworthy that in the Atlantic and Pacific regions smaller percentages of the local control officials and state control officials, respectively, saw confined dredged material disposal sites as major breeding sources. Furthermore, the porpotions of all groups in the Pacific region seeing these sites as major mosquito sources were all quite low. Only in the Gulf States were there significantly divergent views between the Corps of Engineers and the control agencies on this point. There is some suggestion here that interagency problems arising from perceptual differences on confined dredged material disposal sites as mosquito breeding sources might be less in the Atlantic and especially the Pacific than in the Gulf.

A comparison of mosquitoes
with other environmental problems

24. National data. As a final inquiry into the viewpoints of the three groups of respondents regarding the nature of the mosquito problem associated with diked dredged material disposal sites, they were asked to compare environmental problems which sometimes arise in such sites (See question 5). Specifically, they were asked to compare mosquitoes with pollution, botulism (in wildlife), dust, water turbidity, flies (and other insects), and rats (and other organisms). In each case, fairly large percentages indicated that one or both of the problems do not exist or that they have no opinion about which of the problems is more serious. Concentrating on those who did express a comparative opinion, it can be seen that there were clear differences between the Corps of Engineers on the one hand and the control agencies on the other. For example, the CE District personnel were much more prone, proportionally, to see pollution as a more serious problem than mosquitoes, while the control officials (state and local) were significantly more inclined to see mosquitoes as a more serious problem than pollution (see Table A7). Even though the specific figures vary, the same basic pattern appears in each of the other tables (see

Tables A8-A12). In every case, the control agencies saw mosquitoes as a more serious problem than the environmental condition with which the comparison was made; the Corps of Engineers was significantly more inclined to see the situation differently. Interestingly, in each instance, the sharpest differences were between the Corps personnel and the state control officials.

Table A7

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites: Mosquitoes Compared With Pollution

Problem	Corps %	State %	Local %
Mosquitoes are <u>less</u> serious than pollution	26	7	7
Mosquitoes are <u>more</u> serious than pollution	16	43	42
Problems are the same	6	14	8
One or both problems do not exist	38	18	35
No opinion	14	18	8
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 31.68777$, $p < 0.0001$

Table A8

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites: Mosquitoes Compared With Botulism

Problem	Corps %	State %	Local %
Mosquitoes are less serious than botulism	15	7	7
Mosquitoes are more serious than botulism	9	43	31
Problems are same	4	0	2
One or both problems do not exist	42	18	40
No opinion	30	32	20
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 24.66687$, $p < 0.0018$

Table A9

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites: Mosquitoes Compared With Dust

Problem	Corps %	State %	Local %
Mosquitoes are less serious than dust	20	0	1
Mosquitoes are more serious than dust	20	54	38
Problems are same	8	4	2
One or both problems do not exist	41	21	39
No opinion	11	21	20
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 42.11568$; $p < 0.0001$

Table A10

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites: Mosquitoes Compared With Turbidity

Problem	Corps %	State %	Local %
Mosquitoes are less serious than turbidity	17	0	6
Mosquitoes are more serious than turbidity	17	54	34
Problems are same	12	4	4
One or both problems do not exist	41	21	35
No opinion	13	21	21
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 28.98819$; $p < 0.0003$

Table A11

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites: Mosquitoes Compared With Flies

Problem	Corps %	State %	Local %
Mosquitoes are less serious than flies	10	11	2
Mosquitoes are more serious than flies	16	50	41
Problems are the same	20	3	8
One or both problems do not exist	29	18	32
No opinion	25	18	17
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 29.08128$; $p < 0.0003$

Table A12

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites: Mosquitoes Compared With Rats and Other Organisms

Problem	Corps %	State %	Local %
Mosquitoes are less serious than rats	12	7	2
Mosquitoes are more serious than rats	17	39	32
Problems are the same	11	0	4
One or both problems do not exist	29	18	32
No opinion	31	36	30
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 19.49969$; $p < 0.0124$

25. Regional data. The introduction of regional controls did little to alter this general picture (See Appendix B, Tables B7-B12). While there were some indications of regional variations, the basic pattern held with few exceptions. The main exception was found in Gulf States where state vector control personnel were less inclined proportionally than either the local control officials or the Corps officials to see mosquitoes as a more serious problem in dredged material disposal areas than pollution, dust, turbidity, flies, or rats. Even in the Gulf, however, the local control officials were much more likely than the Corps officials to see mosquitoes as more serious than any other problem listed.

26. In spite of the slight regional variations - and even in spite of the exception to the general distribution of opinion found among state control officials in the Gulf - these data again suggest

an area of possible interagency misunderstanding on the question of mosquito control in confined dredged material disposal sites. As was pointed out in the Introduction, it is perhaps understandable that the Corps' views on the nature and seriousness of the mosquito problem in these disposal sites would differ sharply from the views of state and local mosquito control personnel. It is not surprising, then, than there is some evidence of such differences. The key to promoting inter-agency cooperation may well lie in the reduction of such differences in outlook on the nature of the mosquito problem in these areas, and the clear identification and recognition of such differences by the personnel of the agencies themselves can be a valuable first step in this direction.

CE responsibility and involvement in mosquito control programs

27. Introductory commentary. The second broad topic of concern involved these groups' views on agency responsibility for executing mosquito control programs in diked disposal sites. In particular, questions were asked concerning opinions on: (1) which agency has the main responsibility for dealing with the mosquito problem in these disposal sites (at the present time or in the future event that a mosquito problem develops); (2) whether or not the Corps of Engineers should assume or be assigned any responsibility for mosquito control in confined dredged material disposal sites (now or in the future) even if this agency currently has little or no responsibility of this sort; (3) the degree of voluntary involvemant of the Corps ofEngineers (beyond any official responsibility) in mosquito control efforts in these sites; and (4) whether or not the Corps of Engineers should participate in local and/or state mosquito control programs in confined dredged material disposal sites in the future if these control agencies requested such help.

28. National data (Corps responses). On the question of which agency has the main responsibility for mosquito control in diked material disposal sites (See question 6) the Corps of Engineers was

roughly divided with just over a third replying that this is the responsibility of local mosquito abatement commissions and about the same proportion answering that this is the combined responsibility of these agencies and the Corps (see Table A13). Only 10 percent saw this as the exclusive responsibility of the Corps of Engineers, and even fewer saw it as the responsibility of state or local health departments. While relatively few Corps personnel viewed mosquito control in these sites as the sole (or main) responsibility of their agency, it should be noted that almost half (44 percent) did feel that the Corps has at least some of the responsibility (calculated by combining those who felt that the Corps has the main responsibility and those who felt that the Corps has shared responsibility).

29. Regional data (Corps responses). There were some regional variations. The Corps in the Atlantic States indicated the most support for the opinion that the Corps has at least some responsibility for mosquito control in these confined disposal sites (55 percent). About two fifths of the Corps respondents in the Gulf States and just over one fifth (23 percent) of the Corps personnel in the Pacific States felt that their agency has such responsibility (See Appendix B, Table B13).

30. National data (state responses). Overall, the state vector control officials tended to feel that the Corps has primary responsibility - either solely or shared - for mosquito control in confined dredged material disposal sites (see Table A13). Over two thirds (86 percent) of these officials saw the situation in these terms (21 percent viewed the Corps as having exclusive responsibility and 47 percent viewed the Corps as having shared responsibility). The remaining one third saw this as the main responsibility of local mosquito control districts.

31. Regional data (state responses). Regionally, state control officials in both the Atlantic and the Gulf were overwhelming of the opinion that the Corps has at least some responsibility for mosquito control in these disposal areas; only in the Pacific States was the

proportion holding this opinion low and at little variance with the distribution of opinion among Corps officials (See Appendix B, Table B13). On the whole, there were some significant differences of opinion between the Corps of Engineers and state vector control personnel concerning the location of responsibility for mosquito control activities in diked dredged material disposal sites.

Table A13

Opinions on Which Agency Has Main Responsibility for Mosquito Control in Confined Dredged Material Disposal Sites

Agency Seen As Having Main Responsibility	Corps %	State %	Local %
Local health department	6	0	10
Local mosquito abatement district	35	32	66
State health department	9	0	0
Corps of engineers	10	21	9
Other (combined)*	34	47	12
Don't know; not ascertainable	6	0	3
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 49.90663$; $p < 0.0001$

*Corps of Engineers shares responsibility with some other agency

32. National and regional data (local responses). A third pattern of opinion on this point was displayed by local control officials (see Table A13). Nationally, and in every region, clear majorities saw the main responsibility for mosquito control in these areas resting with the local mosquito abatement districts. Relatively few felt that the Corps of Engineers has this responsibility (either solely or shared). None thought the responsibility rested with state health departments. This general pattern existed for each agency in the

Pacific States, but it did not, as discussed previously, exist in the other regions (See Appendix B, Table B13). This might be explained by the rather natural tendency for an agency to carve out and protect for itself a functional area of operation (or niche) (Wamsley and Zald 1973). The business of mosquito control is, after all, the main purpose of the local control agencies (with the few exceptions of health departments included in the study), and they illustrated understandable reluctance to see this taken over by another agency, even on a partial basis.

33. In short, the data revealed the existence of three clearly different sets of opinions on the question of primary responsibility for mosquito control in confined dredged material disposal sites (with the exception of the Pacific States), and this once again identifies an area of possible interagency misunderstanding. This is particularly true as regards the relationship between the Corps of Engineers and state vector control agencies since these aggregates differed in viewpoint fundamentally on the responsibility of the Corps in this type of activity. Some resolution, or at least reduction, of these differences would obviously be helpful in promoting interagency harmony.

Corps responsibility to mosquito control

34. National data. Beyond the question of who has the main responsibility, opinions were requested concerning whether or not the Corps of Engineers should have any responsibility for mosquito control in confined soil disposal sites (question 7), and once again the data show some significant differences in the expected (hypothesized) directions (see Table A14). While just over half of the Corps respondents answered that their agency should have some such responsibility, almost all of the state control officials and nearly four fifths of the local vector control people replied in this manner.

35. Regional data. This pattern was basically consistent in each region with the single exception of the Gulf (See Appendix B, Table B14). Those who answered that the Corps should not assume or be as-

signed any responsibility generally did so on the grounds that the Corps' normal duties leave little or no time for this sort of activity, that this is not what the Corps is designed to do, or that other agencies should bear this responsibility. A few indicated that they believe that the Corps of Engineers should help pay for mosquito control in confined dredged material disposal sites, but Corps involvement should end there.

Table A14

Opinions on Whether the Corps of Engineers Should Assume or Be Assigned Any Responsibility for Mosquito Control in Confined Dredged Material Disposal Sites

Opinion	Corps %	State %	Local %
The Corps should have some responsibility	51	96	78
The Corps should not have some responsibility*	32	0	11
Other	11	0	0
No opinion	6	4	11
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 45.43478$; $p < 0.0001$

*This category combines a series of "no" responses detailing various reasons why the respondent felt the Corps should not be assigned any responsibility; the chi-square figures are based on that original table.

36. Interpretations. There are two ways to interpret this distribution of the data. On the one hand, the fact that half the CE officials felt that their agency should help in mosquito control programs even when this is clearly not the Corps' official responsibility might be considered remarkably high; it is at least an indication of some sensitivity on the part of the Corps. On the other hand, this does not alter or hide the interagency opinion differential on this question, a differential which could easily be related to present or future discord between the Corps and the control agencies.

37. Differences in opinions on the preceding point might be less serious if (1) the Corps of Engineers participates a great deal in mosquito control programs in diked disposal sites on a voluntary basis (question 8), and/or (2) if the agencies agree that the Corps should participate voluntarily in such efforts in the future if requested by the control agencies (question 9). Both of these items avoid the question of official responsibility and are couched solely in terms of voluntary involvement.

Voluntary Corps participation

38. National data. As shown in Table A15, relatively small proportions of each of these three groups felt that there is any voluntary Corps participation. If the two categories of Corps involvement are combined, it is found that 55 percent of the Corps personnel, 50 percent of the state control officials, and only 37 percent of the local control officials saw any Corps participation in their areas. It should be noted that a few of those who said that there is no voluntary participation by the Corps also pointed out that there has simply been no request for such aid in their areas.

39. Regional data. On a regional basis, the Corps' participation record was best in the Pacific (where all three agencies tended to see at least some involvement), followed by the Gulf and the Atlantic, in that order (See Appendix B, TableB15). In each region, smaller proportions of the local control agencies than of the other two consistently saw less Corps involvement; even in the Pacific the differences

between the local officials and the Corps officials on this point were statistically significant. On the whole, and in each region (with the possible exception of the Pacific), there was little indication that any of these agencies see a general level of Corps participation on a voluntary basis that would measure up to the control agencies' expressed feelings about Corps' responsibility for mosquito control in confined dredged material disposal sites illustrated in Table A14 above.

Table A15

Opinions on the Existing Voluntary Involvement of the Corps of Engineers in Mosquito Control Efforts in Confined Dredged Material Disposal Sites

Opinion	Corps %	State %	Local %
The Corps Participates a Great Deal	19	29	14
The Corps Participates Sometimes	36	21	23
The Corps Does Not Participate - Other Agencies Have Not Requested Help	20	0	9
The Corps Does Not Participate - Its Normal Workload Allows No Time	1	0	3
The Corps Does Not Participate - Other	7	32	25
Other	1	0	0
Inapplicable	3	4	8
No Opinion	13	14	18
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 31.87694$; $p < 0.0042$

Future Corps involvement

40. National data. The picture changed, however, when an examination was made of these officials' opinions on whether or not the Corps of Engineers should participate voluntarily in future mosquito control programs upon the request of the control agencies. Large majorities of each agency indicated that the Corps should help at least on a limited basis, and while there were some interagency differences in the expected direction, they were not very large (see Table A16).

Table A16

Opinions on Whether the Corps of Engineers Should Participate in Future Mosquito Control Programs in Confined Dredged Material Disposal Sites Upon the Request of State and/or Local Vector Control Departments

Opinion	Corps %	State %	Local %
Yes, the Corps should participate, at least on a limited basis	78	89	83
No, the Corps should not participate (because of normal workload, nature of its design, etc.	15	7	10
Other	0	0	1
No opinion	7	4	6
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 10.05528$; $p < 0.4357$

41. Regional data. The only regional variation observed occurred in the Atlantic States where the Corps percentage giving a positive answer was clearly below the state and local percentages; even in the Atlantic about two thirds of the Corps officials felt that their agency should respond, at least partially, to future requests for help in controlling mosquitoes in diked material disposal sites (See Appendix B, Table B16). These data are more heartening from the standpoint of the control agencies than any thus far examined because they indicate a possible foundation for generally better interagency cooperation, if the control agencies themselves can recognize and cultivate this broad point of view.

42. Communication patterns and needs. A strong case can be made for the crucial importance of frequent and clear communications between organizations with some shared involvement in the execution of a particular policy. This study has identified a number of areas where communication among the three agencies could play a significant role in their relationships regarding efforts to control mosquitoes in confined dredged material disposal sites. Moreover, the respondents themselves, especially in the state and local mosquito control agencies, repeatedly underscored their concern with communication by adding comments on their questionnaires to this effect. It would seem self-evident that the present and future patterns of interagency communication will bear heavily on the likelihood of success in dealing with some of the existing and/or potential problem areas pointed out in the earlier discussion.

43. Views on interagency communication. As shown in Table A17, the aggregate views on the levels cf existing communication between the Corps of Engineers and the two control agencies differed most clearly when the Corps responses were compared with the responses given by local mosquito abatement officials (based on question 10). Not only a significantly smaller percentage of the local group specifically stated that there is at least some communication (50 percent as compared to 68 percent of the Corps officials), but a much higher pro-

portion stated flatly that there is absolutely no communication at all (35 percent as compared to 9 percent of the Corps respondents). This different perception was reflected in numerous frustrated (and sometimes even bitter) comments made by various local officials in completing this part of the survey. In fact, many felt so strongly about the poor state of present communications with the Corps of Engineers that they elaborated at length in letters returned with their questionnaires: a few even sent copies of letters and memos they had sent to the Corps in their areas requesting improved communication about such things as future plans for dredging. While this should not

Table A17

Agencies' Perceptions of Communication Between the Corps of Engineers Personnel and State and/or Local Vector Control Officials Regarding Mosquito Conditions and Control in Confined Dredged Material Disposal Sites

Communication level	Corps %	State %	Local %
There is frequent and regular communication (once a month)	5	11	6
There is infrequent but regular communication (once every three months)	29	25	11
There is only very seldom communication (once every six months or less)	34	32	33
There is no communication	9	21	35
Other	1	0	0
No opinion; not ascertainable	22	11	15
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 30.75209$; $p < 0.002$

obscure the fact that there was, in the opinion of many in all three agencies, a good deal of communication among these agencies with respect to mosquitoes, it should be recognized as an area of intense concern for many, especially at the local level. It is noteworthy, moreover, that this pattern of clear-cut perceptual differences between the Corps of Engineers and the local control departments existed in each region (See Appendix B, Table B17).

44. The state officials differed less from the Corps officials in their perceptions of present communication than did the local respondents, but they also were proportionally more inclined to say that there is no communication (21 percent as compared to 9 percent of the Corps). On this point, the problem was of much more concern overall to local officials than to state officials, and it would appear that this would be the logical place to focus correction efforts.

45. Views on increasing interagency communication. The differences just noted between the Corps and the state and local vector control departments were even more sharply pronounced with respect to the question of increased interagency communication in the future (see question 13). Approximately two thirds of the state and local officials (68 percent and 64 percent respectively) said that such communication should be increased unconditionally while less than one fourth (23 percent) of the Corps officials expressed this view (see Table A18). About half of the Corps personnel said that more communication would be helpful at least if the mosquito problem develops or worsens in confined dredged material disposal sites while almost nine tenths of the control personnel indicated this point of view (these fractions represent a combination of the two positive responses to this question). At the other extreme, significantly higher percentages of the Corps respondents stated that no more communication is needed under any circumstances (the only regional exception to this pattern was found in the Pacific among state control officials; see Appendix B, Table B18). Given the strong feelings about the present state of communications between the Corps of Engineers and the vector

Table A18

Opinions on the Desirability of Increased Future Communication Between the Corps of Engineers and State and/or Local Vector Control Departments Regarding Mosquito Conditions and Control in Confined Dredged Material Disposal Sites

Communication level	Corps %	State %	Local %
More communication is definitely needed	23	68	64
More communication is needed, but only if a mosquito problem develops	27	21	25
No more communication is needed	35	7	7
Not ascertainable	5	0	1
No opinion	10	4	3
	100%	100%	100%
N =	(86)	(28)	(111)

$X^2 = 51.02859$; $p < 0.0001$

control agencies held by many of the control officials themselves (especially those at the local level), this is a situation which clearly needs recognition and attention if relations between these agencies are to be maintained and improved.

46. Among those saying that communications should be increased in the future, there was some agreement about the types of communication that would be most useful (see question 14). Although the exact percentages mentioning each type of communication varied from agency to agency, informal discussions and an exchange of letters and memos were ranked either first or second (according to the percentages listing them) in each of the three groups (see Table A19). Beyond this, there was little agreement among the types of communications

listed. Regionally, there were no clear patterns (See Appendix B, Table B19).

Table A19

Composite Listing of the Desired Types of Future Communication Between the Corps of Engineers and State and/or Local Vector Control Departments on Mosquito Conditions and Control in Confined Dredged Material Disposal Sites (Percentage Mentioning Each)

Communication level	Corps %	State %	Local %
Exchange of printed material	13	46	30
Exchange of letters, memos, etc.	23	68	50
Personal phone calls	16	54	37
Formal conferences	11	43	45
Informal discussions	33	54	53
N =	(86)	(28)	(111)

47. Finally, as might well be expected from the data just examined, the state and local control officials had a greater tendency than the Corps officials to list a number of types of communication that should be increased in the future. For example, 15 percent of the Corps respondents listed three or more types of communication in this respect as compared to 43 percent of the state respondents and 35 percent of the local respondents. Again, this pattern was found generally in each region when controls were introduced (See Appendix B, Table B20). Not only did the control agencies differ from the Corps in wanting more future communication, but they also varied significantly from the Corps in wanting more kinds of increased communication.

Conclusions

48. Organizational activity is affected by a multitude of external environmental variables, including other organizations (Blau and Scott 1962, Etzioni 1964, and Anderson 1975). This is, as pointed out in the Introduction, an especially important consideration in a system of governmental federalism. In the preceding analysis, an attempt has been made to explore some of the primary points relevant to understanding better the nature of interaction among the Corps of Engineers, state vector control departments, and local mosquito abatement programs as related to mosquito control in confined dredged material disposal sites. It was hypothesized at the outset that there were aggregate differences in the way officials of these three types of agencies recognized and defined the problem and in the way they perceived responsibility for dealing with the problem.

49. Although there were a few notable exceptions, for the most part the general hypothesis was confirmed by the data. The analysis identified a number of interagency differences on the points examined; while the control agencies occasionally differed more from each other than from the Corps of Engineers (for example, in views on the major mosquito breeding sources in the areas surveyed), the predominant pattern of differences revealed in this discussion was between the Corps of Engineers on the one hand and the control agencies on the other. This pattern was clearly seen in the agencies' perceptions of the seriousness of the mosquito problem in these areas, both by itself and in comparison with a number of other environmental problems such as pollution, flies, etc. In addition, there were similar patterns of differences among the agencies on the question of the Corps' responsibility for mosquito control in confined dredged material disposal sites and on the question of present levels of Corps involvement in mosquito control programs in such sites. There were also significant differences of opinion along these lines on the level of interagency communication at the present time and especially on the need for in-

creased communication in the future. The limited regional data indicated a few possible qualifications which should be noted, but the overall group variations were quite striking.

50. There were, of course, some locales where the Corps of Engineers was knowledgeable and concerned about mosquito production in confined dredged material disposal sites, was in regular and frequent communication with state and/or local control agencies about the problem and activities related thereto, and was quite actively engaged in control efforts. For example, in one District surveyed (Philadelphia), the Corps conducts its own mosquito control operations in disposal sites; in some others, there was much evidence of full-scale cooperation with state or local mosquito control programs; and in at least one District (Savannah), a Corps official was a member of the local mosquito control commission. There was other evidence of Corps concern ranging from partial financial support of mosquito programs to conducting independent studies of its own into the problems of mosquito breeding in disposal sites. Moreover, the data showed striking evidence of Corps willingness to participate voluntarily, at least on a limited basis, in future mosquito control programs in confined dredged material disposal sites. There is some evidence from at least one other study that this is not out of line with Corps efforts in recent years to respond more effectively to a wide variety of problems related to its general operations (Mazmanian and Mordecai 1975). This record of activity of concern notwithstanding, however, the overall picture was still one of different aggregate outlooks. It was also clear that many of the Corps Districts did not exhibit a high (or even moderate) level of concern or involvement.

51. The key to improved interagency relations and stronger mosquito control programs in diked disposal sites seems, at least from the data examined, to be improved recognition of the problem and improved communications between the Corps of Engineers and the control agencies, especially at the local level (and secondarily between the control agencies themselves). While it might be impractical to ex-

pect the Corps in every area to devote much of its time and resources to mosquito control in disposal sites, improved communications about such things as dredging schedules and disposal techniques (where alternative techniques are available and feasible) would not be unreasonable. Too often there was evidence of severe misunderstandings among these agencies because each had an inadequate appreciation of the goals and problems of the others. Communication is, of course, no guarantee that the kinds of interagency perceptual differences seen here will be eliminated, and it certainly will not ensure that there will be agreement about future mosquito control strategies in disposal sites. It does, however, have much potential for creating better understanding and awareness of the general situation for all involved if approached with genuine concern for improved relations. This potential was illustrated by the remarks of a number of officials in all agencies, but especially in the Corps of Engineers, indicating that the preparation of their responses to our questionnaire had led them to contact one or both of the other agencies for the first time to get information; for many, this simple communication had already increased their awareness and appreciation of a situation about which they had previously thought little, if at all.

52. The other parts of this report describe a wide range of technical factors related to mosquito conditions, especially those related to breeding and abatement in confined dredged material disposal sites. The ultimate goal of such a descriptive analysis is, of course, to make mosquito control efforts in those areas more effective. This is a form of communication aimed at producing the kind of interagency awareness of the topic identified in this section as being so crucial to policy cooperation.

Summary

53. The major concerns of this section are summarized in the following list.

a. Mailed questionnaires were used to study interagency attitudes regarding mosquito problems associated with confined dredged material disposal sites.

b. The total response rate from all agencies was 85 percent.

c. The data indicated a clear perceptual difference on the nature and extent of mosquito problems that develop as a result of dredged material disposal practices on land.

d. There was also evidence of different perceptions on the current and future agency responsibility for mosquito abatement in confined dredged material disposal sites.

e. Most of those surveyed felt that the Corps of Engineers should give voluntary aid in mosquito control programs in diked disposal areas.

f. The data revealed clear differences in opinions on current communication levels among the agencies surveyed.

g. The three agencies had sharply different views on the need for increased communication about mosquito conditions and control in confined dredged material disposal sites.

APPENDIX B: REGIONAL DATA TABLES

1. This appendix represents a compilation of significant data gathered as a part of Part III, but separated into regional groupings.

Table B1

Opinions on the Degree of the Mosquito Problem, by Region

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Source	%	%	%	%	%	%	%	%	%
Nuisance	42	13	19	31	14	19	29	40	22
Minor health hazard	35	56	39	61	29	39	59	20	30
Major health hazard	2	31	40	8	57	39	6	40	48
Inapplicable	7	0	0	0	0	3	0	0	0
No opinion	14	0	2	0	0	0	6	0	0
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 33.00609$; $p < 0.0001$

Gulf — $X^2 = 11.42022$; $p < 0.0762$

Pacific -- $X^2 = 10.44026$; $p < 0.1073$

Table B2

Perceived Sources of Mosquito Breeding in the Area, by Region

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Source	%	%	%	%	%	%	%	%	%
Natural domestic areas	40	38	73	58	71	61	41	40	74
Saltwater marshes	77	81	65	62	100	94	35	100	30
Freshwater	63	44	71	81	71	83	76	60	78
Confined dredged material disposal sites	54	69	48	19	57	53	12	0	17
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Table B3

Perceived Sources of Mosquito Breeding, by Region:

Natural Domestic Sources

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Source	%	%	%	%	%	%	%	%	%
Natural domestic areas are a breeding source	40	38	73	58	71	61	41	40	74
Natural domestic areas are not a breeding source	51	62	27	35	29	39	47	60	26
No opinion	9	0	0	7	0	0	12	0	0
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic -- $X^2 = 17.51823$; $p < 0.0015$

Gulf -- $X^2 = 3.68164$; $p < 0.4508$

Pacific -- $X^2 = 7.28823$; $p < 0.1215$

Table B4

Perceived Sources of Mosquito Breeding, by Region:

Saltwater Marshes

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Source	%	%	%	%	%	%	%	%	%
Saltwater marshes are a breeding source	77	81	65	62	100	94	35	100	30
Saltwater marshes are not a breeding source	14	19	35	31	0	6	53	0	70
No opinion	9	0	0	7	0	0	12	0	0
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 11.33523$; $p < 0.0230$

Gulf — $X^2 = 13.32302$; $p < 0.0098$

Pacific — $X^2 = 12.02557$; $p < 0.0172$

Table B5

Perceived Sources of Mosquito Breeding, by Region:

Freshwater

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Source	%	%	%	%	%	%	%	%	%
Freshwater is a breeding source	63	44	71	81	71	83	76	60	78
Freshwater is not a breeding source	28	56	29	11	29	17	12	40	22
No opinion	9	0	0	8	0	0	12	0	0
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 11.05347$; $p < 0.0260$

Gulf — $X^2 = 4.43928$; $p < 0.3498$

Pacific — $X^2 = 5.08966$; $p < 0.2782$

Table B6

Perceived Sources of Mosquito Breeding, by Region:

Confined Dredged Material Disposal Sites

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Source	%	%	%	%	%	%	%	%	%
Confined dredged material disposal sites <u>are</u> a breeding source	54	69	48	19	57	53	12	0	17
Confined dredged material disposal sites are <u>not</u> a breeding source	37	25	52	73	43	47	76	100	83
No opinion	9	6	0	8	0	0	12	0	0
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 8.16454$; $p < 0.0857$

Gulf — $X^2 = 10.06396$; $p < 0.0394$

Pacific — $X^2 = 4.53722$; $p < 0.3382$

Table B7

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites, by Region: Mosquitoes Compared With Pollution

Problem	Atlantic			Gulf			Pacific		
	Corps %	State %	Local %	Corps %	State %	Local %	Corps %	State %	Local %
Mosquitoes are less serious than pollution	28	0	6	23	29	6	23	0	13
Mosquitoes are more serious than pollution	16	50	42	19	0	53	12	80	26
Problems are same	7	13	11	8	29	5	0	0	4
One or both problems do not exist	30	13	33	46	29	25	47	20	57
No opinion	19	24	8	4	14	11	18	0	0
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 23.20070$; $p < 0.0031$

Gulf — $X^2 = 18.75198$; $p < 0.0162$

Pacific — $X^2 = 15.35483$; $p < 0.0526$

Table B8

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites, by Region: Mosquitoes Compared With Botulism

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Problem	%	%	%	%	%	%	%	%	%
Mosquitoes are less serious than botulism	7	13	8	19	0	8	30	0	4
Mosquitoes are more serious than botulism	11	37	29	12	29	44	0	80	13
Problems are same	5	0	2	4	0	3	0	0	0
One or both problems do not exist	42	6	38	46	43	31	35	20	61
No opinion	35	44	23	19	28	14	35	0	22
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 12.81197$; $p < 0.1185$

Gulf — $X^2 = 9.95256$; $p < 0.2684$

Pacific — $X^2 = 25.77939$; $p < 0.0002$

Table B9

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites, by Region: Mosquitoes Compared With Dust

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Problem	%	%	%	%	%	%	%	%	%
Mosquitoes are less serious than dust	9	0	0	8	0	0	65	0	4
Mosquitoes are more serious than dust	21	63	39	31	14	50	0	80	17
Problems are same	9	0	4	11	14	0	0	0	0
One or both of the problems do not exist	44	12	36	42	43	31	29	20	61
No opinion	16	25	21	8	29	19	6	0	17
	99%	100%	100%	100%	100%	100%	100%	100%	99%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 18.46669$; $p < 0.0180$

Gulf — $X^2 = 13.15598$; $p < 0.1066$

Pacific — $X^2 = 33.49020$; $p < 0.0001$

Table B10

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites, by Region: Mosquitoes Compared With Turbidity

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Problem	%	%	%	%	%	%	%	%	%
Mosquitoes are less serious than turbidity	14	0	4	15	0	8	29	0	4
Mosquitoes are more serious than turbidity	14	63	36	31	14	39	6	80	22
Problems are same	7	0	8	8	14	0	29	0	4
One or both of the problems do not exist	49	12	31	38	43	28	24	20	57
No opinion	16	25	21	8	29	25	12	0	13
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic -- $X^2 = 20.82349$; $p < 0.0076$

Gulf -- $X^2 = 10.02169$; $p < 0.2635$

Pacific -- $X^2 = 24.12885$; $p < 0.0022$

Table B11

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites, by Region: Mosquitoes Compared With Flies

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Problem	%	%	%	%	%	%	%	%	%
Mosquitoes are less serious than flies	0	0	0	8	14	6	41	40	0
Mosquitoes are more serious than flies	18	75	42	15	0	50	12	40	22
Problems are same	14	0	12	35	14	8	12	0	0
One or both of the problems do not exist	26	6	27	38	43	25	23	20	56
No opinion	42	19	19	4	29	11	12	0	22
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic -- $X^2 = 19.71785$; $p < 0.0031$

Gulf -- $X^2 = 18.95076$; $p < 0.0151$

Pacific -- $X^2 = 19.03979$; $p < 0.0146$

Table B12

Perceived Seriousness of Problems in Confined Dredged Material Disposal Sites, by Region: Mosquitoes Compared With Rats

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Problem	%	%	%	%	%	%	%	%	%
Mosquitoes are less serious than rats	5	0	2	4	0	3	41	40	0
Mosquitoes are more serious than rats	19	56	36	23	0	36	6	40	13
Problems are same	5	0	8	19	0	0	12	0	4
One or both of the problems do not exist	25	6	27	39	43	25	23	20	57
No opinion	46	38	37	15	57	36	18	0	26
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 13.05988$; $p < 0.1098$

Gulf — $X^2 = 16.74007$; $p < 0.0329$

Pacific — $X^2 = 18.66495$; $p < 0.0168$

Table B13

Opinions on Which Agency has Main Responsibility for Mosquito Control in Confined Dredged Material Disposal Sites, by Region

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Agency	%	%	%	%	%	%	%	%	%
Local health department	7	0	17	8	0	6	0	0	0
Local mosquito abatement district	21	25	56	35	14	81	71	80	70
State health department	12	0	0	11	0	0	0	0	0
Corps of Engineers	16	25	12	8	29	8	0	20	4
Other (combined)	39	50	15	31	57	3	23	0	17
No opinion; not ascertainable	5	0	0	7	0	3	6	0	9
	100%	100%	100%	100%	100%	101%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic -- $X^2 = 32.47023$; $p < 0.0003$

Gulf -- $X^2 = 30.52467$; $p < 0.0023$

Pacific -- $X^2 = 2.46291$; $p < 0.9634$

Table B14

Opinions on Whether the Corps of Engineers Should Assume or Be Assigned Any Responsibility for Mosquito Control in Confined Dredged Material Disposal Sites, by Region

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Opinion	%	%	%	%	%	%	%	%	%
The Corps should have some responsibility	37	94	75	73	100	72	53	100	96
The Corps should not have some responsibility	44	0	8	15	0	20	23	0	4
Other	14	0	0	4	0	0	18	0	0
No opinion	5	6	17	8	0	8	6	0	0
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 42.56795$; $p < 0.0001$
Gulf — $X^2 = 7.35629$; $p < 0.6914$
Pacific — $X^2 = 14.34142$; $p < 0.1580$

*This combines a number of specific reasons given for the Corps not having any official responsibility (i.e., this is not what the Corps was designed to do, the Corps has no time for this with its other duties, etc.)

Table B15

Opinions on the Voluntary Involvement of the Corps of Engineers in Mosquito Control Efforts in Confined Dredged Material Disposal Sites, by Region

	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Opinion	%	%	%	%	%	%	%	%	%
The Corps participates a great deal	16	13	6	15	57	22	29	40	17
The Corps participates sometimes	28	25	19	46	0	19	41	40	39
The Corps does not participate - other agencies have not requested help	21	0	8	19	0	8	18	0	13
The Corps does not participate - its normal workload allows no time	0	0	6	4	0	0	0	0	0
The Corps does not participate - other	14	56	29	0	0	25	0	0	18
Other	2	0	0	0	0	0	0	0	0
Inapplicable	7	0	11	0	0	3	0	20	9
No opinion	12	6	21	16	43	22	12	0	4
	100%	100%	100%	100%	100%	99%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic -- $X^2 = 26.28294$; $p < 0.0238$

Gulf -- $X^2 = 25.42680$; $p < 0.0129$

Pacific -- $X^2 = 9.66658$; $p < 0.4702$

Table B16

Opinions on Whether the Corps of Engineers Should Participate in Future Mosquito Control Programs in Confined Dredged Material Disposal Sites Upon the Request of State and/or Local Vector Control Officials, by Region

	Region								
	Atlantic			Gulf			Pacific		
Opinion	Corps %	State %	Local %	Corps %	State %	Local %	Corps %	State %	Local %
Yes, the Corps should participate at least on a limited basis	67	81	81	88	100	81	88	100	91
No, the Corps should not participate	28	13	10	4	0	14	0	0	4
Other	0	0	0	0	0	3	0	0	0
No opinion	5	6	9	8	0	3	12	0	4
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 9.20498$; $p < 0.1624$

Gulf — $X^2 = 8.63291$; $p < 0.3742$

Pacific — $X^2 = 2.19699$; $p < 0.6996$

Table B17

Agency Perceptions of Communication Between Corps Personnel and State and/or Local Vector Control Officials Regarding Mosquito Conditions and Control in Confined Dredged Material Disposal Sites, by Region

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Communication level	%	%	%	%	%	%	%	%	%
There is frequent and regular communication	5	12	6	4	14	8	6	0	4
There is infrequent but regular communication	42	6	6	19	29	14	12	80	18
There is very seldom communication	16	50	35	46	0	28	59	20	39
There is no communication	12	12	35	8	57	39	6	0	30
Other	0	0	0	4	0	0	0	0	0
No opinion	25	20	18	19	0	11	17	0	9
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 33.50563$; $p < 0.0002$

Gulf — $X^2 = 16.47542$; $p < 0.0868$

Pacific — $X^2 = 16.14473$; $p < 0.0404$

Table B18

Opinions on the Desirability of More Future Communication Between the Corps of Engineers and State and/or Local Vector Control Departments Concerning Mosquito Conditions and Control in Confined Dredged Material Disposal Sites, by Region

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Communication level	%	%	%	%	%	%	%	%	%
More communication is is definitely needed	19	69	58	19	57	64	41	80	78
More communication is needed, but only if a mosquito problem develops	21	25	35	38	29	17	23	0	18
No more communication is needed	42	0	4	35	14	14	18	20	4
Not ascertainable	9	0	2	0	0	0	0	0	0
No opinion	9	6	2	8	0	5	18	0	0
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 40.67456$; $p < 0.0001$

Gulf — $X^2 = 13.20705$; $p < 0.0399$

Pacific — $X^2 = 10.40155$; $p < 0.1087$

Table B19

Composite Listing of the Desired Types of Future Communication Between the Corps of Engineers and State and/or Local Vector Control Departments on Mosquito Conditions and Control in Confined Dredged Material Disposal Sites, by Region

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Communication level	%	%	%	%	%	%	%	%	%
Exchange of printed material	12	38	33	8	71	19	24	30	39
Exchange of letters, memos, etc.	14	75	58	31	71	47	35	40	35
Personal phone calls	16	50	42	19	71	31	12	40	35
Formal conferences	7	44	44	24	14	47	0	80	44
Informal discussions	23	50	60	42	43	39	41	80	61
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic — $X^2 = 45.18559$; $p < 0.0001$

Gulf — $X^2 = 23.21277$; $p < 0.0569$

Pacific — $X^2 = 14.67883$; $p < 0.1442$

Table B20

Total Desired Future Increase in Communication Between Corps of Engineers and/or Local Vector Control Departments Concerning Mosquito Conditions and Control in Confined Dredged Material Disposal Sites, by Region

	Region								
	Atlantic			Gulf			Pacific		
	Corps	State	Local	Corps	State	Local	Corps	State	Local
Communication need	%	%	%	%	%	%	%	%	%
None	56	6	17	42	14	17	29	20	4
One	16	6	15	27	0	25	29	0	22
Two	5	44	29	11	29	19	29	40	48
Three	9	25	10	8	14	17	6	0	13
Four	5	6	10	4	29	14	6	0	4
Five or more	0	13	19	8	0	3	0	40	9
DK/NA	9	0	0	0	14	5	0	0	0
	100%	100%	100%	100%	100%	100%	100%	100%	100%
N =	(43)	(16)	(52)	(26)	(7)	(36)	(17)	(5)	(23)

Atlantic -- $X^2 = 45.18559$; $p < 0.0001$

Gulf -- $X^2 = 23.21277$; $p < 0.0569$

Pacific -- $X^2 = 14.67883$; $p < 0.1442$

APPENDIX C: COMPOSITE SUMMARY OF ALL MOSQUITO SPECIES KNOWN TO BE ASSOCIATED WITH DREDGED MATERIAL DISPOSAL SITES

1. This appendix represents a compilation of all species of mosquitoes known or reported from dredged material disposal sites. Species reported from the primary study sites of Charleston District have been reported in Part IV; while species reported during site visitations are listed in Appendix D. This list, presented as Table C1, represents the beginnings of a complete list of the mosquito fauna associated with dredged material disposal areas. All mosquitoes reported in Part IV were identified by the investigators of this study and some samples were submitted to taxonomic specialists for confirmation. Only those mosquitoes that were consistently reported by reliable field workers have been included in Table C1. It will be noted that some of the species listed in Table C1 are to be expected only in older disposal sites; while other species are expected only in younger disposal areas. The positive association of mosquitoes and disposal sites can only be made when specific collections of larvae are made.

Table C1

Composite Listing of All Mosquito Species, Known or Reported, From Dredged Material Disposal Sites

Genera	Species
Aedes	
	atlanticus
	cantator
	dorsalis
	sollicitans
	squamiger
	taeniorhynchus
	tormentor
	triseriatus
	trivittatus
	vexans
Anopheles	
	atropos
	bradleyi
	crucians
	georgianus
	punctipennis
	quadrimaculatus
Culex	
	pipiens
	pipiens quinquefasciatus
	restuans
	salinarius
	tarsalis

(continued)

Table C1 (concluded)

Genera	Species
Culex	
	territans
Coquillettida	
	perturbans
Culiseta	
	inornata
	melanura
Psorophora	
	columbiae
	horrida
	howardii
Uranotaenia	
	sapphirina

APPENDIX D: SITE VISITATIONS TO SELECTED CORPS OF ENGINEER DISTRICTS

Introduction

Rationale

1. Eight Districts of the Corps of Engineers were visited for the purpose of conducting site visitations to different types of dredged material disposal sites and to interview selected personnel from Corps District offices and mosquito abatement programs. In every case, an effort was made to arrange a joint meeting with both groups to mutually discuss mosquito abatement problems at the same time. A list of contact personnel who assisted in the preparation of this report has been included as Appendix D1. In order to obtain as broad a view as possible, interviews were held with managerial, operational, and environmental personnel from both types of agencies. Field trips into various disposal sites were scheduled with mosquito abatement and CE personnel on separate days in order that both agencies would have an equal opportunity to explain disposal area problems from their respective viewpoints. Special attention was devoted to determining which mosquito species were actually known to breed within disposal areas. Districts visited included:

Galveston	Philadelphia
Jacksonville	Sacramento
New Orleans	San Francisco
Norfolk	Savannah

Districts were selected on the basis of their coastal locations and in many cases a history of complaints regarding mosquitoes associated with dredged material disposal sites.

Literature review

2. Only one report was located concerning the relationship of

Appendix D1

SITE VISITATIONS TO
CORPS OF ENGINEERS DISTRICTS

List of Contact and Resource Personnel

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(continued)

Appendix D1 (continued)

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(continued)

Appendix D1 (continued)

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diked disposal areas to mosquito breeding. Berlin (1974) reported in an unpublished document (contracted by the Buffalo District) that *Culex salinarius*, *Culex pipiens*, and *Culex resturans* were collected from diked disposal sites in western New York. This report also contained descriptions of other environmental conditions associated with the above-mentioned mosquito species. Harrison and Chisholm (1974) reported on a survey of a number of different environmental conditions associated with the disposal of dredged material in various Corps Districts.

Galveston District

Description

3. Skjei (1976) reported annual maintenance dredging to be approximately 23 million cu yd of material per year from 1971-1973 in the Galveston District. Disposal of dredged material is divided between open-water disposal techniques and diked disposal areas. Dredging to maintain the Houston Ship Channel is known to have caused some pollution problems (Skjei 1976). Harrison and Chisholm (1974) reported that continuous ponding as a mosquito control practice was not practical due to dike construction methods and the possible enhancement of seepage problems.

Mosquito abatement programs

4. Harris County Mosquito Control District. Two mosquito abatement programs were visited in the Galveston CE District. The Harris County Mosquito Control District reported a number of problems associated with the disposal of dredged material behind dike disposal sites. This District reported that approximately 3500 acres of diked disposal areas were known to support larval mosquitoes during 1975. Harris County maintains a program of mosquito surveillance and Corps cooperation that was not encountered in any of the other site visitations. County personnel are responsible for monitoring

larval and adult mosquito populations within disposal sites. Unusual mosquito concentrations are then reported to a designated contact within the Calveston CE District. Following this mosquito report, the site may be reinspected (by the Corps) or a control measure initiated. A mosquito control contract between the Galveston CE District and an aerial applicator is maintained on a yearly basis. Control materials are recommended by the Harris County Mosquito Control District and implementation of the spray program is under the Galveston CE District. Good relations and cooperation between the two agencies were frequently mentioned during separate interviews.

5. The Harris County Mosquito Control District has suggested other control measures for mosquitoes within disposal sites, including biological control techniques that would allow for the introduction and maintenance of predatory fish populations within disposal areas. These suggestions were not considered reasonbale by the Galveston CE District due to the previously cited problems with dike construction.

6. Galveston County Mosquito Control District. The second mosquito abatement program visited was the Galveston County program. This agency likewise reported good relations with Galveston CE District and mentioned that many problems had been eliminated through cooperation with Corps personnel. Disposal area mosquito problems were reported to have been more serious about 10 years ago than is presently the case. This mosquito abatement program reported a rise in other mosquito problems originating with salt marshes and rice fields.

Disposal site mosquitoes

7. The following species of mosquitoes were reported from Galveston District as being important pests from dredged material disposal areas:

a. *Aedes sollicitans.*

b. *Aedes taeniorhynchus.*

c. *Culex salinarius.*

d. *Culiseta inornata.*

e. *Psorophora columbiae.*

The two *Aedes* spp. were regarded as extremely important because of their habit of producing multiple broods within disposal sites.

Disposal area conditions

8. Sites visited. A total of seven dredged material disposal areas were visited in the Galveston Corps District. Mosquito abatement personnel reported that seepage was often a mosquito problem of equal magnitude with interior disposal area problems. Seepage larval habitats from the Galveston District have been previously illustrated as Figure 17. Seepage problems were frequently reported from some of the higher disposal areas (i.e. greater elevation). In these cases, larvae were usually not found within the disposal site per se, but were abundant in outside seepage habitats.

9. Other disposal sites appeared to follow the same basic successional patterns that have been considered in the earlier sections of this report. The DM stages proposed for disposal area successional patterns would appear to be especially suited to Galveston District conditions. All larval habitats previously cited in Figure 15 are known to occur in the disposal areas of the District. As was noted with the Charleston District sites, the older Galveston disposal areas tended to support a more varied mosquito fauna than the younger locations.

10. Sand mining. The practice of allowing sand mining operations within dredged material disposal sites was frequently cited as a source of mosquito larval habitats. *Psorophora columbiae* collections were reported from a disposal area (Galveston District Disposal Area No. 26) that had been opened to a contractor for sand mining. A typical sand mine operation within this site is shown in Figure D1. In this instance, the habitat created for the mosquitoes was not related to the disposal of dredged material, but to later alterations of the site. Nonetheless, local residents had complained of

Figure D1

Sand Mine Operation within a Dredged Material
Disposal Site in Galveston CE District

"disposal site mosquitoes." For this reason, it is suggested that mining operators be required to develop a suitable management plan (in consultation with local mosquito abatement personnel) to eliminate this mosquito habitat before they are allowed to commence or cease operations. Extensive borrow pits that are allowed to remain open were observed to be frequent sources of mosquito larvae.

11. Unconfined. Unconfined disposal sites near Galveston, Texas, were inspected for the presence of mosquito larval habitats through the courtesy of Galveston District. These sites (Figure D2) were generally undiked. They were frequently subject to tidal erosion. These disposal areas, frequently composed of dredged material containing sea shells, did not appear capable of supporting larval mosquitoes. The DM stages proposed in earlier sections of this report would not apply to such sites.

12. Pelican Island. A more typical disposal area, Pelican Island, near the city of Galveston appeared to present abundant larval mosquito habitats. Most of the habitats that appeared capable of supporting mosquitoes appeared to be under DM-4 and DM-5 conditions. Local residents and workers reported frequent mosquito problems from the area. It was not determined how frequently the area was monitored for larvae by the Galveston County Mosquito Control District. Again, it should be noted that the presence of adult mosquitoes near a disposal site does not necessarily incriminate that site as the source of the adults.

13. Resistance problems. Resistance to some of the common organophosphorous pesticides was reported as a problem by some Texas abatement personnel. The phenomenon of genetic resistance to pesticides is now understood by most entomologists, but many laymen often believe that any insect control problem can be solved by applying enough poison. The experience of mosquito abatement personnel in Texas and many other parts of the U. S. would appear to warrant caution when the application of organic poisons to mosquito larval

Figure D2

Unconfined Dredged Material Disposal Site
in Galveston CE District

habitats is contemplated. Organic poisons are distinct from certain other larvicidal materials whose actions are due to surface tension reduction.

14. Collection of *Culiseta inornata*. Since the Galveston trip was made during January of 1976, few mosquitoes of any variety could be collected. *Culiseta inornata*, however, was encountered in an unusual habitat. Large numbers of this species were collected from a disposal area in which motorcycles and other recreational vehicles had operated and left behind deep ruts in the dredged material. *Culiseta inornata* is known to be more common in the southern U. S. during the winter months. This species has been reported by Pratt et al. (1972) to be naturally infected with Western Encephalitis (WE) virus. *Culiseta inornata* is not regarded as a major pest of man, but it is known to cause considerable annoyance to livestock. Over 2000 larvae of this species were readily collected from the recreational vehicle tracks. It is interesting to note that the collection site (Galveston Disposal Area No. 25) did not have any other additional mosquito breeding locations. For this reason, the investigators believe that the unrestrained use of recreational vehicles within dredged material disposal sites may cause some preventable mosquito breeding.

Plant specimens

15. Only a few plant specimens were collected from Texas disposal sites due to the prevailing winter conditions. However, the following plants were common: *Cyperus* sp., *Glottidium vesicarum* (Jacq.) Harper, *Heliotropium* sp., *Rumex* sp., *Solidago* sp., and *Typha* sp. of the herb group; *Baccharis* sp. and *Tamarix* sp. of the shrub group; and *Salix* sp. of the tree group.

Jacksonville District

Description

16. The Jacksonville District of the Corps of Engineers is

concerned with several types of dredged material, which vary from relatively clean sand to silts and clays that may be polluted with heavy metals. Between 1972 and 1973, Skjei (1976) reported that the District dredged between 3 and 4 million cu yd per year. Major harbors in the District include Jacksonville, Miami, and Tampa, Florida. This latter harbor project was expected to generate substantial amounts of new dredged material. Numerous personnel within both the Jacksonville CE District and mosquito abatement programs mentioned water-quality standards as primary environmental concerns associated with discharge from dredged material disposal sites. Tightened water-quality standards have frequently required that disposal sites be divided into two subdivisions. One side of the disposal area is used as a primary settling basin. Following this settlement operation the supernatant water is then drawn into a second disposal site in which further water clarification may occur. Corps officials also mentioned a reduction in the amount of open water disposal as being as important environmental concern due to the increased cost of located inland sites.

Mosquito abatement programs

17. Duval County Mosquito Control. The Department of Health, Welfare, and Bio-environmental Sciences of Duval County operates a Mosquito Branch which functions as a mosquito control district. Personnel with this agency reported a number of problems with mosquitoes associated with dredged material disposal areas, but generally good communication with the Jacksonville District of the Corps of Engineers. The mosquito control personnel reported that problem areas with mosquitoes fluctuated from year to year. Many disposal sites that were the result of initial dredge operations tended to contain high amounts of sand and therefore did not support larval mosquitoes. Neither the Duval County mosquito control personnel or the Jacksonville Corps maintained regular light trap surveillance for mosquitoes within dredged material disposal sites. Mosquito

resistance to common organophosphorus insecticides was reported as a major problem confronting the mosquito control efforts of Duval County. *Culex* mosquitoes were cited as being of at least equal importance to disposal area mosquitoes. Many of these mosquitoes frequently were derived from polluted sources of water and not related to dredged material disposal sites.

18. Duval County was also one of the few mosquito control districts to report a regular information exhange with the local Corps District. Not only was environmental information received from the Jacksonville District office, but plans and diagrams for ditching and drainage were sent from the mosquito control agencies to the Corps. In many areas of the United States little evidence of real interchange between mosquito control agencies and the Corps of Engineers was located or discussed in interviews.

19. Florida Bureau of Entomology. Discussions were also held with personnel from the Florida Bureau of Entomology, a division of the Florida Department of Health and Rehabilitative Services. This agency was thoroughly familiar with the large numbers of mosquitoes that can result from the formation of fissured soil within disposal sites on a state-wide basis. Copies of letters regarding the response of the Bureau to various projects proposed by the Jacksonville Corps were furnished to the investigators. Interviews with various personnel within the Bureau revealed a mixed record. In some cases, objections regarding mosquito control problems appear to have been resolved by compromises on both sides of environmental issues. In other cases, mosquito control problems were created that had been correctly predicted in advance of the construction of the proposed disposal site.

Disposal site mosquitoes

20. The following species were collected or reported to be associated with the disposal of dredged material in the Jacksonville District:

a. *Aedes taeniorhynchus*, considered the major pest species.

b. *Aedes sollicitans*.

c. *Anopheles crucians*.

d. *Anopheles bradleyi*.

e. *Culex salinarius*.

Aedes taeniorhynchus was considered tha major pest species associated with disposal sites. It is interesting to note than *Aedes sollicitans* is considered a more important pest mosquito north of the Jacksonville, Florida area.

Disposal area conditions

21. Blockage of natural marsh drainage. The blockage of natural marsh drainage by dike construction was the most frequently cited problem source of disposal area mosquitoes. Field trips were conducted to several disposal sites that did not support substantial larval populations within the dredged material per se, but large numbers of *Aedes taeniorhynchus* larvae were readily collected from blocked tidal drainage sites (see also Figure 15, item 7). In other cases, drainage within disposal areas effectively reduced mosquito breeding only to later have additional problems develop near outfall sites of that drainage.

22. Erosion of dike walls. Environmental restrictions on the placement of dredged material in some parts of Jacksonville District have caused dredged material to be placed at higher elevations. This procedure tends to increase the soil erosion along the retaining dikes if they are not contoured and stable spillways installed at runoff points. In some areas erosive water channels have scoured out numerous depressions near the lower edges of the dike (see Figure 15, item 8). These depressions are usually filled with water or replenished daily by high tides. This mosquito control problem could be eliminated by the planning and placing of dikes and spillways contoured for drainage.

23. Discharge sites. Discharge site larval habitats (see Figure

15, item 9) were frequently termed "blow holes" in Florida. This site was noted as a common source of mosquitoes that could have been eliminated by the proper use of a splash pad. The practice of sand mining has been previously illustrated and cited in the section on Galveston District. Larval habitats that were created by this practice were observed in several disposal sites near Jacksonville and Mayport, Florida. As was true with the Galveston sites, mosquitoes resulting from sand mining borrow pits were incorrectly associated with dredged material disposal operations.

24. Dike seepage habitats. The largest concentrations of mosquito larvae were observed on 11 August 1975 within a disposal site near the Mayport Naval Air Station. Over 6000 larvae of *Aedes taeniorhynchus* were collected from a dike seepage larval habitat (see Figure 15, item 10). Several hundred yards away in an outfall site, an additional 500 larvae were obtained within 2 min. In another location within the disposal area, several hundred larvae were aspirated from fissured soil in the DM-4 stage. In all cases, the larvae were identified as *Aedes taeniorhynchus*.

25. Other larval habitats. Other disposal sites appeared to follow the same basic patterns that have been mentioned in earlier sections of this report. The DM stages proposed in Figure 14 would appear to be valid for Florida disposal sites that were observed in the Jacksonville vicinity. All larval habitats that were summarized in Figure 15 were observed during the Jacksonville site visits. More larvae were collected from discharge site larval habitats (see Figure 15, item 9) in the Jacksonville CE District than on the other site visitations. The practice of ponding and subdividing disposal sites for water quality standards may tend to create additional mosquito larval habitats when such areas are allowed to dry and form soil fissures. The presence of protective vegetation was especially noticed within the disposal areas near Mayport, Florida. Careful observations yielded large numbers of larvae that were obvious to

the casual observer.

Plant specimens

26. A list of the common seed plants that were observed to be associated with dredged material disposal areas in Jacksonville, Fla. is presented as Table D2. Many of these plants were also collected from the Charleston District disposal sites (see Appendix E).

New Orleans District

Description

27. The New Orleans District of the Corps of Engineers annually dredged approximately 22.8 million cu yd of dredged material into confined disposal sites (Harrison and Chisolm 1974). Open disposal practices have been used by the District in the recent past. Dredging is necessary to maintain shipping channels in the Mississippi River and the Gulf Outlet Canal. Dike failures have been reported as a major engineering problem in the past. Frequently, dikes are constructed of marsh soils and other highly organic substrates. Harrison and Chisolm (1974) reported that dike failures occur most often near discharge pipes (see also Figure 15, items 8 and 9) where water turbulence is high. Environmental complaints in most areas are reported to be minimal. Mosquitoes were not reported as a major problem in the environmental assessment of Harrison and Chisolm (1974).

Mosquito abatement programs

28. New Orleans Mosquito Control Board. The abatement and control of mosquitoes within Orleans Parish in Louisiana is the responsibility of the Mosquito Control Board of the city of New Orleans. This agency was the primary mosquito abatement contact during the Louisiana site visitation. Contacts with other mosquito abatement programs in Louisiana were made through mail and the opinion survey (see Appendix A). These districts reported a number of mosquito

Table D2

Catalogue of Common Seed Plants Associated With Diked Dredged Material Disposal Sites in Florida

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Herbs

Ambrosia sp. (Asteraceae)
Cenchrus sp. (Poaceae)
Chenopodium ambrosioides L. (Chenopodiaceae)
Cucurbita pepo L. (Cucurbitaceae)
Cyperus sp. (Cyperaceae)
Digitaria sanguinalis (L.) Scopoli (Poaceae)
Diodia teres Walter (Rubiaceae)
Echinochola walteri (Pursh) Heller (Poaceae)
Eleusine indica (L.) Gaertner (Poaceae)
Eragrostis poaeoides Beauvois (Poaceae)
Eragrostis spectabilis (Pursh) Steudel (Poaceae)
Erigeron canadensis L. (Asteraceae)
Erigeron strigosus Muhl. ex Willd. (Asteraceae)
Euphorbia sp. (Euphorbiaceae)
Glottidium vesicarium (Jacquin) Mohr (Fabaceae)
Gnaphalium purpureum L. (Asteraceae)
Heterotheca subaxillaris (Lam.) Britton & Rusby (Asteraceae)
Hydrocotyle sp. (Apiaceae)
Juncus roemerianus Scheele (Juncaceae)
Leptochloa uninervia (Presl.) Hitchcock (Poaceae)
Lippia nodiflora (L.) Michaux (Verbenaceae)
Meliotus alba Desr. (Fabaceae)
Melothria pendula L. (Cucurbitaceae)
Oenothera sp. (Onagraceae)
Paspalum notatum var. saurae Parodi (Poaceae)
Paspalum urvillei Steudel (Poaceae)
Phytolacca americana L. (Phytolaccacae)
Pluchea purpurascena (Swatrz) DC. (Asteraceae)
Salicornia europaea L. (Chenopodiaceae)
Sesuvium portulacastrum L. (Aizoaceae)
Solanum americanum Miller (Solanaceae)
Solidago sp. (Asteraceae)
Sonchus asper (L.) Hill (Asteraceae)
Sonchus oleraceus L. (Asteraceae)
Spartina alterniflora Loisel (Poaceae)
Sporobolus virginicus (L.) Kunth (Poaceae)
Strophostyles helvola (L.) Ell. (Fabaceae)

(continued)

Table D2 (concluded)

Herbs (continued)

Suaeda linearis (Ell.) Moq. (Chenopodiaceae)
Triglochin striata R. & R. (Juncaginaceae)
Uniola paniculata L. (Poaceae)

Shrubs

Baccharis angustifolia Michaux (Asteraceae)
Baccharis halimifolia L. (Asteraceae)
Myrica cerifera L. (Myricaceae)
Parthenocissus quinquefolia (L.) Planchon (Vitaceae)

Trees

Juniperus virginiana L. (Cupressaceae)
Sabal palmetto Lodd. ex Schultes (Arecaceae)
Zanthoxylum clava-herculis L. (Rutaceae)

abatement problems associated with the disposal of dredged material. Dredged material disposal sites were regarded as major sources of mosquitoes in Louisiana. The continuous dredging of the Mississippi River Gulf Outlet has created large disposal sites that have been associated with large numbers of *Aedes sollicitans* larvae. It has been estimated that approximately 20 sq miles of disposal area surface associated with the Gulf Outlet Canal alone are capable of producing *Aedes sollicitans* mosquitoes at the present time (Personal Communication, 8 January 1976, G. T. Carmichael, Division of Mosquito Control, City of New Orleans, 6601 Lakeshore Dr., New Orleans, Louisiana).

29. The remote location of many disposal sites in the state of Louisiana renders routine inspection of such sites difficult and expensive. In most areas light traps are not operated, but areas are inspected following heavy rains. The New Orleans Mosquito Control Board was the only mosquito abatement program encountered during the study that was actively engaged in the study of remote sending procedures that might be applied to locate mosquito larval habitats within dredged material disposal sites. Some aspects of this study have been published by the National Aeronautics and Space Administration (1973).

30. Lack of communication between the Corps and mosquito abatement programs was cited by some mosquito abatement personnel in Louisiana as a problem. Mosquito abatement personnel in New Orleans also stated the need to be informed of pumping schedules in order that they might better plan mosquito inspections and/or control measures. In some limited cases drainage ditches constructed within disposal sites for mosquito control are reported to have been filled with fresh dredged material. On the contrary, as noted in other sections of this report, on some occasions the pumping of fresh dredged material onto an active mosquito site can temporarily control mosquitoes (in some cases for a season dependent upon the

formation of fissured soil and other larval habitats). For example, if a choice is available regarding two disposal sites for a given disposal operation and one site offers drainage, while the second location (supporting larval mosquitoes) may be helped by the addition of fresh dredged material, then obviously the new material should be added to the latter site. It must be understood that most disposal sites will eventually develop larval habitats for mosquitoes unless water can be removed from the various larval habitats that develop during the successional cycle (see Figure 14), but in some cases the planning of pumping schedules could assist in mosquito control for short periods of time.

31. Studies regarding mosquito egg density have been conducted by the New Orleans Mosquito Control Board that indicate large numbers (more than 2000 eggs/sq ft in some cases) have been located within fissured soil. In the early 1960's major outbreaks of mosquitoes were associated with disposal sites. Again, the alternate wetting and drying of disposal sites was noted in Louisiana as the major reason for the affinity of *Aedes* mosquitoes for dredged material. As was the case in Charleston District, mosquitoes tend to develop within disposal sites approximately 9 to 14 months following the cessation of a dredged material disposal operation.

32. Other mosquito abatement programs. A number of other mosquito control districts reported by telephone and correspondence of numerous problems associated with mosquito breeding within dredged material disposal sites. Recently, major problems from disposal sites have been reported from Calcasieu Parish. Jefferson Parish considered the problem to be moderate.

Disposal site mosquitoes

33. During site visitations sponsored by both New Orleans Mosquito Control officials and the New Orleans CE District, adults of *Aedes sollicitans* were numerous and common on dikes and within Louisiana disposal sites. During a site visitation sponsored by the

New Orleans District to disposal sites located along the Mississippi River Gulf Outlet, larvae of *A. sollicitans* were collected in small numbers in these locations. The following species of mosquitoes are reported by the New Orleans Mosquito Control Board as positive collections from larval habitats with dredged material disposal sites:

a. *Aedes sollicitans*, considered the major pest species.

b. *Aedes vexans*, mainly in older locations.

c. *Anopheles crucians*, mainly in older sites with fresher water.

d. *Culex salinarius*.

e. *Psorophora columbiae*.

The following species of mosquitoes have been associated with dredged material disposal sites, but larvae have not yet been collected from a larval habitat with the sites per se:

a. *Aedes taeniorhynchus*.

b. *Anopheles quadrimaculatus*.

c. *Culex pipiens quinquefasciatus*.

Disposal area conditions

34. Engineering observations. Many of the disposal areas in the New Orleans District were observed to have purposely breached dikes that allowed for water movement. This procedure did not appear to increase erosion of dredged material (once consolidation had occurred). Dikes were also observed to be constructed primarily of marsh soils for the initial construction with subsequent dike construction restricted to material with the disposal site. As mentioned earlier, this practice creates borrow pit swales. Channelization and crossdikes are frequently employed to separate sand from finer grained materials. Sand bases were preferred in dike construction.

35. DM conditions. In almost all cases dredged material disposal sites closely resembled those of Charleston District, especially with regard to msoquito larval habitats. The DM stages proposed in

Figure 14 would appear to suit New Orleans District conditions. All larval habitats cited in Figure 15 were observed in the New Orleans District disposal areas.

36. Problem species. Unlike Florida (i.e. Jacksonville CE District), *Aedes taeniorhynchus* was not considered as a pest present in sufficient numbers to warrant control considerations. This phenomenon is probably due to the location of the city of New Orleans and the high adaptability of *Aedes sollicitans* to more than one type of larval habitat. It is interesting to note that the exact niche partition between the larval habitats of *Aedes sollicitans* and *Aedes taeniorhynchus* is not known (see Part V). More research is needed to explain how these two species are separated within dredged material disposal sites. Most of the other species associated with disposal sites were regarded as incidental varieties except under very specialized conditions. In summary, *Aedes sollicitans* was considered as the major problem and pest species developing within Louisiana disposal areas.

37. Larval conditions. Small numbers of larvae of *Aedes sollicitans* were located under algal mats within disposal sites along the Mississippi River-Gulf Outlet. These larvae would have normally been overlooked if the investigators had not previously encountered similar conditions within Charleston District. As noted in previous sections on larval ecology, unusual concentrations of algae within disposal sites should be regarded as suspect sources for mosquito larvae.

Plant specimens

38. A list of plant species that were observed and/or collected from Louisiana disposal sites is presented in Table D3. In general, trees and shrubs were scanty or absent from the sites that were visited. Most of the sites were obviously affected by frequent pumpings. The halophytic stage of plant succession was a commonly encountered sere (see Part IV), and many of the same plants that had

Table D3

Catalogue of Seed Plants Found Within Diked Dredged Material Disposal Sites in Louisiana

Herbs

Amaranthus arenicola I. M. Johnst (Amaranthaceae)
Ambrosia sp. (Asteraceae)
Aster subulatus Michaux (Asteraceae)
Cyperus sp. (Cyperaceae)
Distichlis spicata (L.) Greene (Poaceae)
Heliotropium curassavicum L. var. *curassavicum* (Boraginaceae)
Leptochola uninervia (Presl.) Hitchcock (Poaceae)
Panicum sp. (Poaceae)
Pluchea purpurascens (Swartz) DC. (Asteraceae)
Salicornia bigelovii Torrey (Chenopodiaceae)
Salicornia virginica L. (Chenopodiaceae)
Scirpus sp. (Cyperaceae)
Sesuvium maritimum (Walter) BSP. (Aizoaceae)
Spartina alterniflora Loisel (Poaceae)
Suaeda depressa (Pursh) Wats. (Chenopodiaceae)

been observed in Charleston District under similar successional conditions were also noted in Louisiana.

Norfolk District

Description

39. The Norfolk District of the Corps of Engineers had an annual maintenance dredging rate of 3.5 to 5.5 million cu yd between 1971 and 1973 (Skjei 1976). The District is unique in that a large amount of dredged material from Norfolk Harbor is placed in one large disposal site, Craney Island. The District also has a number of smaller disposal areas associated with the AIWW and other navigation projects. Because of its large size (4 sq miles), Craney Island was selected as a major disposal site for the Norfolk site visitation. In general, Norfolk District officials discussed many projects of a long-term nature that tended to require more planning and site preparation than was the case with other Corps Districts. The relatively small amount of dredged material being processed in the District perhaps allowed for more planning than was possible in some of the other larger Districts.

40. Harrison and Chisolm have reported considerable environmental opposition to many of the disposal sites. New sites were said to be especially opposed by various groups. Odors from disposal areas in the Norfolk District have been cited as a major environmental complaint. Harrison and Chisolm (1974) reported sulferous odors and anaerobic conditions could be located within the Craney Island disposal area. Turbidity was not considered to be a major environmental consideration as was the case in the Jacksonville District. Harrison and Chisolm (1974) did not report mosquitoes as an environmental concern in the Norfolk District.

Mosquito Abatement Programs

41. Virginia Bureau of Solid Waste and Vector Control. The

overall direction of mosquito control efforts in the state of Virginia is under the direction of the Bureau of Solid Waste and Vector Control. This agency coordinates the work of a number of individual mosquito control districts. The bureau was the main mosquito abatement contact during the Norfolk site visitation. The bureau's director reported that approximately seven local districts in Virginia had reported problems associated with mosquitoes and disposal sites, ranging from moderate to severe. The problem was reported to have been much greater in the past than is presently the case.

42. In general, mosquito abatement officials spoke favorably of the Craney Island disposal site. The construction of Craney Island apparently allowed a large number of smaller disposal sites to become inactive. It was also noted that Craney Island was not frequently inspected by Mosquito Control personnel, but that the average number of complaints about mosquitoes from residents was lower than had been the case in earlier years. In general, while some mosquitoes have been located within Craney Island, the problem was thought to have lessened in recent years. Favorable comments regarding the practice of impounding some water over portions of Craney Island were regarded favorably by Norfolk mosquito control officials.

43. Major problems. The most frequently cited mosquito control problem with disposal areas in Virginia concerned the blockage of marsh drainage. It should be recalled at this point that marsh drainage was also a major complaint in the Jacksonville District. Virginia personnel seemed to regard mosquito breeding in poorly drained pools near disposal area dikes as a major larval habitat (see also Figure 15, item 7). These pools were normally outside the disposal areas per se and located between dikes and natural marsh.

Disposal site mosquitoes

44. The following mosquitoes were reported to the investigators as definitely associated with dredged material disposal sites in Virginia:

a. *Aedes sollicitans*.

b. Some *Culex* spp.

Disposal area conditions

45. Craney Island. Intensive investigations were made within the Craney Island disposal site. Other limited surveys were conducted in the general vicinity around the disposal site. *Aedes sollicitans* were infrequent during the site visitation (20 August 1975). No larvae were collected, but several larval habitats were located that appeared capable of supporting *Aedes sollicitans*. Two areas were located outside the Craney Island dike that appeared capable of supporting larvae due to blocked tidal drainage. As previously mentioned, the practice of frequently adding fresh dredged material to the Craney Island site appeared to negetively affect potential mosquito populations. No dredged material was observed within Craney Island that was beyond stage DM-5, and most of the site was retained in stages DM-1, DM-2, and DM-3 (see Figure 14). It should be recalled at this point that these last three stages were not observed to be associated with larval mosquitoes during the studies in Charleston District.

46. Other sites. A number of additional sites were visited in Norfolk that had produced mosquitoes in the past. One site, known locally as "the Navy fill" or Little Bay, was of some historical interest in that it was one of the first disposal sites to be noted in the literature as a known source of mosquitoes (see also Part II, Early References). The site is no longer active as a mosquito source. Another non-Corps disposal site was known locally as the "Standard Oil Fill." This location was of interest in that sewage sludge had been added to the surface of the dredged material. This

practice had polluted the site and allowed for the development of *Culex* mosquitoes (probably *C. pipiens*). However, the familiar fissured soil habitat developed despite the addition of the sludge. While no collections were made at the site, the investigators were assured that the site had produced large numbers of *Culex* mosquitoes. This is yet another example of dredged material disposal sites producing mosquitoes that are not actually related to the proper disposal of dredged material. It is the opinion of the investigators that the practice of dumping sewage sludge should be discouraged or done only under closely supervised conditions. Another site, known locally as the Gilberton Fill, was visited as an example of an older disposal site that had formerly produced mosquitoes. The site was last pumped approximately 9 years ago. Close inspection revealed that the site could be considered in stage DM-6 (see Figure 14). When loose soil was brushed from the surface, fissured soil could still be detected. The site presently produces mosquitoes only under heavy rainfall conditions.

47. The proposed DM stages (Figure 14) appeared to be valid for all observed Virginia conditions. All larval habitats noted in Figure 15 except one (depression habitats) were located within the various Virginia disposal sites. Resistance to pesticides was not cited as a major mosquito control problem.

Plant specimens

48. The major plant species that dominated most Virginia disposal sites was *Phragmites communis*. The frequent pumping of Craney Island appeared to be kept at the succulent halophyte stage (see also Appendix E). In those areas where the dredged material had been allowed to form soil fissures (DM-3, DM-4, and DM-5 stages), *Salicornia* spp. was the most common pioneer plant. On the retaining dikes, where better drainage may have changed soil conditions, *Phragmites communis* was observed to grow in dense stands. As previously noted this plant is regarded as a pest species in many

states, especially New Jersey. *Phragmites* was also observed to invade fissured soil where *Salicornia* was previously established. This observation suggests that *Salicornia* may modify dredged material and enable *Phragmites* to develop. A list of plant species collected and/or observed as common within Virginia disposal sites is presented in Table D4.

Philadelphia District

Description

49. The Philadelphia CE District maintains a number of confined dredged material disposal sites ranging in size from 150 to 1200 acres. A number of large disposal areas are located along the Delaware River and the vicinity of Cape May, New Jersey. Harrison and Chisolm (1974) reported that the Philadelphia District dredges approximately 11.4 million cu yd into confined disposal sites. This report also noted that mosquitoes were regarded as an environmental problem along the Chesapeake and Delaware Canal. Other environmental problems cited were dike instability and noise from the operation of motorcycles within disposal areas. It should be recalled that the operation of motorcycles within disposal sites in the Galveston District led to the establishment of a larval habitat for *Culiseta inornata*.

50. The Philadephia CE District maintains an excellent mosquito control program along the Chesapeake and Delaware Canal (C and D Canal). This program was unique among the Corps Districts studied. The C and D Canal mosquito control program depends heavily upon surveillance of adult mosquitoes by light traps along the canal. The mosquitoes are collected and indentified by U. S. Army entomologists. This mosquito control effort is limited to the C and D Canal and does not extend to other parts of the District.

Table D4

Catalogue of Seed Plants Found Within Craney Island Diked Disposal Site, Norfolk, Va.

Herbs

Amaranthus hybridus L. (Amaranthaceae)
Ambrosia sp. (Asteraceae)
Cakile edentula (Bigelow) Hooker (Brassicaceae)
Chenopodium album L. (Chenopodiaceae)
Chenopodium ambrosioides L. (Chenopodiaceae)
Cycloloma artripliciflorium (Sprengel) Counter (Chenopodiaceae)
Cyperus odoratus L. (Cyperaceae)
Diaitaria sanguinalis (L.) Scopoli (Poaceae)
Echinochola crusgalli (L.) Beauvois (Poaceae)
Eragrostis pectinacea (Michx.) Nees (Poaceae)
Erigeron canadensis L. (Asteraceae)
Eupatorium capillifolium (Lam.) Small (Asteraceae)
Euphorbia supina Raf. (Euphorbiaceae)
Lepidium virginicum L. (Brassicaceae)
Leptochola fascicularis (Lam.) Gray (Poaceae)
Melilotus alba Desr. (Fabaceae)
Oenothera rhombipetala Nuttall ex. T. & G. (Onagraceae)
Phragmites communis Trinius (Poaceae)
Phytolacca americana L. (Phytolaccaceae)
Polygonum pensylvanicum L. (Polygonaceae)
Salicornia europaea L. (Chenopodiaceae)
Salsola kali L. (Chenopodiaceae)
Setaria geniculata (Lam.) Beauvois (Poaceae)
Solidago sp. (Asteraceae)
Sonchus oleraceus L. (Asteraceae)
Spergularia marina Grisebach (Caryophyllaceae)
Strophostyles helvola L. Ell. (Fabaceae)
Xanthium strumarium L. (Asteraceae)

Shrubs

Baccharis halimifolia L. (Asteraceae)
Iva frutescens L. (Asteraceae)
Parthenocissus quinquefola (L.) Planchon (Vitaceae)
Rhus copallina L. (Anacardiaceae)

Trees

Morus alba L. (Moraceae)

Mosquito abatement programs

51. The following mosquito abatement programs were contacted during site visitations in the Philadelphia District:

a. City of Philadelphia, Environmental Health Service.

b. Camden County Mosquito Extermination Comm. (New Jersey).

c. Bucks County Department of Health (Pennsylvania).

d. State of Delaware, Division of Fish and Wildlife, Mosquito Control Section (Delaware).

e. Cape May County Mosquito Control Commission (New Jersey).

f. Burlington County Mosquito Control Commission.

g. U. S. Army Corps of Engineers, Philadelphia District, C and D Canal Mosquito Control.

52. Due to the large number of different and varied habitats that were sampled during the Philadephia District site visitations, data regarding mosquito fauna and disposal area conditions will be presented separately in the sections that follow. In some cases the mosquito fauna will overlap other areas, while in others mosquito species were determined to be very specific.

53. City of Philadelphia. Mosquito control in the city of Philadelphia, Pennsylvania, is under the direction of the Environmental Health Service. This agency reported that disposal areas in the general vicinity of the city were sources of *Culex pipiens*. Some sites that were common sources of mosquitoes were also reported to be polluted. The city maintains an active program of inspection and control within the disposal sites. Mosquito problems were nonexistent on those disposal sites whose dredged material contained a large concentration of sand. Many of the disposal areas were reported to have been greater problems in the past than is presently the case.

54. Camden County Mosquito Extermination Comm. The control of mosquitoes in Camden County, New Jersey, is a county agency task. This agency reports that *Culex pipiens*, *Culex salinarius*, *Culex*

restuans, *Aedes trivittatus*, *Aedes vexans*, *Anopholes bradleyi*, and *Culiseta melanura* have been collected from light traps located near dredged material disposal sites. No larval collections were reported by this agency from disposal sites. Camden County officials did not regard dredged material disposal sites to be a major source of mosquitoes. Sand mining (previously illustrated as Figure D1) was cited as a frequent source of mosquito larvae within older disposal sites.

55. Bucks County Department of Health. Bucks County in Pennsylvania has charged the Department of Health, a county agency, with mosquito control. Disposal sites in this county were not operated by the Corps of Engineers, but were of interest as they represent another type of mosquito control problem. One disposal site, known locally as the "Hidden Valley Landfill." was reported to be severely polluted by sewage. The placement of sewage on the surface of this site has been associated with the presence of *Culex pipiens*, *Aedes vexans*, and *Anopheles punctipennis* as larvae. As was the case in Virginia, the disposal of sewage within dredged material disposal sites tends to greatly compound mosquito control efforts.

56. Delaware Mosquito Control. Mosquito control in Delaware is under the Mosquito Control Section of the state Division of Fish and Wildlife. This agency reports that mosquitoes are frequently associated with fissured soil habitats in Delaware. Mosquitoes reported from disposal sites in Delaware include: *Aedes cantator*, *Aedes sollicitans*, *Aedes vexans*, *Anopheles punctipennis*, *Anopheles quadrimaculatus*, and *Culex salinarius*. The *Aedes* spp. were regarded as the more serious pests. Larvicidal organophosphate pesticides are used as a mosquito control measure.

57. Cape May Mosquito Control Comm. The Cape May Mosquito Control Commission is the county agency charged with mosquito control in parts of southern New Jersey. This agency maintains both control and surveillance operations within dredged material disposal sites. Species of mosquitoes that are reported from Cape May disposal sites

include: *Culex pipiens*, *Culex salinarius*, *Aedes sollicitans*, and *Anopheles crucians*. Mosquito control is especially important in this county whose income is derived mainly from tourism. Larval control measures are effected through the use of organophosphate pesticides. No resistance to these compounds has been reported within disposal sites. Mosquitoes from disposal sites were considered as major environmental problems under certain conditions. In some areas, it was estimated that 40 percent of the mosquitoes were derived from disposal sites.

58. Burlington County Mosquito Control Comm. In another part of New Jersey, the Burlington County Mosquito Control Commission attempts to control mosquitoes by a variety of techniques. This county maintains an active program of mosquito control and surveillance within disposal sites. Mosquito species reported to develop within disposal sites include: *Aedes vexans*, *Aedes sollicitans*, *Aedes cantator*, and *Culex pipiens*. Larvicidal oils and organophosphate pesticides are used to control mosquitoes developing within disposal areas. The Commission is also concerned with the development of physical control measures for mosquitoes. Contact with the Philadelphia District by both the Burlington and Cape May Mosquito Control officials was termed frequent.

59. C and D Canal Mosquito Control. The only mosquito control efforts sponsored by the Corps of Engineers per se encountered during this study were observed in Delaware. This program is especially commendable for the use of light trap surveillance techniques and the frequent identification of mosquitoes. This agency reported that *Phragmites* was a problem plant species that frequently hindered mosquito control. The Philadelphia District Field Office near the C and D Canal has maintained records of mosquitoes since the mosquito control efforts began. Common species collected from light traps located near disposal sites included: *Culex salinarius*, *Aedes cantator*, *Aedes sollicitans*, *Aedes atlanticus*, *Aedes vexans*, *Anopheles crucians*,

and *Anopheles quadrimaculatus*.

Disposal area conditions

60. Disposal area conditions were highly variable in the Philadelphia District. The most striking contrast with inland disposal sites was the widespread appearance of pure stands of *Phragmites communis*. An example of ideal habitat conditions for larval mosquitoes within a disposal site along the C and D Canal is shown in Figure D3. While some mosquito abatement programs did not appear to actively inspect *Phragmites* covered habitats, it was assumed that most of these areas would support larval mosquitoes if rainwater was available. Local residents living near many *Phragmites* covered disposal sites regarded them as fire hazards in the fall and winter.

61. A number of disposal sites in the Philadelphia CE District had higher elevations than had previously been encountered. For example, in Cape May County two large disposal sites had cumulative elevations that exceeded 35 ft. These areas were reported to drain well in most cases and mosquitoes were not common on the site. The site had supported mosquito larvae when its elevation was lower. Local officials reported that mosquito production had actually tended to decline as the dredged material became higher (due to better internal drainage). Additional studies are needed on such sites that have a history of producing mosquitoes, but no longer support larvae.

62. The previous criteria for DM stages of larval habitats would appear to apply to New Jersey and Pennsylvania. Larval habitats that were postulated in the Charleston CE District studies were commonly observed during the site visitation to the Philadelphia CE District. No mosquitoes were collected due to the prevailing winter conditions (December 1975).

Plant species

63. No plant collections were made in the Philadelphia District due to prevailing winter conditions.

Figure D3

Mosquito Habitat Dominated by the Common Reed, *Phragmites communis*, in Philadelphia CE District

San Francisco and Sacramento Districts

Description

64. Two Corps of Engineers Districts, San Francisco and Sacramento, were visited in California. Since both the disposal sites and mosquito breeding conditions in the two Districts were similar, the California sites will be discussed concurrently. The Sacramento CE District disposal sites that were visited were concerned with maintaining shipping channels from Sacramento to the San Francisco Bay area. The Sacramento CE District is fortunate in that much of its dredged material consists of sand. District personnel reported that many disposal sites were frequently used as sources of sand. Harrison and Chisolm (1974) reported that the District dredged and confines approximately 756,000 cu yd of dredged material each year in disposal sites. Mosquito breeding problems have been reported in the past (Harrison and Chisolm 1974), but seemed to have been reduced in recent years due to the District's policy of reducing ponding time. These authors further reported that motorcycle operations and the presence of unauthorized personnel on disposal sites were additional environmental concerns.

65. The San Francisco CE District is reported by Skjei (1976) to have dredged between 4 and 5 million cu yd per year of material during the period 1971 to 1973. The District is active in environmental research and is presently completing its own dredged material disposal studies for the San Francisco Bay Area and estuary. A few large projects were discussed during site visitations that would require the creation of new dredged material disposal sites if approved. Both Districts cooperate closely and a number of joint operations were cited during interviews. Mosquitoes resulting from dredged material disposal sites were not regarded as an environmental problem by any of the Corps personnel interviewed during the visit.

Mosquito abatement programs

66. The following California mosquito abatement programs and government agencies were contacted during site visitations to the San Francisco and Sacramento CE Districts.

a. Alameda Mosquito Abatement District.

b. Solano County Mosquito Abatement District.

c. Marin-Sonoma Mosquito Abatement District.

d. San Joaquin Mosquito Abatement District.

e. Contra Costa Mosquito Abatement District.

f. Sacramento-Yolo County Mosquito Abatement District.

g. California State Department of Health and Vector Control Section.

In most cases, typical disposal area habitats for mosquitoes were encountered. For this reason, most of the California data will be presented concurrently.

67. In general most mosquito abatement districts encountered during this study did not regard dredged material disposal sites to be major mosquito sources during the study period. In many cases disposal sites were cited as producing mosquitoes in the past. This observation was not due to the lack of disposal site habitats, but to the climate of California that does not allow significant rainfall during much of the summer months. Mosquitoes resulting from faulty irrigation practices and runoff waters were regarded as more likely sources of larvae than disposal sites. However, all abatement personnel regarded disposal sites as potential sources of mosquitoes that should be monitored. There were some exceptions to this general rule which will be considered.

Disposal site mosquitoes

68. The following mosquitoes were reported to utilize dredged material disposal sites in the California Districts that were visited:

a. *Aedes dorsalis*, one of two principal pest species associated with disposal sites.

b. *Aedes squamiger*, a univoltine winter salt marsh mosquito that was cited as a significant pest under special conditions.

c. *Culiseta inornata*, (see also notes on this species from Galveston site visitations).

d. *Culex tarsalis*, a vector of encephalitis.

The first two species were considered important pests under specialized weather conditions. The latter two species were not as important as pests, but significant breeding of *Culex tarsalis* (because of its vector potential) should always be monitored. It should be stated that disposal sites were not regarded as the major larval habitats of *C. tarsalis*; however, they are more frequently associated with a wide variety of rural habitats, including roadside ditches, artificial containers, and other pools containing either clear or polluted water. Gjullin and Eddy (1972) reported that the species was the most important known vector of western equine encephalitis (WEE) and St. Louis encephalitis (SLE).

Disposal area conditions

69. In Alameda County, disposal sites were located that exhibited fissured soil patterns similar to those of other Districts with one notable exception. The soil fissures were considerably deeper with average depths ranging to 35 in or more. Two disposal sites were visited that had produced mosquitoes in the past, but both sites were presently under DM-6 conditions. Alameda County reports good success in mosquito control using disk harrows to break up dredged material. The usual procedure on small disposal sites is to use a No. 25 disk harrow (i.e. 25 in. solid disks) pulled by a small bulldozer. One additional mosquito habitat was encountered that was associated with marsh restoration projects. In some cases dredged material has been used in an attempt to reestablish marsh conditions. These marsh restoration projects are not dredged material disposal sites in the usual sense of the term, but they have created mosquito

habitats in some cases in California. The Alameda County Mosquito Abatement District has offered a number of suggestions that are designed to enable marsh restoration to occur without the threat of additional mosquitoes. (Personal Communication, 30 March 1976, Fred C. Roberts, Manager of Alameda County Mosquito Abatement District, 3024 East Seventh Street, Oakland, California, 94601). Among the more prominent of these suggestions are the following:

a. All fissured soil in the proposed marsh should be disked prior to the breaching of levees.

b. Plans for long-term maintenance should include the cleaning of all sloughs, connecting ditches, and lateral canals.

c. Plans for water circulation should be formulated before the marsh restoration is initiated.

d. Plans should be made for the construction of some small ditches to connect small, isolated pools that may develop and support mosquito larvae.

e. Plans for a program of mosquito inspection.

Within disposal sites of the normal variety, *Aedes squamiger* was regarded as the major pest species in this district.

70. Disposal sites in Solano, San Joaquin, and Sacramento counties were similar. A successful mosquito control program implemented by the Corps of Engineers within one disposal site was of special interest. (Personal Communication, 16 October 1975, Embree G. Mesger, Entomologist, Solano County Mosquito Abatement District, P. O. Box 304, Suisun, California, 94585). This site, known locally as the Suisun Slough disposal area, received dredged material a number of years ago. Following consolidation of the dredged material, the District (Corps) disked the area and later provided small (18 in. by 18 in.) surface drains that removed water from the site. The general opinion among mosquito personnel from these three counties was that disposal sites were a minor problem, but that the potential for mosquitoes under certain environmental conditions was ever present. The

best procedure for permanent control was generally agreed to be surface disking. Sand mining was cited as a source of mosquito larvae within dredged material disposal sites in San Joaquin County. This problem has been previously discussed in site visitation discussions from the Galveston and Philadelphia Districts (see also Figure D1).

71. Extensive dredged material disposal areas that were more reminiscent of east coast sites were located in Contra Costa County. Most of these disposal sites were near Martinez, California. The appearance of DM-4 conditions (i.e. mature fissures) within a typical west coast disposal site is shown in Figure D4. The principal difference between these sites and east coast areas is the depth of the soil fissures.

72. Conversations with mosquito abatement personnel at Marin-Sonoma district revealed an increased focus on physical control of mosquitoes associated with disposal sites. Disking was the primary physical control measure employed. It should be noted, however, that most of the disposal sites that were treated in this manner were less than 50 acres in size. Other local dredging projects (non-Corps) were visited on two occasions. These disposal sites were essentially the same as east coast projects in that they were generally small and concerned with short-term projects.

73. The California State Department of Health, Vector Control Section, is the primary state agency concerned with the overall management of the various state mosquito abatement districts. Conversations with personnel from this agency were interesting in that they gave a state-wide perspective to the prevalence of dredged material disposal areas. In general, the agency noted that the potential for disposal sites becoming mosquito larval habitats were definitely present in California and that the problem had occurred in the past. The agency indicated that it encouraged the surveillance of older disposal sites for the presence of any variety of larvae, especially *Culex tarsalis*. The species was known to occur

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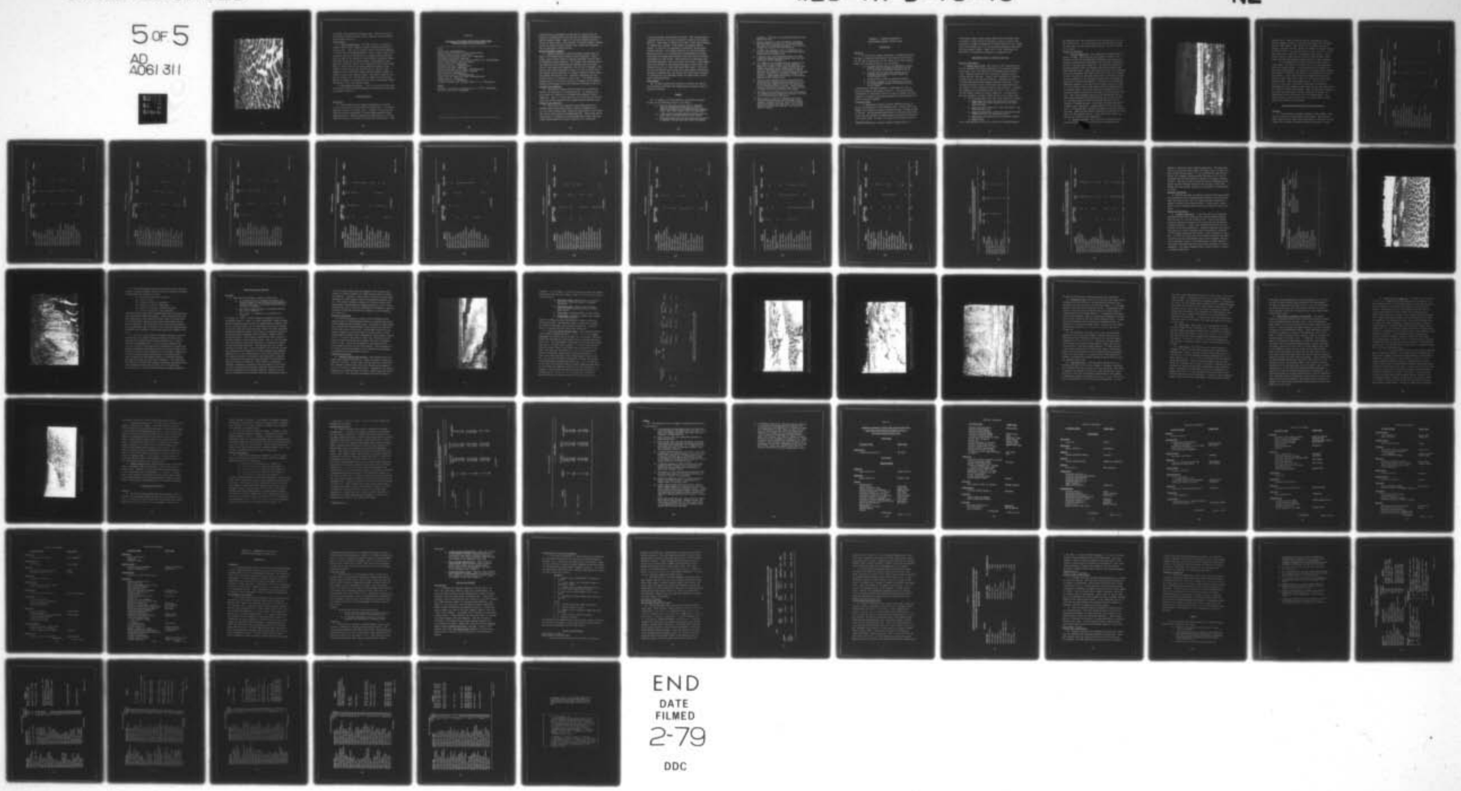

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Figure D4
Swale and Hummock Habitats under DM-4 (Mature Fissures)
Conditions near Martinez, California

in seepage sites around older disposal areas. The Vector Control Section also reported frequent contacts with both the San Francisco and Sacramento Districts.

Plant species

74. General observations. The scant rainfall of California summers effects drastic changes in plant successional patterns on the west coast. This lack of rainfall tends to retard the leaching of soluble salts from dredged material. This, in turn, tends to retard plant succession and diversity. In general the most obvious effect is that of the retention of the halophytic stage much longer than would be the case on the east coast. Older disposal sites under DM-5 conditions tended to have grasses and other similar plant species. These sites did not have as many mixed shrubs as were commonly observed on the east and gulf coasts. The DM-5 stage appeared to last considerably longer than was commonly observed or reported from the east and gulf coasts. With these exceptions, the earlier concepts (i.e., the DM stages of Figure 14 and the larval habitats of Figure 15) introduced in this report would appear reasonably valid for west coast disposal sites.

75. Plant species collected. A list of the various plants that were observed and/or collected during the California site visitations is presented in Table D5.

Savannah District

Description

76. The Savannah District dredges approximately 6.5 million cu yd of material per year (Harrison and Chisolm 1974). The District maintains a variety of disposal sites. A number of these sites are large and receive large amounts of fresh dredged material during a pumping operation. Mosquito problems have been reported as an environmental concern by the District (Harrison and Chisolm 1974). Other

Table D5

Catalogue of Seed Plants Found Within Diked Dredged Material Disposal Sites in California

Herbs

Atriplex spp. (Chenopodiaceae)
Brassica geniculata (Desf.) J. Ball (Brassicaceae)
Centaurea solstitialis L. (Asteraceae)
Epilobium paniculatum Nutt. ex T. & G. (Onagraceae)
Foeniculum vulgare Mill. (Apiaceae)
Heliotropium curassavicum var. *oculatum* (Heller) Jnt. (Boraginaceae)
Jaumea carnosa (Less.) Gray (Asteraceae)
Lactuca serriola L. (Asteraceae)
Lepidium latifolium L. (Brassicaceae)
Melitotus albus Desr. (Fabaceae)
Plantago major var. *pilgeri* Domin. (Plantaginaceae)
Polypogon monspeliensis (L.) Desf. (Poaceae)
Rumex crispus L. (Polygonaceae)
Salicornia virginica L. (Chenopodiaceae)
Salsola kali var. *tenuifolia* Tausch (Chenopodiaceae)
Sonchus asper L. (Asteraceae)
Sonchus oleraceus L. (Asteraceae)
Xanthium strumarium var. *canadense* (Mill.) T. & G. (Asteraceae)

Shrubs

Baccharis pilularis var. *consanguinea* DC. C. B. Wolf (Asteraceae)
Nicotiana glauca Grah. (Solanaceae)

than mosquitoes, environmental issues have not surfaced over the disposal of dredged material near the Port of Savannah and along the AIWW in northern Georgia. Many of the largest disposal sites are located in Jasper County, South Carolina. Urbanized Savannah, Georgia (across the Savannah River), however, must contend with mosquitoes that are generated in South Carolina.

Mosquito abatement programs

77. Savannah maintains a mosquito abatement program under the aegis of the Chatham County Mosquito Control Commission. Jasper County, South Carolina (which is sparsely populated), does not have an organized mosquito commission. The Chatham County program reports that mosquitoes from dredged material disposal areas are a major source of salt marsh *Aedes* mosquitoes for the city of Savannah. This district has placed considerable stress on the use of larval reduction methods (source reduction) as a means of mosquito control within both marshes and disposal sites. Excellent cooperation with the Savannah Dsitrict is reported in recent years. The Chatham County program was one of the earlier districts to suggest cource reduction methods within disposal sites (see literature citations in Part II).

Disposal site mosquitoes

78. The mosquito species previously reported for Charleston Dsitrict are applicable for Savannah District. No changes in mosquito fauna were reported by the Chatham County Mosquito Control Commission. *Aedes sollicitans* and *Aedes taeniorhynchus* are the principal pest species associated with dredged material disposal sites.

Disposal area conditions

79. Almost all of the previously cited characteristics of disposal sites in Charleston District apply to Savannah District. In a few older disposal areas, dikes were constructed as river levees that did not fully enclose the dredged material. These sites had the unique effect of creating a crescent-shaped band of marsh edge vegetation characterized by *Baccharis halimifolia, Iva frutescens,*

Juncus roemerianus, and *Borrichia frutescens*. This crescent band of vegetation was due to the rise in elevation created by the dredged material. These types of disposal sites tend to have reduced amounts of fissured soil habitats. This decrease in mosquito habitat, however, is offset by the appearance of additional "natural marsh mosquito habitats." The original habitats for larval salt marsh mosquitoes prior to the construction of dredged material disposal sites were the extreme upper reaches of the marsh that were flooded infrequently by tidal action. These habitats were associated with marsh edge vegetation, such as the plants cited above. When dredged material is allowed to flow unchecked through a natural marsh, the long-term effect is to create additional "marsh edge." Such sites may not have fissured soil and may not produce mosquito populations as large as disposal areas, but natural salt marsh mosquito habitats will develop near the interphase between the marsh proper and the newly created marsh edge.

<u>Plant species</u>

80. No plant species were observed or collected that had not been previously associated with dredged material disposal sites in Charleston District.

<u>Summary</u>

81. In summary, the following major observations were made during the site visitation section of the study.

- <u>a</u>. Prior to this study only one Corps of Engineers District (Buffalo) had conducted any studies on mosquitoes associated with dredged material disposal sites. This report (Berlin 1974) was unpublished.
- <u>b</u>. A wide variety of dredged material disposal sites in eight Corps of Engineer Districts were visited.
- <u>c</u>. Conversation and interviews were held with both Corps of Engineer officials and local mosquito abatement

personnel. Frequently, joint meetings between the two groups were held.

d. With the exception of the Philadelphia, Sacramento, and San Francisco CE Districts, the mosquito fauna was found to be remarkably consistent. A few species changes were noted in the above Dsitricts.

e. In almost all locations, *Aedes*, or floodwater mosquitoes, were determined to be the major pest species associated with disposal areas.

f. A complete list of all mosquitoes known to be associated with dredged material disposal sites has been previously cited in Appendix C.

g. In a number of cases dredged material disposal sites were cited as being sources of larval mosquitoes. Inspection of some of these sites revealed that later surface alterations of the dredged material had resulted in the development of new mosquito habitats that were not related to the proper disposal of dredged material. Common surface alterations included the practice of sand mining and operation of recreational vehicles within disposal sites.

h. Mosquito larval habitats that were associated with the disposal of dredged material included all of the previously known habitats that had been identified in the Charleston District studies. Larval habitats that were identified in Figure 15 were found to exist in almost all the Districts that were visited.

i. The disposal successional patterns that were proposed for dredged material changes were observed to be valid in all Districts except California.

j. Other practices that were frequently mentioned as contributing to mosquitoes were blockage of tidal drainage, seepage, borrow pit swales, and standing water near disposal area sump sites. All of these habitats were previously defined in the Charleston District studies.

APPENDIX E: VEGETATION ANALYSIS OF DIKED DREDGED MATERIAL DISPOSAL SITES

Introduction

Objectives

1. In view of the economic importance of dredging activities, the need to understand plant-mosquito successional relationships, and the lack of baseline data on the vegetation of diked disposal areas, the following objectives were established:

   a. To gather baseline data on the vegetation of diked disposal sites in the Charleston District of the U. S. Army Corps of Engineers (Figures 4 and 5).

   b. To gather data on those plant species that are frequently associated with larval mosquitoes within disposal areas.

   c. To gather data on plant successional patterns.

   d. To obtain estimates of the standing crop of some of the more common disposal site plants that occur in pure stands.

In many mosquito abatement programs, a large amount of time is devoted to mosquito surveillance activities. Any mosquito-plant relationships or observations that can be used to enhance the effectiveness of a mosquito surveillance program will greatly benefit the cause of mosquito abatement.

Literature review

2. A computerized literature search* revealed a paucity of data on the vegetation of diked disposal areas. Carlson (1972) and Beaman (1973) conducted extensive botanical surveys of dredge islands in Florida. The term dredge island refers to those land masses that result from the disposal of dredged material in areas that previously were natural areas. No dikes are constructed for these operations.

*Technical Information Services, Research Triangle Park, N. C.

These dredge islands, unlike diked dredged material disposal sites, are subject to tidal action and frequently return to typical marsh conditions or assume the appearance of a marsh hummock island. Windom (1972) has recorded some of the physiochemical parameters associated with these dredge islands. Camen, et al. (1974) investigated the possibility of revegetation techniques on dredged material.

Vegetational Survey: Charleston District

Materials and methods

3. Habitat descriptions This portion of the vegetational survey was concerned with habitat preferences of the various herbaceous seed plants, trees, and woody shrubs in dredged material disposal sites. Numerous field trips were conducted to disposal sites of varying ages and locations. Figures 4 and 5 indicate the locations of these areas in the Charleston District. Specimens were also collected and pressed using standard herbarium techniques. Voucher specimens from this section of the project have been deposited in the herbaria of The Citadel and Louisiana Tech University. Sampling was conducted over an 18-month period (July 1975 to Dec. 1976) to include temporal changes in species composition. No quantitative data were obtained. Listing of plant species is by presence only.

4. The following habitat types were established for the survey:

   a. Sandy areas (including sand mounds around discharge pipes, sand bars within disposal areas, and wind-deposited sand).

   b. Silt (including fissured soil, bare mud deposits, and wind-deposited silt).

   c. Dikes (including dikes constructed from natural marsh, dredged material, and imported materials).

   d. Waste areas (including natural and man-made islands).

   e. Aquatic sites.

Two of these habitats (a and b) are derived from dredged material;

the remaining three are associated with the construction of the disposal areas per se. Since the latter group may frequently provide the seed source for the dredged material group, they were included in the survey.

Results and discussion

5. Habitat composition. Silt comprised the largest habitat in terms of acreage. Sandy habitats were normally confined to the immediate area of the discharge pipe, although in some sites with multiple discharge points this habitat type comprised a substantial portion of the total area (Figure E1). The greatest elevation and drainage gradients within the disposal areas were invariably near these discharge points. While often the first areas to be colonized, these sites frequently lost plant species due to the rapid drainage of water from the site during the dryer parts of the growing season. (See also Appendix F for a discussion of the value of nonvegetated sandy areas to certain bird species). The waste areas outside and immediately adjacent to the dikes of the disposal areas were found to be the sources of many of the plants that later appeared within the disposal areas. These waste areas were frequently found to be constructed and/or used prior to the onset of a given dredging operation. Dikes were frequently observed to be multilayered with the bottom layer frequently derived from natural marsh substrate, but all subsequent layers were derived from the disposal areas and consisted of dredged material. Dike height frequently appeared to influence plant propagation. Aquatic habitats varied from small pools to large ponds that resulted from improper placement of drainage weirs. These habitats varied in salinity from brackish to fresh water (in older disposal sites). In the tables that follow, no distinction is made in these conditions.

6. Species collected. Table E1 lists the herbaceous seed plants by habita[illegible]ference associated with dredged material

Figure E1

Sandy Habitat near Discharge Site within a Dredged Material Disposal Site near McClellanville, South Carolina disposal areas. Table E2 lists the habitat preferences of tree species frequently found near disposal areas; while Table E3 enumerates the woody shrubs. Many species were collected, as might be expected, from more than one habitat (see numbers of multiple listing in Tables E1-E3). A few species, such as *Aster pilosus* var. *pilosus* were found to be restricted to one habitat (sandy areas). A much greater variety of plant life was collected from the dikes, waste areas, and older silt habitats than the aquatic or sandy locations.

7. Of the herbaceous seed plants, 81 species were found in silty areas; 77 on dikes; 65 in waste areas; 35 in sand substrates; and 9 were aquatic species. It was observed that 14 species occupied four of the habitats. An additional 14 occupied three locations, and a total of 39 species were found to be associated with at least two habitats. Of the trees located on dredged material disposal areas, the dikes were found to support 8 species; the waste areas and silt areas, 7 each; and dredged sand, 2. Only *Juniperus virginiana* (red cedar), frequently encountered, was capable of utilizing all of the habitats except aquatic areas. Five tree species were found to utilize three habitats. When the habitat preferences of the shrubs were considered, the dikes supported 18 species; the waste areas 17; the silt areas 12; and the dredged sand 6. Ten species shared at least two habitats, six utilized three, and two species were found to use four areas.

Plant Species Associated With Larval Mosquitoes

Rationale

8. In most mosquito abatement programs, a large number of manhours are devoted to larval habitat surveillance. Under natural marsh conditions some plants have become known as "indicator species" because their presence frequently indicates the presence of water

Table E1

Habitat Preference of Herbaceous Seed Plants Associated With Diked Dredged Material Disposal Sites in Coastal South Carolina

	Disposal Area Habitats				
	Dredged Material				
Species	Sand	Silt	Dike	Waste Area	Aquatic
Abutilon theophrastii			x		
Acalypha gracilens				x	
Agalinis fasiculata			x	x	
Alternanthera philoxeroides			x		
Amaranthus cannabinus		x	x	x	
Amaranthus retroflexus		x			
Ambrosia artemisiifolis			x	x	
Andropogon sp.	x	x			
Arundo donax			x		
Asparagus officinalis				x	
Aster exilis		x	x		
Aster pilosus var. *pilosus*	x				
Aster subulatus		x			
Aster tenuifolius		x	x		

(continued)

(Sheet 1 of 10)

Table E1 (continued)

	Disposal Area Habitats				
	Dredged Material				
Species	Sand	Silt	Dike	Waste Area	Aquatic
Atriplex patula	x	x	x	x	
Bacopa monneri					x
Batis maritima		x	x		
Bidens cernua		x			
Bromus catharticus			x		
Bulbostylis barbata			x		
Calystegia sepium		x	x	x	
Carduus sp.			x		
Cassia obtusifolia		x			
Chaerophyllum tainturieri			x	x	
Chenopodium album		x	x	x	
Chenopodium ambrosioides		x	x		
Chenopodium desiccatum var. *leptophylloides*			x	x	
Chenopodium standleyanum		x	x		
Cladium jamaicense		x			x
Cleome gynandra	x	x			

(continued)

(Sheet 2 of 10)

Table E1 (continued)

	Disposal Area Habitats				
	Dredged Material				
Species	Sand	Silt	Dike	Waste Area	Aquatic
Commilina diffusa		x			
Crotalaria spectabilis		x			
Croton punctatus	x			x	
Cyperus erythrorhizos		x			
Cyperus polystachyos var. *texensis*		x			
Descurainia pinnata			x		
Dioda virginiana			x		
Digitaria ischaemum var. *ischaemum*	x	x	x	x	
Digitaria sanguinalis	x	x	x	x	
Distichlis spicata		x		x	x
Duchesnea indica			x		
Echinochloa crusgalli			x		
Eclipta alba		x			
Eleocharis parvula		x			x
Eleusine indica		x			
Eragrostis curvula				x	

(continued)

(Sheet 3 of 10)

Table E1 (continued)

	Disposal Area Habitats				
	Dredged Material				
Species	Sand	Silt	Dike	Waste Area	Aquatic
Erechtites hieracifolia			x		
Erigeron canadensis	x		x		
Erigeron strigosus	x				
Eupatorium capillifolium	x	x	x	x	
Eupatorium compositifolium		x	x		
Eupatorium serotinum		x	x		
Euphorbia ammannioides			x		
Euphorbia maculata			x		
Fimbristylis dichotoma		x			
Fimbristylis spadicea			x	x	
Foeniculum vulgare				x	
Galium sp.		x			
Gaura angustifolia				x	
Geranium carolinianum		x		x	
Glottidium vesicarium	x	x	x	x	
Gnaphalium purpureum	x				

(continued)

(Sheet 4 of 10)

Table E1 (continued)

	Disposal Area Habitats				
	Dredged Material				
Species	Sand	Silt	Dike	Waste Area	Aquatic
Gnaphalium obtusifoilum	x		x	x	
Helenium amarum	x	x	x		
Heliotropium curassavicum		x	x		
Heterotheca subaxillaris	x	x	x	x	
Hydrocotyle bonariensis		x	x	x	
Ipomoea sagittata				x	
Iresine rhizomatosa				x	
Iva annua				x	
Juncus acuminatus Michaux	x				
Juncus roemerianus		x		x	
Kosteletsyka virginica				x	
Lactuca scariola		x	x		
Lepidium virginicum		x	x	x	
Leptochloa uninervia		x	x		
Limonium sp.		x		x	
Linaria canadensis	x				
Lippia nodiflora	x				

(continued)

(Sheet 5 of 10)

Table E1 (continued)

Species	Dredged Material Sand	Dredged Material Silt	Disposal Area Habitats Dike	Disposal Area Habitats Waste Area	Disposal Area Habitats Aquatic
Lolium multiflorum			x	x	
Medicago lupulina		x			
Melica mutica				x	
Melilotus alba			x		
Melilotus indica	x	x	x	x	
Melothria pendula			x	x	
Modiola caroliniana				x	
Muhlenbergia capillaris	x			x	
Oenothera biennis				x	
Oenothera drummondii				x	
Oenothera rhombipetala	x			x	
Opuntia compressa	x				
Opuntia drummondii	x				
Oxalis sp.			x		
Panicum amarum			x		
Panicum sp.				x	

(continued)

(Sheet 6 of 10)

Table E1 (continued)

Species	Dredged Material Sand	Dredged Material Silt	Dike	Waste Areas	Aquatic
	Disposal Area Habitats				
Paspalum dilatatum			x		
Paspalum praecox		x			
Paspalum urvillei		x			
Passiflora incarnata		x		x	
Phalaris caroliniana			x	x	
Phragmites communis	x	x	x		
Physalis angulata			x	x	
Physalis viscosa var. *maritima*				x	
Phytolaca americana	x	x	x	x	
Pluchea purpureascens		x	x		
Polygonum arifolium		x			
Polygonum hydropiperoides			x		
Polygonum pennsylvanicum		x	x		
Polygonum persicaria		x			
Polygonum punctatum		x			
Polygonum monspeliensis		x		x	

(continued)

(Sheet 7 of 10)

Table E1 (continued)

Species	Dredged Material Sand	Dredged Material Silt	Disposal Area Habitats Dike	Disposal Area Habitats Waste Area	Disposal Area Habitats Aquatic
Polypremum procumbens				x	
Portulaca olerecea			x		
Ptilimnium capillaceum		x	x		
Pyrrhopappus carolinianus			x		
Richardia scabra		x			
Rumex crispus		x			
Rumex verticulatus		x			
Ruppia maritima					x
Salicornia bigelovii		x	x	x	
Salicornia europaea		x	x		
Salicornia virginica		x			
Salsola kali		x			
Samolus parviflorus		x			
Scirpus acutus					x
Scirpus americanus			x		
Scirpus robustus		x		x	x
Sesuvium maritima		x			

(continued)

(Sheet 8 of 10)

Table E1 (continued)

Species	Disposal Area Habitats: Dredged Material Sand	Dredged Material Silt	Dike	Waste Area	Aquatic
Sesuvium portulacastrum	x				
Setaria magna	x	x	x		
Setaria sp.	x			x	
Sida rhombiflora		x			
Silene antirrhina forma apetala	x				
Solanum americana			x	x	
Solanum carolinense			x		
Solanum gracile			x		
Solidago altissima	x	x	x	x	
Solifago sempervirens	x	x	x	x	
Sonchus asper	x	x	x	x	
Sonchus oleraceus	x	x	x	x	
Sorghum halepense		x			
Spartina alterniflora		x		x	x
Spartina cynosuroides		x	x	x	
Spartina patens		x			
Specularia perfoliata		x			

(continued)

(Sheet 9 of 10)

Table E1 (concluded)

	Disposal Area Habitats				
	Dredged Material				
Species	Sand	Silt	Dike	Waste Area	Aquatic
Spermolepsis divaricata	x				
Spergularia marina		x			
Sphenopholis nitida x obtusata				x	
Sporobolus poiretii				x	
Sporobolus virginicus				x	
Stellaria media		x	x		
Strophostyles helvola			x	x	
Suaeda linearis	x	x	x	x	
Teucrium canadense			x		
Trifolium repens			x		
Typha latifolia		x			x
Verbena brasiliensis				x	
Vicia dasycarpa				x	
Zea Mays			x		
TOTALS	35	81	77	65	9

(Sheet 10 of 10)

Table E2

<u>Habitat Preference of Trees Associated With Diked Dredged Material Disposal Sites in the South Carolina Coastal Zone</u>

Species	Dredged Material: Sand	Dredged Material: Silt	Dike	Waste Area	Aquatic
Celtis laevigata		x	x	x	
Juniperus virginiana	x	x	x	x	
Ligustrum japonicum			x		
Melia azedarach		x	x	x	
Morus alba		x	x	x	
Prunus caroliniana		x			
Prunus serotina		x	x	x	
Salix sp.					x
Sapium sebiferum		x	x	x	
Sassafras albidum				x	
Zanthoxylem clava-herculis	x		x		
Totals	2	7	8	7	1

Table E3

<u>Habitat Preference of Shrubs Associated With Diked Dredged Material Disposal Sites in the South Carolina Coastal Zone</u>

Species	Dredged Material Sand	Dredged Material Silt	Dike	Waste Area	Aquatic
Ampelopsis arborea			x	x	
Baccharis angustifolia			x		
Baccharis halimifolia	x	x	x	x	
Borrichia frutescens		x	x	x	
Campsis radicans			x	x	
Iva frutescens		x	x	x	
Iva imbricata			x	x	
Ilex vomitoria			x	x	
Lantana horrida		x			
Ligustrum sinense		x			
Lonicera japonica		x	x	x	
Mikania scandens	x				
Myrica cerifera			x	x	
Parthenocissus quinquefolia			x	x	
Prunus angustofolia	x				
Pyracantha sp.		x			
Rhus copallina		x	x	x	
Rhus radicans		x		x	
Rubus argutus	x				
Rubus spp.	x		x	x	
Sambucus canadensis		x	x		
Tamarix gallica	x	x	x	x	
Vitis aestivalis			x	x	
Yucca aloifolia	x		x	x	
Yucca glorisa			x	x	
Totals	6	12	18	17	0

capable of supporting larval mosquito populations. The marsh grass *Distichlis spicata* has been termed "salt grass," but it is more commonly called "mosquito grass." It is not definitely known why mosquitoes are frequently associated with this grass, but *D. spicata* is perhaps the best known botanical indicator of mosquito breeding activity. With this in mind, it was felt by the research group that special activity should be devoted to the listing of those plant species that were actually observed in the presence of living mosquito larvae.

Materials and methods

9. Searches were made on numerous occasions for mosquito breeding microhabitats within dredged material disposal sites during the study (see also Parts IV and V for additional data on patterns of mosquito breeding within disposal areas). In most cases, a plant species was not recorded unless larvae were located on several occasions.

Results and discussion

10. Volunteer vegetation. It was soon obvious that mosquito breeding was most often associated with fissured dredged material (see also Part IV) in older disposal sites. Table E4 and Figures E2 and E3 indicate the results of this survey and typical mosquito breeding conditions. In most cases, dredged material that was unfissured did not breed mosquitoes. Volunteer vegetation that appears soon after soil fissure formation tends to maintain the integrity of the original fissure and the process of soil weathering is retarded. It can now be stated that most volunteer vegetation that develops during the early successional stages tends to maintain disposal sites as mosquito sources. This observation is further supported by evidence from areas which were not rapidly colonized by volunteer vegetation. Such areas frequently have a shorter history of mosquito breeding conditions.

Table E4

Major Species of Seed Plants Associated with Fissured Dredged Material and Mosquito Breeding Conditions in Coastal South Carolina

Herbaceous Seed Plants	Shrubs	Trees
Aster exilis	*Baccharis halimifolia*	*Celtis laevigata*
Aster subulatus	*Borrichia frutescens*	*Morus alba*
Atriplix patula	*Iva frutescens*	*Juniperus virginiana*
Distichlis spicata	*Tamarix gallica*	
Heliotropium curassavicum		
Phragmites communis		
Pluchea purpurascens		
Salicornia bigelovii		
Salicornia europaea		
Salicornia virginica		
Setaria magna		
Spartina alterniflora		
Spartina cynosuroides		
Suaeda linearis		
Totals 14	4	3

Figure E2

Spartina alterniflora Growth on Fissured Dredged Material

Figure E3

Dense Stand of *Suaeda linearis* on Fissured Dredged Material

11. The following plant species were not only found to be indicators of mosquito breeding conditions, but were especially effective in maintaining the fissured soil state:

a. *Borrichia frutescens*, sea ox-eye.

b. *Suaeda linearis*.

c. *Salicornia bigelovii*, glasswort.

d. *Phragmites communis*, common reed.

e. *Spartina alterniflora*, smooth cord grass.

f. *Spartina cynosuroides*, big cord grass.

In numerous cases, large larval concentrations were found associated with these plants (Figures E2 and E3). Other locations, within the same disposal site, that lacked the plants tended to weather faster or lose their water content with the result that mosquito larvae were not supported. The above plants have the additional advantage of being relatively easy to identify if the field and subprofessional personnel can be trained to locate these species with minimal training.

12. *Distichlis spicata* was not frequently observed to maintain fissured soil. The species remains an indicator of moist (and mosquito) soil conditions, but in many disposal sites it tends to grow best on unfissured soil. *Morus alba* (white mulberry) and *Juniperus virginiana* (red cedar) were found growing on fissured soil and were associated with mosquito larvae on two older disposal sites. The ages of the trees were estimated at 6 and 20 years, respectively. If these two shade producing species had not developed during a crucial stage of the successional pattern, the fissured (mosquito breeding) soil would have long since disappeared. This observation also supports the notion that volunteer vegetation, developing during certain stages or seres (see also Part IV) of a disposal area successional cycle, tends to maintain mosquito breeding conditions.

Plant Successional Patterns

Rationale

13. Odum (1971) has defined ecological succession as:

- a. an "orderly process of community development that involves changes in species structure and community processes with time...is reasonably directional and, therefore, predictable."
- b. the result of modification of the physical environment by the community...".
- c. the process "...culminates in a stabilized ecosystem...".

The concept of a plant or animal community undergoing a series of predictable stages, or seres, is firmly established in modern ecology. The successional patterns observed on dredged material disposal sites are of a secondary nature, as the term primary succession is usually reserved for those areas that previously lacked life forms altogether. Classical introductory papers on the nature of ecological succession include the works of Shelford (1911a and 1911b), Clements (1916), and Oosting (1942). These workers established the basic concept of succession shared by most ecologists today: that is, that the community, collectively (rather than singularly), influences the pattern of plant and animal succession. This approach has received some criticism in recent years. Drury and Nesbet (1971 and 1973) contend that individual species adaptation is more important than community adaptation in the successional process. Smith (1974) believes that the classical concept of succession is most applicable to biologically controlled ecosystems and least applicable to ecosystems influenced by physical disruption. These recent criticisms were carefully considered, particularly since the subject of this report is solely concerned with ecological situations resulting from the physical disturbances of the dredged material. However, the concepts of succession in the classical sense were nevertheless adhered to in this study because they are familiar to most observers and provide an effective approach for gathering data useful for predictive purposes. Therefore, a major effort was directed toward understanding the various stages of plant and arthropod succession (Part VI). This effort included an analysis of the seral patterns that develop after the deposition of dredged material on a site, including differing effects caused by differences in the amount of material deposited on different sites and the frequency of such operations on a given site.

Materials and methods

14. With the exception of Carlson (1972) and Beaman (1973) there have been no well-documented studies of ecological succession within dredged material disposal areas. The methods of these authors were concerned with undiked dredge islands and were not applicable to the study areas of this report. Successional studies were conducted by deduction and field studies of a wide variety of diked dredged material disposal sites including all sites listed in Figures 4 and 5. The short time period of this study (18 months) did not allow for detailed observations of single sites over an extended period of time. Some error is admitted in this method in that every possible sere may not have been observed. Age determinations of various sites and the number of prior pumpings were determined from personnel of the Charleston District.

Results and discussion

15. Botanical successional patterns. When dredged material is pumped into a diked disposal area, a number of stages or seres were observed to develop. In most cases these disposal sites (Figure E4) were located in natural marsh areas that had previously supported *Spartina alterniflora* (smooth cord grass). Assuming that the initial pumping was of sufficient depth to prevent further vegetative growth of the *Spartina*, four discrete successional seres were frequently

Figure E4

New Dredged Material Disposal Site in Charleston CE District
Prior to Receiving Dredged Material with Dense
Stand of *Spartina alterniflora*

observed . In this manner, a typical disposal site along the Atlantic Intra-Coastal Waterway was normally found to be in one of the following four states:

a. Halophytic stage, characterized by the development of pure and mixed stands of succulent halophytes.

b. Forb-shrub stage, characterized by intense growth of herbaceous plants mixed with young woody shrubs.

c. Shrub stage, consisting mainly of older shrubs.

d. Climax stage, dominated by larger trees tolerant of maritime conditions.

Figure E5 illustrates these relationships in terms of seres and chronological time. The halophyte stage is illustrated in Figure E6, while the forb-shrub sere is shown in Figure E7. The oldest study sites illustrated the climax stage (Figure E8).

16. *Spartina* or presuccessional stage. This condition normally occurs before a pumping operation. *Spartina alterniflora* (smooth cord grass) and related species normally were the original substrate plants that preceeded the successional pattern previously indicated (Figure E4). Two environmental conditions were observed that allowed this stage to continue and/or reappear. If a dike failed and was washed by unusual tides or high water, then the intrusion of salt water would allow for the return of *Spartina* conditions and the proposed successional pattern would be halted indefinitely. In other cases, where the depth of the dredged material was not very deep, *Spartina* was observed to vegetatively reproduce and a marsh-like appearance was reestablished (Figure E2). It is of interest to note that this condition occurred in some dredged material disposal sites that were completely devoid of all tidal influences. In a number of sites, where the successional pattern was halted (or characterized by a return to *Spartina* conditions), there was a noticeable decline in mosquito production (see also Part IV for a

	Pumping ↓							
Representative Species:	Marsh	→	*Salicornia* *Suaeda* *Batis* *Borrichia*	→	*Solidago* *Aster* *Iva* *Baccharis*	→	*Baccharis* *Iva* *Tamarix*	→ *Morus* *Celtis*
Seres:			Halophyte		Forb-Shrub		Shrubs	Trees
Time:			1-3 years		3-5 years		5-10 years	10 +

Figure E5

Proposed Plant Successional Pattern for Typical Diked Dredged Material Disposal Area, coastal South Carolina

Figure E6

Halophyte Successional Stage within a Dredged Material Disposal Site with Dense Stands of *Salicornia bigloveii* (foreground) and *Borrichia frutescens* (background)

Figure E7

Forb-Shrub Successional Stage within a Dredged Material Disposal Site Vegetated by Various Species of *Aster*, *Solidago*, *Baccharis*, and *Iva*

Figure E8

Early Climax Successional Stage within a Dredged Material Disposal Site Vegetated by *Morus alba* discussion of arthropod successional patterns and conditions).

17. Halophytic stage. This sere is the first true stage of the secondary succession pattern of dredged material disposal sites. Halophytes are usually termed "salt tolerant plants." It is perhaps necessary that this sere follows the *Spartina* presuccessional stage because of the high saline conditions that are retained from the original marsh and the dredged material. For mosquito surveillance, as previously indicated, many of the succulent halophytes are indicators of water conditions that may support mosquito larvae. In other cases, the halophytes tend to maintain the dredged material in a fissured (i.e., mosquito breeding) state. This sere is best characterized by the genera *Batis, Borrichia, Salicornia,* and *Suaeda* (Figure E5).

18. The halophytic stage may occur in pure or mixed stands. During this sere it was not uncommon to observe vast areas in a disposal area that consisted of only one or two species of plants (frequently *Salicornia* or *Suaeda*). The pattern of large numbers of few species (as opposed to large numbers of many species) is a characteristic of many successional patterns. In other sections of this report, data will be presented that support the halophytic plant sere as being concurrent with an equally productive mosquito stage. For this reason, it is important that field personnel be trained to recognize the mosquito breeding potential that this sere may represent (Figure E3).

19. Forb-shrub stage. If no additional pumping occurs on a disposal site and the soil salinity begins to decrease, conditions are established for the next sere, the forbs and shrubs. This stage is generally an amorphous collection of plant species that varies from site to site, but is generally characterized by the presence of herbaceous composites including *Aster* spp., *Solidago sempervirens*, and less frequently by *Pluchea purpurascens* (Figure E6). As this

sere ages, woody composites *Baccharis halimifolia* and *Iva frutescens* begin to appear. In some areas *Tamarix gallica* may be found with these species. Also present will be numerous species of "opportunistic weeds," but the general pattern remains that of a mixed herbaceous flora that slowly gives rise to a small group of woody shrubs. This sere may last for three years, but shorter periods were observed during this study period. The sometimes rapid development of forb-shrubs is usually related to the presence of a waste area that functions as a seed source. In some of the more remote marsh locations that lacked a seed source, this stage was delayed for as much as three years.

20. Shrub stage. This stage is the continuation of events previously begun in the forb-shrub sere. The onset of the stage is usually gradual and requires several years to completely eliminate the forb species (by shade). *Baccharis halimifolia, Iva frutescens*, and other woody plant species dominate the disposal areas during this period. Of these, *B. halimifolia* is the most dominant and most numerous. Frequently a mixed stand of the three species will develop.

21. Climax stage. The final sere in the study areas was a community of trees. Several older disposal areas, including the southern end of Drum Is. (Figure 4), were used as study areas for this section. All older disposal areas were dominated by *Morus alba* (white mulberry) and *Celtis laevigata* (sugarberry) with the former being more prevalent. Since the previous stages (shrub and forb-shrub) are frequently used by birds for nesting, it appears that the two main tree species are partially established by seeds carried by birds. Frequently, the slow process of *Baccharis* elimination (by shading from *Morus* or *Celtis*) was observed in older disposal sites. This was especially true on south Drum Is. (Figure 4) and the Magnolia Cemetery disposal area (not illustrated). This latter site had not

been pumped with dredged material for approximately 20 to 25 years and was the oldest disposal area available to the investigators. It cannot be stated with assurance that the other tree species may not invade these sites, but at the present time the *Morus-Celtis* climax appears to represent the dominant tree species that utilize older disposal areas.

22. Observations on mosquito relationships. Two salient features of mosquito biology relate to plant successional relationships on dredged material disposal sites. First, the halophytic stage tended to be the most productive for mosquito numbers (see also Part IV). This observation has great bearing on the future training of mosquito field surveillance workers. These individuals should be trained to recognize the dangers of large disposal sites in this stage. Secondly, mosquito species diversity tends to increase with the older plant successional seres. To summarize, the greatest numbers of mosquitoes (representing a few species) were frequently associated with the succulent halophyte stage; a greater diversity of mosquito species (but often fewer in overall numbers than found on the halophytic stage) could be located in the older disposal sites as they approached the climax sere (see also Parts IV and V). This latter observation should have some special bearing on mosquito workers concerned with public health entomology. Older disposal sites may harbor disease vectors that could not or did not use the site during the earlier successional stages. This increase in species diversity with the increasing age of the ecosystem is also a general characteristic of both plant and animal successional patterns. A final word of caution regarding plant-mosquito relationships. The patterns discussed are greatly generalized and it must be understood that localized pockets of mosquitoes can and do exist in all of the stages that have been discussed. The overall pattern discussed is thought to be valid (with the exception noted below) for much of the Atlantic and Gulf coasts.

23. *Phragmites* as an exception. The Common reed, *Phragmites communis*, is a common plant in many disposal areas (Figure E9). In many inland sites (e.g. Philadelphia District), this plant may exist in pure stands and prevent the establishment of any other plant species. The species is new to the Charleston District with the first record being that of Barry (1968) from Georgetown County. Stalter (1975) reported the species from a dredged material disposal site. Since these initial reports, the species appears to be rapidly spreading in the Charleston District. Wass (1972 indicates that the species is slowly increasing in Virginia and that it dominates "spoiled marsh." In parts of New Jersey (Personal Communication, 27 January 1977, Dr. J. K. Shisler, Rutgers University, New Brunswick), *Phragmites* is regarded as a pest plant species and detrimental to good mosquito surveillance. Kadlec and Wentz (1974) indicated that *Phragmites* was most commonly located in brackish to fresh waters. This characteristic may prevent *Phragmites* from becoming the dominant disposal site plant in some parts of the southeast. At the present time *Phragmites* is confined to two disposal areas in Georgetown County and two sites in Charleston County.

24. If it is postulated that *Phragmites* may become a dominant plant in Charleston District, the evidence (based on observations in other states) suggests an invasion at approximately the same time as halophytic state (Figure E5). The addition of *Phragmites* would perhaps change the halophyte stage to a mixed halophyte-*Phragmites* stage in which *Phragmites* would rapidly eliminate neighboring species resulting in pure stands of the reed. In other cases, *Phragmites* may be the only species with the previously mentioned halophytes being completely eliminated or excluded. The future of this introduced plant on the saline and estuarine dredged material disposal sites of Charleston District remains in question at this writing. There is no reason to doubt that the species will successfully colonize the estuarine disposal areas. If this is indeed the case, mosquito

Figure E9

Monoculture of the Common Reed, *Phragmites communis*, within a Dredged Material Disposal Site in the Philadelphia CE District surveillance and control will be considerably more difficult.

25. Interrupted succession. The climax (tree) stage cited in Figures E5 and E8 is not common. As earlier indicated, the most powerful physical force affecting plant succession on disposal areas is the arrival of the dredged material per se. In most cases, the destruction of one of the later stages of plant succession (by the pumping of dredged material tends to bring the entire ecosystem back to a more primitive sere, usually the succulent halophyte stage. At this point the entire cycle is repeated until the next pumping operation. It is this cycle of repeated pumpings that tends to keep disposal areas productive for mosquitoes. The constant reversal of the successional patterns usually means that some areas that have reached a low mosquito potential will be restored to breeding status. At this point, it perhaps should be reiterated that the return to the halophyte stage means also a return to mosquito breeding in most disposal sites.

26. Climax disposal areas. While disposal areas in the climax state are uncommon, they are frequently of great importance as natural areas. Appendix F of this report outlines the importance of one such disposal site in Charleston, S. C., harbor. For mosquito control purposes climax disposal areas should continue under surveillance because of the previously mentioned tendency of these areas to develop larval breeding habitats for freshwater mosquitoes.

Standing Crop Estimations

Rationale

27. The flow of energy through any ecosystem begins with the fixation of solar energy through the process of photosynthesis. One effect of this process can be estimated by determining plant organic material present in a given area. A measurement of this type is

termed standing crop biomass. This quantity is normally expressed as grams per square meter or calories per square meter. Standing crop estimates can be used to compare differences in the amount of plant material in different areas.

28. Far from being the "dead ecosystems... because of their isolation from the (marsh) ecosystem..." described in a report on dredged sediments by the S. C. Wildlife and Marine Resources Department (1972), the succulent halophyte sere on dredged material (previously described) was frequently observed to have as much standing crop as plants in the open marsh. Many of these species were found in pure stands exhibiting such pronounced growth, that it was decided to quantitatively describe these observations.

Materials and methods

29. Standing crop biomass was determined for the following plant species associated with silty habitats within the dredged material disposal sites indicated:

a. *Aster subulatus* from Morris Is. (Figure 4).

b. *Borrichia frutescens* from site N-22 (Figure 5).

c. *Salicornia bigelovii* from site N-22 (Figure 5).

d. *Spartina alterniflora* from site S-1B (Figure 5).

e. *Suaeda linearis* from site N-22 (Figure 5).

In order to make standing crop biomass determinations, a dense, pure stand of each species was located. These stands were then crossed by a transect. Five points each 10 m apart were selected for square metre samples. These samples were taken during the last week of September and the first two weeks of October 1975. Measurements included dry weight (grams/square m.), average height in meters, and numbers of stems per square meter plot. Samples were dried in an oven until no further weight loss was evident. Dry weight was then determined. For *S. alterniflora* and *B. frutescens*, specimens were cut at ground level, excluding the root systems. For

A. subulatus, *S. bigelovii*, and *S. linearis*, the root systems were included in the samples.

Results and discussion

30. Table E5 presents the results of standing crop biomass determinations. In general, the figures presented are exceptional for each species in question. Suitable pure, dense stands of the specimens studied could not be located under natural marsh conditions during the time period of the study. However, Reed et al. (1974) found *S. alterniflora* standing crop biomass values (grams per square mile) to average 1025.6 during their study two years earlier in a natural marsh in the same general area as site S-1B (Albemarle Point). This figure is lower than the 1799 g/sq m observed in this study. These figures compare with standing crop biomass figures of 2,240 g/sq m as noted by Wass and Wright (1969) for *S. alterniflora* in Georgia salt marshes. Porcher* found that *Salicornia bigelovii* in a natural marsh averaged 294 g/sq m as compared with 1721 g/sq m noted for the same species (Table E5) during this study. With the exception of *S. alterniflora*, whose values were exceeded by the Georgia study, it was felt that the figures, stem heights, and number of stems obtained during this phase of the study were unusual for the species in question. It should be observed that this high standing crop biomass occurred in those plant species associated with the subclimax seres. Large pure stands of one species were never located on older sites. These standing crop biomass figures would appear to support the observation that dredged material disposal sites are certainly not "ecologically dead" in terms of the plant fauna supported, but instead represent a highly modified, man-made ecosystem that is capable under certain conditions of supporting a luxuriant plant growth of some common marsh plants.

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* Unpublished data.

Table E5

Measurements of Standing Crop Biomass of Five Selected Plant Species From Disposal Sites in Coastal South Carolina

		Measurements		
Species	Samples	Dry weight g/m^2	Height m	No. stems/m^2
Aster subulatus	1	1501	1.32	67
	2	1428	1.01	72
	3	510	0.97	33
	4	1010	1.11	47
	5	709	0.91	41
	Avg	1031	1.06	52
Borrichia frutescens	1	1653	o.87	274
	2	1341	0.90	116
	3	1110	0.91	135
	4	1492	1.05	139
	5	2183	0.96	163
	Avg	1556	0.94	165
Salicornia bigelovii	1	2157	0.67	18
	2	1428	0.65	13
	3	1356	0.65	7
	4	1912	0.70	25
	5	1753	0.67	20
	Avg	1721	0.67	17

(continued)

Table E5 (concluded)

Species	Samples	Measurements		
		Dry weight g/m^2	Height m	No. stems/m^2
Spartina alterniflora	1	2504	2.52	220
	2	1830	2.41	145
	3	1116	2.42	144
	4	2203	2.67	234
	5	1343	2.61	163
	Avg	1799	2.53	181
Suaeda linearis	1	905	0.97	237
	2	754	0.87	426
	3	824	0.85	77
	4	633	0.82	180
	5	946	1.07	30
	Avg	812	0.92	190

Summary

31. The following list is a summary of the major observations of this section.

- a. A wide variety of plant species were collected from five major habitats (dredged sand, silt, dikes, waste areas, and aquatic locations) associated with the disposal of dredged material.
- b. Plant species lists were maintained according to habitat preference.
- c. Plant species that were most frequently associated with fissured soil (and therefore mosquito breeding conditions) were identified. It is suggested that such plants may serve as indicator species of mosquito breeding conditions.
- d. A common indicator species, *Distichlis spicata* (mosquito grass), on natural marshes was not often associated with fissured soil in diked disposal areas. It appears that this species may be more valuable as an indicator of mosquito larval conditions in the natural marsh than in disposal areas.
- e. A tentative pattern of plant succession for diked dredged material disposal sites was proposed for Charleston District which may be applicable to much of the southeast coast.
- f. The impact of a new (and probably introduced) disposal site plant species in the Charleston District, *Phragmites communis*, was considered.
- g. Mosquito breeding was found to be most productive where successional pattern is interrupted on a regular (two to five-year) basis.
- h. Climax stage disposal areas were usually found to harbor reduced numbers of mosquitoes, but may also have a greater diversity of mosquito species. Climax (tree) seres may also harbor unusual localized breeding conditions that warrant continued surveillance long after pumping operations have ceased on a given site.
- i. Under some conditions, pure, dense stands of single plant species were located. Biomass, height, and stem counts confirmed that the rich organic nature of some disposal sites can support luxuriant plant growth under certain conditions.

j. A complete listing of all seed plant species observed or collected from dredged material disposal sites (including data from Appendix D) is presented as Table E6. Nomenclature for this table was taken from two sources, Hitchcock & Chase (1951) for Poaceae and Radford et al. (1968) for the remaining families. A total of 196 Taxa representing 56 families and 151 genera are reported. The order of families is phylogenetic after the arrangement of Radford et al. (1968), but genera within families are alphabetical for convenience. The following works were also useful in the preparation of the list: Daubenmire (1959), Munz and Keck (1959), Correll and Johnson (1970), and U. S. National Aeronautics and Space Administration (1973).

Table E6

Composite Catalogue of Major Plant Species Associated With Diked Dredged Material Disposal Sites in the South Carolina Coastal Zone

GYMNOSPERMS

Scientific Name	Common Name
Cupressaceae	
Juniperus virginiana L.	Red Cedar

ANGIOSPERMS

MONOCOTYLEDONS

Scientific Name	Common Name
Typhaceae	
Typha latifolia L.	Common Cat-Tail
Ruppiaceae	
Ruppia maritima L.	Widgeon Grass
Poaceae	
Andropogon sp.	
Arundo donax L.	Giant Reed
Bromus catharticus Vahl.	Brome Grass
Cynodon dactylon (L.) Persoon	Bermuda Grass
Digitaria sanguinalis (L.) Scopoli	Crab Grass
Distichlis spicata (L.) Greene	Salt Grass
Echinochloa crusgalli (L.) Beauvois	Barnyard Grass
Eleusine indica (L.) Gaertner	Goose Grass
Eragrostis curvula (Schrader) Nees	Love Grass
Leptochloa uninervia (Presl) Hitchcock	Sprangletop
Lolium multiflorum Lam.	Rye Grass
Melica mutica	
Muhlenbergia capillaris	
Panicum amarum	
Panicum	

(continued)

(Sheet 1 of 8)

Table E6 (continued)

Scientific Name	Common Name
Paspalum dilatatum Poiret	Dallis Grass
Paspalum praecox Walter	
Paspalum urvillei Steudel	
Phalaris caroliniana Walter	Canary Grass
Phragmites communis Trinius	Reed
Polypogon monspeliensis (L.) Desf.	Rabbitfoot Grass
Setaria magna Grisebach	Giant Foxtail
Setaria sp.	Foxtail Grass
Sorghum halepense (L.) Persoon	Johnson Grass
Spartina alterniflora Loisel	Smooth Cord Grass
Spartina cynosuroides (L.) Roth	
Spartina patens (Aiton) Muhl.	
Sphenopholis nitida x *obtusata*	
Sporobolus poiretii (R&S) Hitchcock	Smut Grass
Zea Mays L.	Corn
Cyperaceae	
Bulbostylis barbata (Rottboell) Clarke	
Cladium jamaicense Crantz	Saw Grass
Cyperus erythrorhizos Muhl.	
Cyperus polystachyos var. *texensis* (Torrey) Fernald Spike-rush	
Elocharis parvula (R&S) Link	
Fimbristylis dichotoma (L.) Vahl	
Fimbristylis spadicea (L.) Vahl	
Scirpus acutus Muhl.	
Scirpus americanus Persoon	
Scirpus robustus Pursh	Bulrush
Arecaceae	
Sabal palmetto Lodd. ex Schultes	Cabbage Palmetto
Commelinaceae	
Commelina diffusa Bruman f.	Dayflower
Juncaceae	
Juncus acuminatus Michaux	
Juncus roemerianus Scheele	
Liliaceae	
Asparagus officinalis L.	Asparagus
Yucca aloifolia L.	Spanish Bayonet
Yucca gloriosa L.	

(continued)

(Sheet 2 of 8)

Table E6 (continued)

Scientific Name	Common Name
DICOTYLEDONS	
Salicaceae	
Salix sp.	Willow
Myricaceae	
Myrica cerifera L.	Wax Myrtle
Fagaceae	
Quercus virginiana Miller	Live Oak
Ulmaceae	
Celtis laevigata Willd.	Hackberry, Sugarberry
Moraceae	
Morus alba L.	White Mulberry
Polygonaceae	
Polygonum arifolium L.	
Polygonum hydropiperoides Michaux	
Polygonum pensylvanicum L.	
Polygonum persicaria L.	
Polygonum punctatum Ell.	
Rumex crispus L.	
Rumex verticillatus L.	Swamp Dock
Chenopodiaceae	
Atriplex patula L.	Orach
Chenopodium album L.	Lamb's quarters
Cheopodium ambrosioides L.	Mexican-tea
Chenopodium standleyanum Aellen	
Salicornia bigelovii Torrey	Glasswort
Salicornia europaea L.	Glasswort
Salicornia virginica L.	Glasswort
Salsola kali L.	Russian Thistle
Suaeda linearis (Ell.) Moq.	

(continued)

(Sheet 3 of 8)

Table E6 (continued)

Scientific Name	Common Name
Bataceae	
Batis maritima L.	
Amaranthaceae	
Alternanthera philoxeroides (Martius) Griesbach	Alligator-weed
Amaranthus cannabinus (L.) J.D. Sauer	Water Hemp
Amaranthus retroflexus L.	
Iresine rhizomatosa Standley	
Phytolaccaceae	
Phytolacca americana L.	Pokeweed
Aizoaceae	
Sesuvium maritimum (Walter) BSP	Sea Purslane
Sesuvium portulacastrum L.	Sea Purslane
Portulacaceae	
Portulaca oleracea L.	
Caryophyllaceae	
Silene antirrhina L. forma *apetala* Farw.	
Spergularia mariana (L.) Griesbach	Sand Spurrey
Stellaria media (L.) Cyrillo	Chickweed
Lauraceae	
Sassafras albidium (Nuttall) Nees	Sassafras
Capparaceae	
Cleome gynandra L.	
Brassicaceae	
Descurainia pinnata (Walter) Britton	
Lepidium virginicum L.	Poor-man's Pepper

(continued) (Sheet 4 of 8)

Table E6 (continued)

Scientific Name	Common Name
Rosaceae	
Duchesnea indica (Andrz.) Focke	Indian Strawberry
Prunus angustifolia Marshall	Chicksaw Plum
Prunus caroliniana Aiton	Carolina Cherry Laurel
Prunus serotina Ehrhart	Black Cherry
Pyracantha sp.	
Rubus argutus Link	Blackberry
Rubus sp.	
Fabaceae	
Cassia obtusifolia L.	Sicklepod
Crotalaria spectabilis Roth	Rattlebox
Glottidium vesicarium (Jackquin) Mohr	
Medicago lupulina L.	Black Medic
melilotus alba Desr.	
Melilotus indica (L.) All	Sour Clover
Strophostyles helvola (L.) Ell.	
Trifolium repens L.	
Vicia dasycarpa Tenore	Smooth Vetch
Oxalidaceae	
Oxalis sp.	
Geraniaceae	
Geranium carolinianum L.	
Rutaceae	
Zanthoxylum clava-herculis L.	Hercules-club
Meliaceae	
Melia axedarach L.	Chinaberry
Euphorbiaceae	
Acalypha gracilens Gray	Three-seeded Mercury
Croton punctatus Jacquin	
Euphorbia ammannioides HBK	
Euphorbia maculata L.	
Sapium sebiferum (L.) Roxb.	Popcorn Tree

(continued)

(Sheet 5 of 8)

Table E6 (continued)

Scientific Name	Common Name
Anacardiaceae	
Rhus copallina L.	Winged Sumac
Rhus radicans L.	Poison Ivy
Aquifoliaceae	
Ilex vomitoria Aiton	Yaupon
Vitaceae	
Ampelopsis arborea (L.) Koehne	Pepper Vine
Parthenocissus quinquefolia (L.) Planchon	Virginia Creeper
Vitis aestivalis Michaux	Summer Grape
Malvaceae	
Abutilon theophrastii Medicus	Velvet Leaf
Kosteletskya virginica (L.) Prsel.	Seashore Mallow
Modiola caroliniana (L.) G. Don	
Sida rhombiflora L.	
Tamaricaceae	
Tamarix gallica L.	Tamarisk
Passifloraceae	
Passiflora incarnata L.	Maypops
Cactaceae	
Opuntia compressa Graham	Prickly Pear
Opuntia drummondii (Salisbury) Macbride	
Onagraceae	
Gaura angustifolia Michaux	
Oenothera biennis L.	
Oenothera drummondii Hooker	
Oenothera rhombipetala Nuttall ex T&G	
Apiaceae	
Chaerophyllum tainturieri Hooker	Wild Chervil
Foeniculum vulgare Miller	Fennel
Hydrocotyle bonariensis Lam.	
Ptilimnium capillaceum (Michaux) Raf.	
Spermolepis divaricata (Walter) Raf.	

(continued)

(Sheet 6 of 8)

Table E6 (continued)

Scientific Name	Common Name
Primulaceae	
Samolus parviflorus Raf.	Water Pimpernel
Plumbaginaceae	
Limonium sp.	Sea Lavender
Oleaceae	
Ligustrum japonicum Thunberg	Privet
Ligustrum sinense Lour	Privet
Loganiaceae	
Polypremum procumbens L.	
Convolvulaceae	
Calystegia sepium (L.) R. Brown	
Opomoea sagittata Cav.	
Boraginaceae	
Heliotropium curassavicum L.	Seaside Heliotrope
Verbenaceae	
Lantana horrida HBK	
Lippia nodiflora (L.) Michaux	
Verbena bonariensis L.	
Teucrium canacense L.	
Solanaceae	
Physalis angulata L.	Ground Cherry
Physalis viscosa ssp. Maritima (Curtis) Waterfall	Ground Cherry
Solanum americanum Miller	
Solanum carolinense L.	
Solanum gracile Link	
Scrophulariaceae	
Agalinis fasciculata (Ell.) Raf.	
Bacopa monneri (L.) Pennell	
Linaria canadensis (L.) Dumont	Toad-flx
Bignoniaceae	
Campsis radicana (L.) Seeman	Cow-itch Vine

(continued)

(Sheet 7 of 8)

Table E6 (concluded)

Scientific Name	Common Name
Rubiaceae	
Diodia virginiana L.	
Galium sp.	
Richardia scabra L.	
Caprifoliaceae	
Lonicera japonica Thunberg	Japanese Honeysuckle
Sambucus canadensis L.	Elderberry
Cucurbitaceae	
Specularia perfoliata (L.) A. DC.	
Asteraceae	
Ambrosia artemisiifolia L.	
Aster exilis Ell.	
Aster pilosus Willd. var. *pilosus*	
Aster subulatus Michaux	
Aster tenuifolius L.	
Baccharis angustifolia Michaux	False Willos
Baccharis halimifolia L.	Groundsel-tree
Bidens cernua L.	
Borrichia frutescens (L.) DC	Sea ox-eye
Carduus sp.	
Eclipta alba (L.) Hasskarl	
Erechitites hieracifolia (L.) Raf.	
Erigeron canadensis L.	Horseweed
Erigeron strigosus Muhl. ex Willd.	Daisy Fleabane
Eupatorium capillifolium (Lam.) Small	Dog Fennel
Eupatorium compositifolium Walter	Dog Fennel
Eupatorium serotinum Michaux	
Gnaphalium purpureum L.	
Gnaphalium obtusifolium L.	Rabbit Tobacco
Helenium amarum (Raf.) H. Rock	Bitter-weed
Heterotheca subaxillaris (Lam.) Britton & Rusby	
Iva annua L.	
Iva frutescens L.	Marsh Elder
Iva imbricata Walter	
Lactuca scariola L.	Prickly Lettuce
Mikania scandens (L.) Willd	Climbing Hempweed
Pluchea purpurascens (Swatrz) DC	Camphorweed
Pyrrhopappus carolinianus (Walter) DC	
Solidago altissima L.	
Solidago sempervirens L.	
Sonchus asper (L.) Hill	Spiny-leaved Sow-thistle
Sonchus oleraceus L.	Common Sow-thistle

(Sheet 8 of 8)

APPENDIX F: OCCURRENCE OF AVIAN SPECIES WITHIN DREDGED MATERIAL DISPOSAL SITES

Introduction

Background

1. Dredged material disposal areas occupy an interesting number of acres along the Atlantic and Gulf coasts and other areas where navigable waters have to be maintained by dredging. The creation of these sites often alters existing habitats as well as producing new environments. To better manage the coastal ecosystem, the use of dredged material disposal sites by plants and animals needs to be evaluated. Birds, especially, colonial water birds, are an important part of the coastal biotic communities and are a sensitive indicator of environmental quality. Hence information on avian utilization of disposal areas is important for proper valuation and management.

Bird-mosquito relationships

2. Birds and mosquitoes have long been closely associated with one another. One scheme of mosquito classification (James and Harwood, 1969) employs the blood meal preference of the insect for its respective host. Under this scheme, certain mosquito species may be termed ornithophilous (i.e. bird feeding), while other species may be termed anthrophilous (i.e. man feeding). Many species are zoophilous (i.e. mainly mammal feeders). In general, mosquito-bird relationships are most important to man where the possibility of arthropod borne virus transmission from birds to man exists. Such viruses are generally termed arboviruses. Chamberlain and Sudia (1961) and Sudia (1974) have estimated that one half of the bird orders and one third of the bird families occurring in the United States are susceptible to Eastern (EE), Western (WE), and St. Louis (SLE) encephalitis viruses. The fact that the highly virulent Eastern Encephalitis virus is endemic in many areas that also harbor

dredged material disposal sites is evidence enough of the need to relate mosquito-bird populations. Hayes et al. (1962) concluded that *Aedes sollicitans* (a mosquito frequently encountered within dredged material disposal sites) was the primary vector of this disease in coastal areas of New Jersey in 1959. Many other bird and mosquito species that are not associated with disposal sites are also known to carry arboviruses.

Literature review

3. Although there is an increasing interest in bird use of disposal areas, few studies have been made. Harrison and Chisolm (1974) listed the birds found in Craney Island, Virginia; Lewis and Dunstan (1974) reported on Tampa Bay, Florida; and Olsen (1975) on the disposal sites of southeastern Louisiana. Soots and Parnell (1974, 1975) and Buckley and Buckley (1974) documented the importance of disposal areas as breeding areas for colonial water birds in North Carolina, New York, and New Jersey. Additional studies need to be made in other geographic areas to provide baseline information on use of dredged islands by birds, their importance as breeding areas for colonial water birds, and the management of disposal areas for water birds.

Purpose

4. The objectives of this section were twofold:

   a. To determine the utilization of disposal sites by birds in the Charleston, South Carolina area.

   b. To determine management practices to increase desirable bird utilization of disposal sites.

Study area

5. The study was conducted on dredged disposal sites in the vicinity of Charleston, Charleston County, South Carolina. The study area was bounded on the north by Bull's Bay, the south by the South Edisto River, the east by the Atlantic Ocean, and the west by Charleston County line (see Figures 4 & 5). With regards to their avifauna and geography, three types of disposal sites could be

delineated:

a. Inland Waterway Disposal Sites: These are a series of approximately 40 small to medium-sized sites located North and South of Charleston adjacent to the Atlantic Intra-Coastal Waterway (AIWW) S-18 and N-16 (Figure 5) are examples of this type.

b. Barrier Island Disposal Sites: These consist of large disposal sites located on barrier islands between salt marshes and the Atlantic Ocean. Morris Island is the only example of this type in the Charleston area (Figure 4).

c. Estuarine Disposal Sites: These are large disposal sites situated on islands adjacent to coastal rivers. Drum, Daniel's, and Hog (Patriot's Point) islands are examples of this type (Figure 4).

Materials and Methods

Field methods

6. Fieldwork was conducted between 30 June 1975 and 1 July 1976. All sites were visited at least once a season during the study with more intensive surveys conducted once a month on typical examples of the three major types of disposal sites. These sites included: Morris Island (Barrier type, Figure 4); sites N-10 through N-23 (AIWW locations, Figure 5); and Drum Island (Estuarine type, Figure 4). On each visit, notes were made on species composition, number, habitat utilization, and behavior activities. In addition, aerial censuses were made of all major disposal areas at least once a month from 1 January - 30 December 1976 in conjunction with another research project. These censuses were especially useful in studying the larger disposal sites and rookeries. Also data on species occurrence on Charleston County dredged material disposal sites were obtained from Sprunt, Chamberlain, and Burton (1970), American Birds (formerly Audubon Field Notes), The Chat, (Journal of the Carolina Bird Club), The Lesser Squawk (Journal of the Charleston Natural History Society), and the collections of The Charleston Museum.

Determination of status and abundance

7. The status and abundance of avian species was determined by the occurrence and population of the species in dredged material disposal sites. These were then compared with that species' status for South Carolina in general (Sprunt, Chamberlain, and Burton 1970) and the coastal plain specifically (Forsythe in press). The following abbreviations and definitions, modified from Forsythe (in press), are used through this section.

Abundance

a. C - common, seen in good number in appropriate season.

b. FC - fairly common, seen in moderate number in appropriate season.

c. U - uncommon, seen in small numbers and/or not seen every time in appropriate season.

d. R - rare, seen in small numbers but not every season.

e. AC - accidental, outside normal range, very few recorded.

Status

a. PR - permanent resident, found year around.

b. SR - summer resident, breeds.

c. SV - summer visitor, present in summer but does not breed.

d. WV - winter visitor, present in winter.

e. M - migrant, transient.

The arrangement and nomenclature of birds in this section is that of the American Ornithologists' Union (AOU) Checklist (1957) and its 32nd and 33rd supplements (1973a, 1973b, 1976).

Results and Conclusions

Distribution of birds on dredged material disposal sites

8. About 164 species of birds were observed on Charleston

disposal sites (Table F1) showing that a diversity of species can utilize such areas. The total represents about 45 percent of the species known to occur in the lower coastal plain of South Carolina (Forsythe in press). On the dredged material disposal sites, 56 percent of the species were as common and 38 percent were less common than they were in the total coastal plain. Only three species: the black-necked stilt *(Himantopus mexicanus)*; american avocet *(Recurvirostra americana)*; and Wilson's phalarope *(Steganopus tricolor)* were more common on disposal areas.

9. The composition of the avian community on disposal sites when compared with the total coast has a higher proportion of water birds (loons, grebes, pelicans, herons, egrets, rails, gulls, and terns), water fowl (geese and ducks), and shorebirds (plovers and sandpipers) and a lower proportion of birds of prey (hawks and owls) and passerines (song birds) (Table F1). This is a reflection of the semiaquatic nature of the sites and their proximity to marshes and other aquatic environments.

Importance of dredged material disposal sites and breeding colonial water birds

10. In the Charleston area, nine species of colonial water birds breed. These include: brown pelican *(Pelecanus occidentalis)*, laughing gull *(Larus atricilla)*, gull-billed tern *(Gelochelidon nilotica)*, Forster's tern *(Sterna fosteri)*, common tern *(S. hirundo)*, least tern *(S. albifons)*, royal tern *(S. maximus)*, sandwich tern *(S. sandvicensis)*, and black skimmer *(Rynchops nigra)*. With the exception of least terns, all species breed only on three natural islands: Deveaux Bank in the mouth of the Edisto River, Bird Key in the mouth of the Folly River, and the Bird Banks in the Cape Romain National Wildlife Refuge. Least tern colonies were found on two dredged material disposal sites. One colony of about 40 birds was found on Hog Island (Figure 4) an estuarine site in Charleston harbor, while the other consisting of 10 birds was

Table F1

Comparison Of the Avian Community Composition of Charleston Dredged Material Disposal Sites With the South Carolina Coastal Plain

Area	Number of Species (% Composition)						
	Water Birds	Water Fowl	Shore-Birds	Birds of Prey	Passerines	Misc.	Total
Dredged D.S.	41(25%)	20(12%)	25(15%)	10(6%)	59(35%)	11(7%)	164(100%)
Total Coastal Plain	80(22%)	36(10%)	41(11%)	28(8%)	151(41%)	28(8%)	364(100%)

located on S-17 (Figure 5, pt. D), an Inland Waterway site. Both sites were situated on high sand piles within diked disposal areas and, except for the dikes, resembled colonies described by Soots and Parnell (1974) for North Carolina. Neither colony bred successfully as the nests were washed out by abnormally heavy rain in May.

11. During this study dredged material disposal sites were not found to be important areas for colonial water birds. Only about 3 percent of the nests of one species (least tern) were located on dredged material disposal sites in the Charleston, S. C. area, unlike the situation in North Carolina where 82.5 percent of the nests of 10 species were located on disposal areas (Soots and Parnell 1974). This effect might be attributed to two factors: a lack of sand in the Charleston sites, or the abundance of other natural sites. However, the increasing encroachment of man's activities on these natural breeding areas may make dredged material disposal sites more important as colonial water bird breeding locations.

Dredged material disposal sites and breeding long-legged waders

12. Unlike the situation with colonial water birds, Charleston disposal areas are important breeding sites for long-legged waders. Several small colonies of 5 to 10 pairs of black-crowned night herons *(Nycticorax nyticorax)* and yellow-crowned night heron *(N. violacea)* bred in trees on Inland Waterway disposal areas (i.e. N-22, Ashe Island). But the most important rookery was located on Drum Island (an Estuarine disposal site) in Charleston Harbor (Beckett 1965, Forsythe and Gauthreaux 1977). About 44,000 individuals of 9 species bred on Drum Island (Table F2). Drum Island is one of the most important heron rookeries in South Carolina (personal communication, 4 Sept. 1976, D. McCrimmon, Laboratory of Ornithology, Cornell University, Ithaca, New York). This is especially true for white ibis *(Eudocimus albus)* whose breeding population represents about 40 percent of the east coast population (personal communication,

Table F2

Breeding Population of Long-Legged Waders on Drum Island, Charleston, South Carolina, Summer 1975 (Data from Dr. T. Custer, U.S. Dept. Laurel, Maryland)

Species		
Common Name	Scientific Name	No. of Breeding Adults
Little Blue Heron	*Florida caerulea*	2,046
Cattle Egret	*Bubulcus ibis*	1,000
Great Egret	*Casmerodius albus*	600
Snowy Egret	*Egretta thula*	11,000
Louisiana Heron	*Hydranassa tricolor*	4,618
Black-crowned Night Heron	*Nycticorax nyticorax*	368
Yello-crowned Night Heron	*N. violacea*	144
Glossy Ibis	*Plegadis falcinellus*	1,104
White Ibis	*Eudocimus albus*	23,552
Total Species: 9	Total Individuals:	44,432

4 Jan. 1976, T. Custer, Wildlife Biologist, U. S. Dept. of Interior, Patuxent Wildlife Research Center, Laurel Maryland). Also this rookery is valuable because a number of long-term studies on the ecology of wading birds are presently being conducted. Thus, Drum Island represents a disposal area (Figure 4) that has become a nationally valuable resource which should be protected and managed.

Dredged material disposal sites as breeding areas for other avian species

13. Disposal sites also provide breeding habitats for a variety of other bird species. But such areas are especially important for two species of shorebirds: black-necked stilt and Wilson's plover *(Charadrius wilsonia)*. Stilts were only one of three species that occurred more frequently in disposal areas than in the coastal region as a whole. This is because they are almost completely restricted to disposal sites for reproduction. These sites are the only habitat in the Charleston area that resemble the stilt's primary breeding habitat in the western United States. In the Charleston area it is clear that the black-necked stilt population would be reduced or completely absent if no disposal areas were present.

14. Also, the Wilson's plover is dependent on disposal areas for breeding habitat. This will become especially true with the increasing encroachment by human activities and recreation in its natural habitat of barrier islands and sand dunes. These developments are reflected in the plover's population decline all along its Atlantic coast range. If these trends continue, Wilson's plover may become entirely dependent upon disposal areas for its survival.

Other aspects of bird disposal sites interactions

15. Disposal sites were also important as loafing and feeding areas for migrating and wintering waterfowl and shorebirds. Areas with standing water were especially attractive for these groups. This suggests a possible manipulation of water levels on disposal

sites to increase their attractiveness for birds. If relatively constant highwater levels could be maintained on these areas between dredge operations, they would be excellent waterfowl and shorebird habitats. An additional benefit might be the reduction of mosquito populations (especially *Aedes* spp.) which are associated with fissured soil conditions and fluctuating water levels.

Management suggestions

16. Charleston dredged material disposal sites often attract significant numbers of game birds, which beside waterfowl include mourning doves *(Zenaida macroura)*, clapper rail *(Rallus longirostris)*, and common snipe *(Capella gallinago)*. Thus such areas have considerable recreational values as sites for public hunting especially for waterfowl. They are even more valuable in densely inhabited urban areas such as Charleston County where opportunities for public waterfowl hunting are restricted. Perhaps the Corps of Engineers should consider the establishment of leasing arrangement with the State Wildlife and Marine Resources Departments to designate specific disposal sites as public hunting areas. Such a system would not only have great public relations value, but also would generate additional monies to help defray the cost of managing such areas for wildlife.

Summary

17. The following eight points summarize the important avian relationships observed in this study.

- a. Birds are an attractive and useful part of many coastal ecosystems.
- b. Birds and mosquitoes are frequently associated with the transmission of arboviruses to man. In view of this fact, any association of large bird populations with large mosquito populations may have public health implications.
- c. This section of the study was concerned with

documenting the extent of bird utilization of dredged material disposal sites in coastal South Carolina and secondarily the development of management suggestions that might minimize mosquito breeding and encourage further bird utilization.

d. A total of 164 species of birds were observed on disposal sites.

e. S. C. disposal areas were not found to be important bird breeding sites for colonial water birds, with the possible exception of the least tern.

f. S. C. disposal sites were found to be significantly important breeding sites for long-legged wading birds.

g. Other avian species for whom dredged material disposal sites are important include the black-necked stilt and Wilson's plover.

h. Certain dredged material disposal sites might be managed for the elimination of *Aedes* spp. of mosquitoes and the enhancement of bird utilization.

i. A composite summary of all birds known or observed from dredged material disposal sites in the Charleston CE District is presented as Table F3.

Table F3

Occurrence of Birds on Dredged Material Disposal Sites in Charleston County, South Carolina

Common Name	Scientific Name	Abundance** & Status*	Remarks
Common	*Gavia immer*	FC-WV	Present in all water areas
Red-throated Loon	*G. stellata*	U-WV	Present in all water areas
Horned Grebe	*Podiceps auritus*	C-WV	Present in all water areas
Pied-billed Grebe	*Podilymbus podiceps*	C-PR	Breeds on Morris Is. & AIWW
Brown Pelican	*Pelecanus occidentalis*	FC-PR	Morris Island only
Double-crested Cormorant	*Phalacrocorax auritus*	FC-WV	
Great Blue Heron	*Ardea heriodias*	C-PR	Breeds on Drum Island
Northern Green Heron	*Butorides striatus virenscens*	U-SR	Estuarine sites only
Little Blue Heron	*Florida caerulea*	FC-PR	Breeds on Drum Island
Cattle Egret	*Bubulcus ibis*	C-SR	Breeds on Drum Island
Great Egret	*Casmerodius albus*	C-PR	Breeds on Drum Island

(continued)

*Status

a. PR - permanent resident, found year around.
b. SR - summer resident, breeds.
c. SV - summer visitor, present in summer but does not breed.
d. WV - winter visitor, present in winter.
e. M - migrant, transient.

**Abundance

a. C - common, seen in good number in appropriate season.
b. FC - fairly common, seen in moderate number in appropriate season.
c. U - uncommon, seen in small numbers and/or not seen every time in appropriate season.
d. R - rare, seen in small numbers but not every season.
e. AC - accidental, outside normal range, very few recorded.

(continued)

(Sheet 1 of 6)

Table F3 (continued)

Common Name	Scientific Name	Abundance** & Status*	Remarks
Snowy Egret	*Egretta thula*	C-PR	Breeds on Drum Island
Louisiana Heron	*Hydranassa tricolor*	C-PR	Breeds on Drum Island
Black-crowned Night Heron	*Nycticorax nycticorax*	C-PR	Breeds on Drum Is. & AIWW
Yellow-crowned Night Heron	*Nycticorax violacea*	FC-PR	Breeds on Drum Is. & AIWW
Least Bittern	*Ixobrychus exilis*	U-SR	
American Bittern	*Botaurus letiginosus*	FC-SR	
Wood Stork	*Mycteria americana*	FC-SR	
Glossy Ibis	*Plegadis falcinellus*	FC-SR	Breeds on Drum Is. Estu. areas
White Ibis	*Eudocimus albus*	C-PR	All disposal areas
Roseate Spoonbill	*Ajaia ajaja*	AC	1 Rec. Drum, Sp. 74,R.Porcher
American Flamingo	*Phoenicopterus ruber*	AC	1 Rec. Morris,Aug 76,P.Laurie
Canada Goose	*Branta canadensis*	R-WV	Morris Island only
Snow Goose	*Chen caerulescens*	R-WV	Morris Is. & Estuarine areas
Mallard	*Anas platyrynchos*	C-WV	
Black Duck	*Anas rubripes*	C-WV	
Gadwall	*Anas strepera*	FC-WV	
Pintail	*Anas acuta*	FC-WV	
Green-winged Teal	*Anas crecca*	C-WV	
Blue-winged Teal	*Anas discors*	C-WV	
American Widgeon	*Anas americana*	C-WV	
Shoveler	*Anas clypeata*	C-WV	
Wood Duck	*Aix sponsa*	U-PR	Estuarine disposal areas
Redhead	*Aythya americana*	U-WV	
Ring-necked Duck	*Aythya collaris*	C-WV	
Canvasback	*Aythya valisineria*	U-WV	
Scaup species	*Aythya* sp.	C-WV	
Common Goldeneye	*Bucephala clangula*	U-WV	Morris Island only
Bufflehead	*Bucephala albeola*	C-WV	
Ruddy Duck	*Oxyura jamaicensis*	C-WV	

(continued)

(Sheet 2 of 6)

Table F3 (continued)

Common Name	Scientific Name	Abundance & Status	Remarks
Hooded Merganser	*Lophodytes cucullatus*	C-WV	
Red-breasted Merganser	*Mergus serrator*	C-WV	
Turkey Vulture	*Cathartes aura*	FC-PR	
Black Vulture	*Coragyps atratus*	FC-PR	
Sharp-shinned Hawk	*Accipiter striatus*	U-PR	R - in summer
Cooper's Hawk	*Accipiter cooperii*	U-PR	R - in summer
Red-tailed Hawk	*Buteo jamaicensis*	FC-PR	
Bald Eagle	*Haliaetus leucocephalus*	R-PR	1 obs. Ashe Is. June 75,Brooks
Marsh Hawk	*Circus cyaneus*	C-WV	
Osprey	*Pandion haliaetus*	U-PR	Estuarine disposal areas
Merlin	*Falco columbarius*	U-WV	
American Kestrel	*Falco sparverius*	FC-WV	
Clapper Rail	*Rallus longirostris*	C-PR	Breeds on disposal island
Virginia Rail	*Rallus limicola*	FC-WV	Breeds on disposal island
Sora	*Porzana carolina*	FC-WV	
Common Gallinule	*Gallinula chloropus*	U-PR	
American Coot	*Fulica americana*	C-PR	
American Oystercatcher	*Haematopus palliatus*	FC-PR	Breeds on disposal island
Semipalmated Plover	*Charadrius semipalmatus*	C-PR	
Piping Plover	*Charadrius melodus*	FC-WV	Morris Island only
Wilson's Plover	*Charadrius wilsonia*	C-SR	Breeds on disposal island
Black-bellied Plover	*Pluvialis squatarola*	C-PR	
Ruddy Turnstone	*Arenaria interpres*	C-PR	Morris & AIWW disposal is.
Common Snipe	*Capella gallinago*	FC-WV	
Long-billed Curlew	*Numenius americanus*	R-WV	1 Rec. 1bird,N-22,Forsythe
Whimbrel	*Numenius phaeopus*	FC-M	
Spotted Sandpiper	*Actitis macularia*	C-WV	
Solitary Sandpiper	*Tringa solitaria*	FC-M	
Greater Yellowlegs	*Tringa melanoleucus*	FC-WV	
Lesser Yellowlegs	*Tringa flavipes*	FC-WV	
Willet	*Catoptrophorous semipalmatus*	C-PR	Breeds on disposal island

(continued)

(Sheet 3 of 6)

Table F3 (continued)

Common Name	Scientific Name	Abundance & Status	Remarks
Red Knot	*Calidris canutus*	FC-M	
Pectoral Sandpiper	*Calidris melanotos*	FC-M	
Least Sandpiper	*Calidris minutilla*	C-PR	Less C in summer
Semipalmated Sandpiper	*Calidris pusillus*	FC-M	
Western Sandpiper	*Calidris mauri*	C-PR	
Dunlin	*Calidris alpina*	FC-WV	
Sanderling	*Calidris alba*	FC-PR	
Short-billed Dowitcher	*Limnodromus griseus*	C-PR	Less C in summer
American Avocet	*Recurvirostra americana*	FC-M	
Black-necked Stilt	*Himantopus mexicanus*	FC-SR	Breeds on disposal island
Wilson's Phalarope	*Steganopus tricolor*	R-M	2 records, Morris Is. only
Great Black-backed Gull	*Larus marinus*	U-WV	Morris Island only
Herring Gull	*Larus argentatus*	C-PR	Less C in summer
Ring-billed Gull	*Larus delawarensis*	C-PR	Less C in summer
Laughing Gull	*Larus atricilla*	C-PR	Less C in winter
Bonaparte's Gull	*Larus philadelphia*	C-WV	
Gull-billed Tern	*Gelochelidon nilotica*	FC-SR	May breed on disposal is.
Forster's Tern	*Sterna fosteri*	C-PR	
Common Tern	*Sterna hirundo*	U-PR	Morris Island only
Least Tern	*Sterna albifrons*	C-SR	Breeds on disposal areas
Royal Tern	*Sterna maximus*	C-PR	
Sandwich Tern	*Sterna sandvicensis*	U-SR	Morris Island only
Caspian Tern	*Sterna caspia*	FC-WV	
Black Tern	*Chlidonias niger*	FC-M	Mainly Morris Island
Black Skimmer	*Rynchops nigra*	FC-PR	Mainly Morris Island
Mourning Dove	*Zenaida macroura*	C-PR	Breeds on disposal areas
Ground Dove	*Columbina passerina*	FC-PR	Breeds on disposal areas
Yellow-billed Cuckoo	*Coccyzus americanus*	C-SR	Breeds on disposal areas
Common Nighthawk	*Cordeiles minor*	C-SR	Breeds on disposal areas
Chimney Swift	*Chaetura pelagica*	FC-SV	
Ruby-throated Hummingbird	*Archilochus colubris*	FC-SV	

(continued)

(Sheet 4 of 6)

Table F3 (continued)

Common Name	Scientific Name	Abundance & Status	Remarks
Belted Kingfisher	*Megaceryle alcyon*	C-PR	
Common Flicker	*Colaptes auratus*	FC-PR	Breeds on wooded disp. site
Red-bellied Woodpecker	*Melanerpes carolinus*	U-RP	May breed on wooded disp.site
Red-headed Woodpecker	*Melanerpes erythrocephalus*	FC-PR	Breeds on dis.area w/dead tree
Yellow-bellied Sapsucker	*Sphyrapicus varius*	FC-WV	Wooded disposal areas
Eastern Kingbird	*Tyrannus tryannus*	FC-SR	
Eastern Phoebe	*Sayornis phoebe*	C-WV	
Tree Swallow	*Iridoprocne bicolor*	FC-WV	Over water
Rough-winged Swallow	*Stelgidopteryx ruficollis*	FC-SV	Over water
Barn Swallow	*Hirundo rustica*	FC-PR	
Purple Martin	*Progne subis*	FC-SV	
Blue Jay	*Cyanocitta cristata*	FC-PR	Wooded areas
Common Crow	*Corvus brachyrhychos*	FC-PR	
Fish Crow	*Corvus ossifragus*	C-PR	
House Wren	*Troglodytes aedon*	C-WV	
Winter Wren	*Troglodytes hiemalis*	U-WV	
Carolina Wren	*Thryothorus ludovicianus*	C-PR	Breeds on wooded disp. sites
Long-billed Marsh Wren	*Cistothorus palustris*	C-PR	Br. on dis. area in *Spartina*
Short-billed Marsh Wren	*Cistothorus platensis*	FC-WV	
Mockingbird	*Minus polyglottos*	C-PR	Breeds on disposal areas
Catbird	*Dumetella carolinensis*	FC-WV	
Brown Thrasher	*Toxostoma rufum*	FC-PR	Breeds on disposal areas
American Robin	*Turdus migratorius*	C-WV	
Blue-gray Gnatcatcher	*Polioptila caerulea*	FC-PR	
Ruby-crowned Kinglet	*Regulus calendula*	C-WV	
Water Pipit	*Anthus spinoletta*	C-WV	
Cedar Waxwing	*Bombycilla cedrorum*	FC-WV	
Loggerhead Shrike	*Lanius ludovicianus*	FC-PR	Breeds on bushy disp. areas
White-eyed Vireo	*Vireo griseus*	FC-SR	Breeds on bushy disp. areas
Solitary Vireo	*Vireo solitarius*	FC-WV	Breeds on bushy disp. areas
Red-eyed Vireo	*Vireo olivaceus*	FC-SR	Breeds on bushy disp. areas

(continued)

Table F3 (concluded)

Common Name	Scientific Name	Abundance & Status	Remarks
Black & White Warbler	*Mniotilta varia*	U-WV	Breeds on bushy disp. areas
Orange-crowned Warbler	*Vermivora celata*	U-WV	Breeds on bushy disp. areas
Northern Parula	*Parula americana*	FC-SR	Breeds on disp.areas w/tree
Yellow Warbler	*Dendroica petechia*	FC- M	Breeds on bushy disp. areas
Yellow-rumped Warbler	*Dendroica coronata*	C-WV	
Yellow-throated Warbler	*Dendroica dominica*	FC-SR	Breeds in pines on disp.area
Pine Warbler	*Dendroica pinus*	FC-SR	Breeds in pines on disp.area
Prairie Warbler	*Dendroica discolor*	FC- M	
Palm Warbler	*Dendroica palmarum*	C-WV	
Northern Waterthrush	*Seiurus noveboracensis*	C- M	
Kentucky Warbler	*Oporonis formosus*	FC- M	
Common Yellow Throat	*Geothlypsis trichas*	C-PR	Less C in winter
Hooded Warbler	*Wilsonia citrina*	FC- M	
American Redstart	*Setophaga ruticilla*	FC- M	
Eastern Meadowlark	*Sturnella magna*	FC-WV	
Red-winged Blackbird	*Agelaius phoeniceus*	C-PR	Breeds on disposal areas
Rusty Blackbird	*Euphagus carolinus*	U-WV	
Boat-tailed Grackle	*Quiscalus major*	C-PR	Breeds on disposal areas
Cardinal	*Cardinalis cardinalis*	C-PR	Breeds on disposal areas
Indigo Bunting	*Passerina cyanea*	FC-SR	Breeds on disposal areas
Painted Bunting	*Passerina ciris*	FC-SR	Breeds on disposal areas
American Goldfinch	*Carduelis tristis*	C-WV	
Rufous-sided Towhee	*Pipilo erythrophthalmus*	C-PR	Breeds in marsh
Savannah Sparrow	*Passerculus sandwichensis*	C-WV	
Sharp-tailed Sparrow	*Ammospiza caudacuta*	C-WV	
Seaside Sparrow	*Ammospiza maritima*	FC-PR	Breeds in *Spartina*
Vesper Sparrow	*Pooecetes gramineus*	FC-WV	
Dark-eyed Junco	*Junco hyemalis*	FC-WV	
White-throated Sparrow	*Zonotrichia leucophrys*	C-WV	
Swamp Sparrow	*Melospiza georgiana*	C-WV	
Song Sparrow	*Melospiza melodia*	C-WV	

(Sheet 6 of 6)

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.

Ezell, William Bruce, ed.
An investigation of physical, chemical, and/or biological control of mosquitoes in dredged material disposal areas / edited by Wm. Bruce Ezell, Jr., The Citadel, The Military College of South Carolina, Charleston, S. C. Vicksburg, Miss. U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
266, [184] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-48)
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