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DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-45

IMPACT OF FLUID MUD DREDGED MATERIAL ON BENTHIC COMMUNITIES OF THE TIDAL JAMES RIVER, VIRGINIA

by

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Final Report

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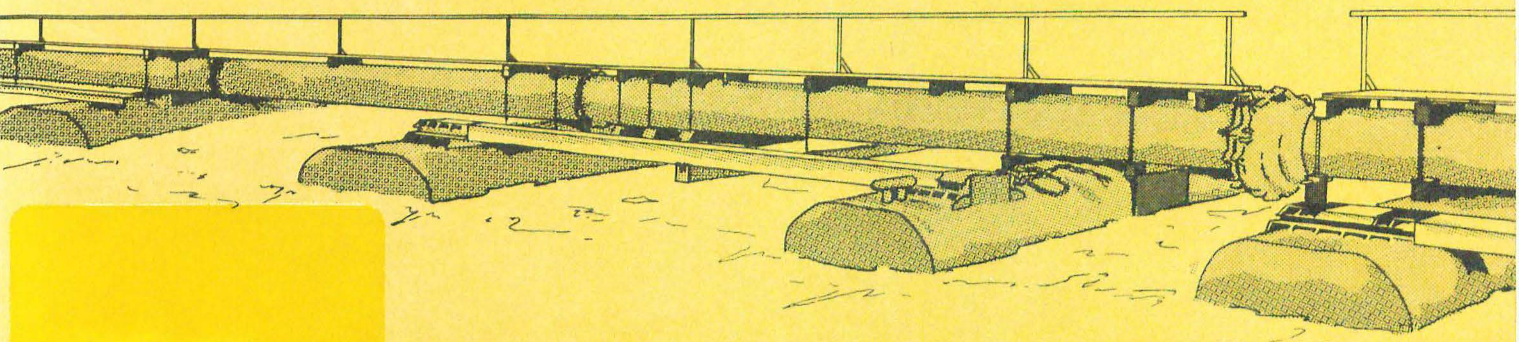

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31 January 1978

SUBJECT: Transmittal of Technical Report D-77-45

TO: All Report Recipients

1. The work reported herein was undertaken as Work Unit 1D12 of Task 1D, Effects of Dredging and Disposal on Aquatic Organisms, of the Corps of Engineers' Dredged Material Research Program. Task 1D is a part of the Environmental Impacts and Criteria Development Project (EICDP), which has a general objective of determining on a regional basis the direct and indirect effects on aquatic organisms due to dredging and disposal operations. The study reported herein was part of a series of research contracts developed to achieve the EICDP general objectives.

2. The specific objectives of this research were (a) to determine the acute impact of hydraulic pipeline dredging and disposal on a freshwater benthic community, (b) to document the effects of the fluid mud layer associated with the dredged material discharged on these biological communities, and (c) to evaluate the persistence of the impact and the recoverability or resiliency of the biological communities. The site chosen for this investigation was the Jordan Point-Windmill Point channel of the James River, Virginia. The organisms studied were associated with a tidal freshwater benthic community. Specific goals included investigation of the physical behavior and biological effects of fluid mud resulting from the disposal operation and subsequent smothering of benthic organisms in its path. This study was conducted as an adjunct to more extensive studies on the physical properties of fluid mud at several estuarine sites as part of DMRP Task 6C, Turbidity Prediction and Control (Work Unit 6C07).

3. The results indicate that the benthic community, dominated by oligochaetes, chironomid insect larvae, and the Asiatic clam Corbicula, was acutely impacted by the disposal. The impact was noted by reductions in the fauna and was proportional to the accumulation of dredged material. Low sediment bulk density (i.e., fluid mud), low dissolved oxygen, and some possible unknown factors (release of toxins) were probable contributors to the impact. Insects and small clams were most affected; oligochaetes were relatively unaffected. Due to the resilience and opportunistic nature of the fauna, the site was recolonized within three months.

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4. It is recommended that fluid mud from different types of dredged material be assessed and that practices which minimize the formation of fluid mud be established. Particular attention should be given to bottom topography and tidal currents in order to minimize spread. Disposal site selection could then consider likely biological community responses and impacts on the most sensitive or valuable communities could be avoided.

5. The information and data published in this report contribute to a further understanding of the complex nature of sediment, water, and physical/biological interactions and establish a baseline from which to develop meaningful evaluations for the selection of an environmentally compatible disposal alternative. It is expected that the methodology employed in this study and the resulting interpretation of the physical/biological interactions will be of significant value to those concerned with CE dredged material permit programs.

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)

The unconfined open-water disposal resulting from the maintenance dredging of the Jordan Point - Windmill Point channel had an acute impact on the macrobenthic community. The fluid mud produced from the disposal operation probably had both physical and physiological effects on the fauna. Responses varied by species. Insects were the most sensitive and oligochaetes the least affected. Due to the resilience and opportunistic nature of the fauna the detectable impacts lasted less than 3 months. Fluid mud produced from disposal of

(Continued)

20. ABSTRACT (Continued).

fine-grained dredged material has properties and effects different than natural sediments. Its low density, instability and low oxygen concentration present severe problems of support, respiration and feeding of benthic organisms.

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SUMMARY

Maintenance dredging of the Jordan Point - Windmill Point navigation channel of the James River, Virginia, in July 1976 resulted in the unconfined open-water pipeline disposal of fine-grained dredged material on an adjacent shoal site. This provided an opportunity to study the physical behavior and biological effects of fluid mud resulting from the disposal operation. Fluid mud driven by gravity or tidal currents could spread far outside the intended disposal area, smothering benthic organisms in its path. The large quantity of fluid low-bulk-density sediment often produced by the disposal operation presents unique biological problems not associated with turbidity or burial by more consolidated material.

This report presents the results of a pilot study consisting of a field assessment of the effects of fluid mud on tidal freshwater benthic communities at the Windmill Point disposal site. The study was conducted as an adjunct to more extensive studies on the physical properties of fluid mud at several estuarine sites conducted for the U. S. Army Engineer Waterways Experiment Station by the Virginia Institute of Marine Science.

The benthic community at the disposal shoal before the disposal operation was characterized by a low-diversity fauna dominated by oligochaetes, chironomid insect larvae and the Asiatic clam *Corbicula*. The disposal operation did have an acute impact on the benthos causing reductions in the fauna in proportion to the amount of dredged material accumulated. Low sediment bulk density, low dissolved oxygen and possibly other unmeasured factors (e.g. mobilization of toxins), all may have contributed to the measured effects. Fluid mud, which may move beyond the bounds of the disposal site, interferes with support, feeding and respiration of benthic organisms. All taxa were affected but the insects were most affected, followed by small *Corbicula*. Oligochaetes were relatively unaffected and subsequently became more abundant at the disposal site than at the reference site.

The resilient and opportunistic nature of the fauna buffered the

impact of the disposal operation in the tidal freshwater James River. All but a few of the more sensitive insect species had repopulated the site 3 months after disposal, mainly through immigration of individuals from the surrounding unaffected areas. *Corbicula* recolonized by setting of planktonic larvae.

The potential for the creation of fluid mud from different types of dredged material and dredging methods needs to be assessed, so that practices which minimize the formation of fluid mud can be established. The relative susceptibility of various communities to the effects of fluid mud should be studied in order to help guide disposal site selection.

PREFACE

This report presents the results of an investigation to assess the impact of fluid mud produced by unconfined open-water pipeline disposal of fine-grained dredged material on the macrobenthic community in the James River Windmill Point area, Virginia. This study was conducted as part of the Dredged Material Research Program (DMRP) which is sponsored by the Office, Chief of Engineers, U. S. Army, and is being managed by the Environmental Effects Laboratory (EEL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The investigation was conducted under Contract No. DACW39-75-C-0121 to the Virginia Institute of Marine Science, Gloucester Point, Virginia. This report was prepared by Robert J. Diaz and Donald F. Boesch, and has been designated by the Institute as Special Report in Applied Marine Science and Ocean Engineering Number 153.

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The report was prepared for the Environmental Impacts and Criteria Development Project of the DMRP (Dr. Robert M. Engler, Project Manager) as part of Task 1D, "Effects of Dredging and Disposal on Aquatic Organisms." The contract was monitored by Dr. Richard K. Peddicord under the general supervision of Dr. John Harrison, Chief, EEL.

COL J. L. Cannon, CE, was Director of WES during the period of this contract and Mr. F. R. Brown was the Technical Director.

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LIST OF FIGURES

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

U. S. customary units of measurement can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
miles (U. S. nautical)	1.852	kilometres
cubic yards	0.7645549	cubic metres

IMPACT OF FLUID MUD DREDGED MATERIAL ON BENTHIC COMMUNITIES OF THE TIDAL JAMES RIVER, VIRGINIA

INTRODUCTION

1. A major concern about open-water disposal of dredged material is its impact on the benthic biota in the disposal area. Ideally the extent of such impacts is confined within prescribed disposal sites. In practice, however, it is often difficult to control the ultimate distribution of the dredged material, such that potential impacts to the benthos may extend well outside the confines of the disposal site. This is particularly the case with very fine, unconsolidated sediment often generated by maintenance dredging. Such material may flow in concentrated suspension along the bottom driven by gravity or tidal currents. This so-called "fluid mud" has the potential to smother any benthos it may cover. Fluid mud is arbitrarily defined as sediment with bulk density of less than 1.3, high water content and suspended concentrations higher than 10 g/l (Nichols et al. 1977).

2. This report presents the results of a pilot field study assessing the effects of fluid mud on tidal freshwater benthic communities in the James River, Virginia (Figure 1). The study was conducted as an adjunct to more extensive studies on the physical properties of fluid mud at several estuarine sites by Nichols et al. (1977).

3. The goal of this study was to provide a semiquantitative estimate of the effects on the natural benthic communities of fluid mud resulting from disposal of material removed by maintenance dredging from the Jordan Point - Windmill Point navigation channel. The limited effort involved in this study did not permit a rigor of design necessary for highly quantitative assessments. Rather, it was intended to evaluate the feasibility of the approach and to determine whether the detection of effects was possible under the boundary condition of a naturally highly stressed community.

4. The area studied was a silty shoal environment near Bucklers

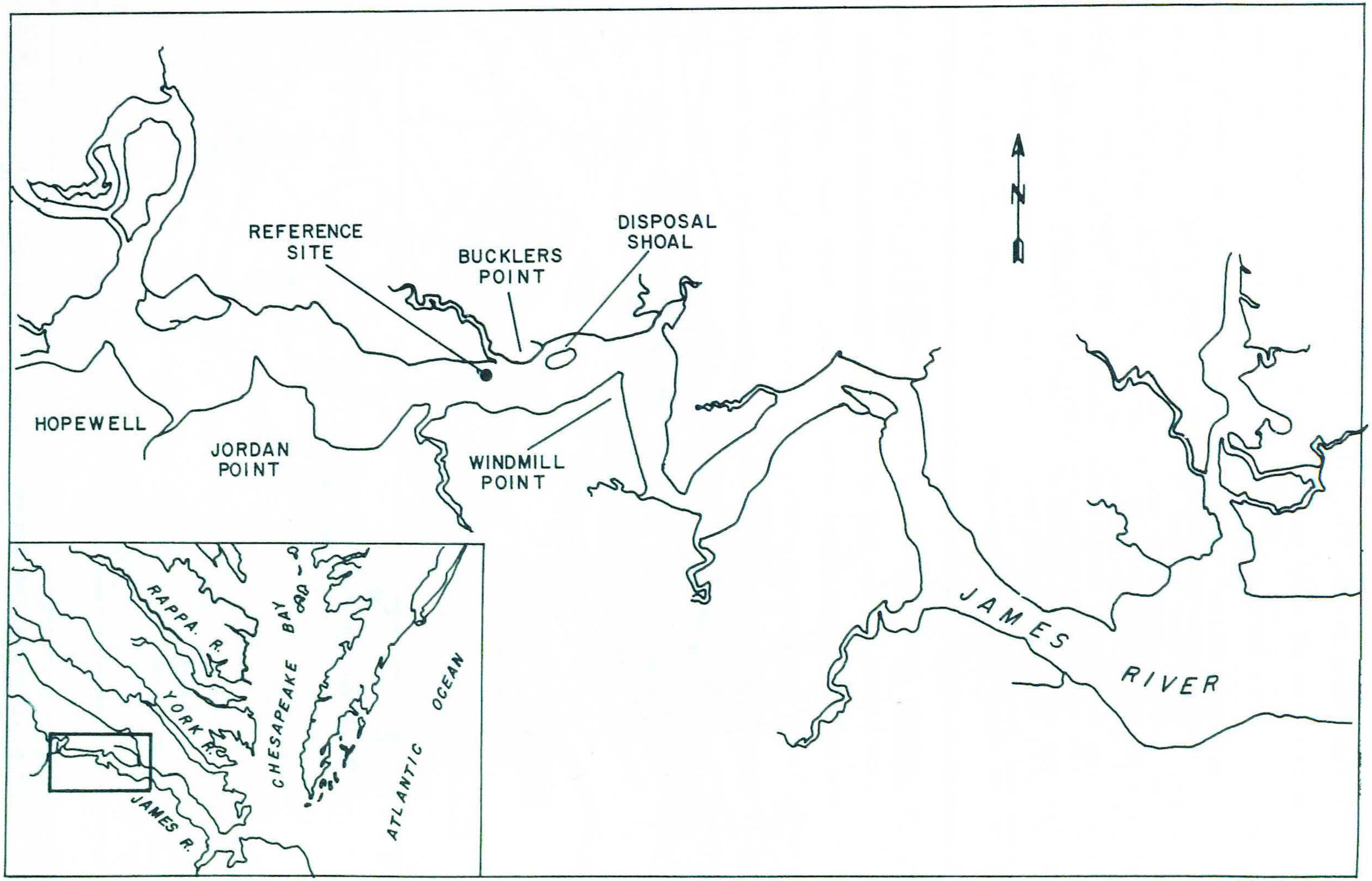

Figure 1. Location of study site in the tidal James River

Point in the James River, Virginia. During the past 15 years the area has been the site of many open-water unconfined disposal operations (Figure 2). This section of the river is influenced by tides but it is 20 to 25 nautical miles* upriver of the current estuarine-freshwater transition. The river bottom is inhabited by a low-diversity macrobenthic community dominated by oligochaetes, chironomid larvae and the Asiatic clam *Corbicula manilensis* (Jensen 1974; Diaz 1977). Detailed descriptions of the marcobenthos at nearby Windmill Point can be found in Diaz and Boesch (1977a, b).

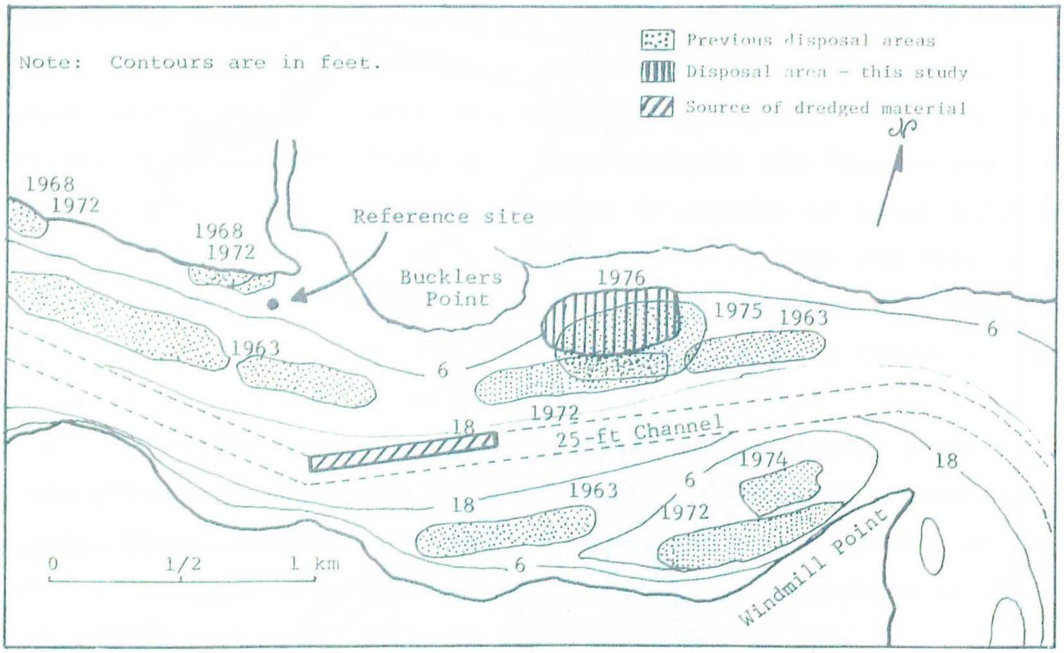

Figure 2. Sites of recent dredged material disposal in the Windmill Point area

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 7.

MATERIALS AND METHODS

Sampling Design

5. Pre-operational benthic macroinvertebrate sampling sites were located on the most probable paths of the fluid mud. After the resulting fate of the dredged material was determined by Nichols et al. (1977) the sampling sites were stratified *a posteriori* based on the total thickness of dredged material deposited on the previous shoal (Figure 3). Inability to predict the exact distribution of the dredged material led to an imbalance of information in the stratified design with some strata having more sampling sites than others. This did not hinder the evaluation of fluid mud effects but precluded the use of many parametric statistical techniques that require a more equitable distribution of data.

6. A transect was run starting 1350 m downstream from the end of the planned disposal site and parallel to the channel (Figure 3). In

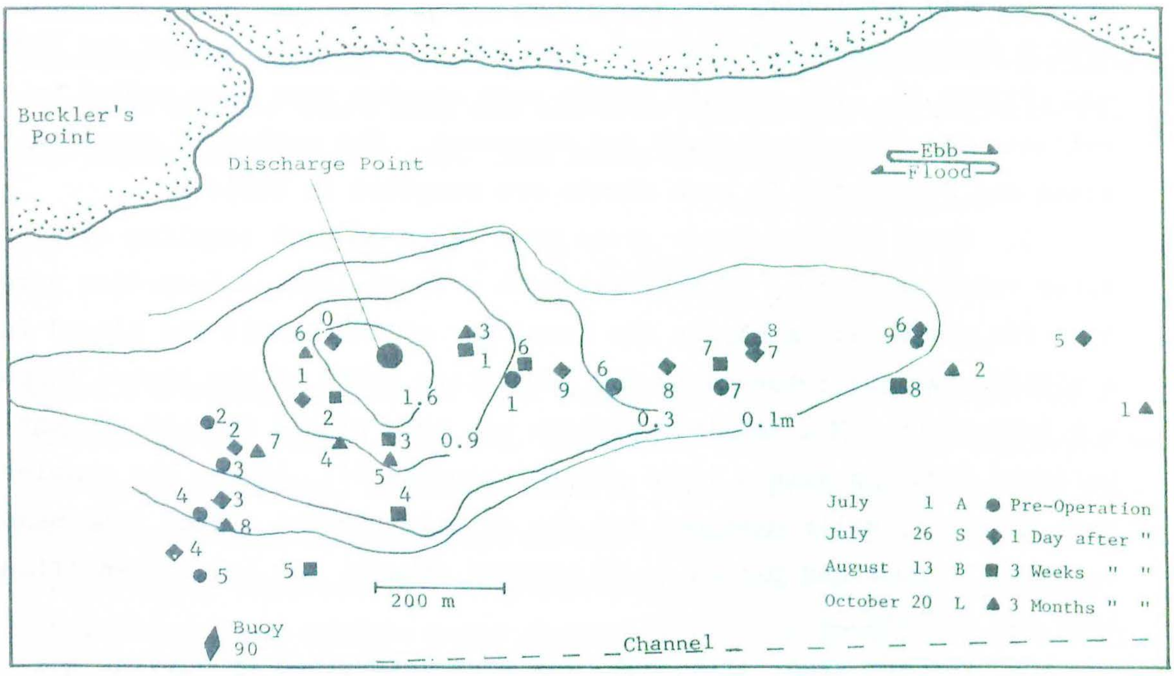

Figure 3. Location of benthic sampling sites on the disposal shoal. Contours indicate the thickness of fluid mud on July 20

the area of the discharge point the transect turned and ran perpendicular to the channel out toward channel buoy 90. Stations were scattered along the transect and not kept at fixed sites. This insured that the fluid mud and newly deposited material would be adequately sampled.

7. To provide a reference to pre-disposal conditions of both sediments and benthic communities, the disposal shoal was sampled 1 July 1976, 11 days before the start of channel dredging. The day after the disposal operation ended, 26 July 1976, the shoal was resampled to determine the species that quickly recolonized or survived in the disposal area. On 13 August, 3 weeks after disposal, and 20 October, 3 months after disposal, the shoal was resampled to monitor recolonization (Figure 3).

8. After the disposal shoal was sampled, each benthic sampling site was classified based on acoustical thickness and visual fluff measurement of fluid mud made by Nichols et al. (1977). Five strata were chosen corresponding to fluid mud thicknesses of less than 0.1, 0.1 to 0.3, 0.3 to 0.9, 0.9 to 1.6, and greater than 1.6 m above the bottom contour before the disposal operation. A reference site was located 1650 m upriver from the disposal site out of the influence of any fluid mud (Figure 1). All samples within each stratum were then pooled to evaluate the effects of fluid mud dispersal. The number of sampling sites and replicates in each strata are compiled in Table 1.

9. Three 0.05-m^2 Ponar grabs were taken at each sampling site. After removing 40-50 g of sediment with a 10-cm-long, 2.5-cm-diam core tube for grain-size analysis the remainder of the sample was placed in a plastic bag and returned to the laboratory where it was washed through a 0.5-mm sieve. The retained portion was then placed in 5-10 percent buffered formalin with a vital stain (phloxine B). Later, the samples were microscopically examined and the animals present sorted into major taxonomic groups and placed in 70 percent ethanol for later identification and enumeration.

10. Percent sand, silt, and clay were determined by sieving and pipette analysis following procedures of Folk (1968). Sediment descriptions refer to the Udden-Wentworth classification (Pettijohn 1957).

Total solids and volatile solids were determined for the 26 July and 20 October samples and for one of the 13 August samples in accordance with procedures of Standard Methods (American Public Health Association 1971). The amount of detritus, or light material retained on a 0.063-mm screen including vermiculite, mica, plant roots, leaves and stems, was determined and expressed as a percent of the total dry weight of the sediment.

11. Dissolved oxygen and temperature were measured 0.5 m from the sediment surface at each sampling site with a YSI model 54 oxygen meter. Oxygen measurements were not taken in October (3 months after disposal) because the meter malfunctioned.

Numerical Methods

Diversity index

12. Species diversity was measured by the commonly used index of Shannon (Pielou 1975), which expresses the information content per individual. The index denotes the uncertainty in predicting the specific identity of a randomly chosen individual from a multispecies assemblage. The more species there are, and the more evenly they are represented, the higher this uncertainty. The index is given by:

$$H' = - \sum_{i=1}^{s} p_i \log_2 p_i \qquad (1)$$

where s = number of species in a sample and p_i = proportion of the i-th species in the sample. Species diversity, particularly as expressed by the Shannon measure, is widely used in impact assessments and may correlate well with environmental stress (Wilhm and Dorris 1968; Armstrong et al. 1971; Boesch 1972). More adverse and stressful environmental conditions often exhibit lower species diversity although this relationship is often not simple (Goodman 1975; Jacobs 1975).

13. As considered above, species diversity is a composite of two components: species richness, the number of species in a community;

and evenness, how the individuals are distributed among the species. Two measures of species richness were used: the number of species per unit area (in this case 0.05 m^2) or areal richness, and the other a measure standardized on the basis of the size of the sample in terms of numbers of individuals:

$$SR = \frac{(S - 1)}{\log_e N} \qquad (2)$$

where S = number of species and N = number of individuals in a sample. Evenness was expressed as (Pielou 1975):

$$J' = \frac{H'}{\log_2 S} \qquad (3)$$

where H' is determined by equation (1).

Similarity coefficient

14. Qualitative and quantitative similarity measures were calculated between sampling sites and averaged by stratum to detect any changes in community structure. When the coefficients are 1 (or very close to it) the sites compared are identical; when 0 (or very close to it) the sites have no species in common. The qualitative (based on species presence/absence) similarity coefficient chosen was the Dice (Sorensen) coefficient (Goodall 1973) calculated as:

$$D_{ij} = \frac{2a}{2a + b + c} \qquad (4)$$

where a is the number of species occurring at both sites i and j, b the species occurring at site j only, and c the species occurring at site i only. The quantitative (based on patterns of species abundance) coefficient chosen was the Bray-Curtis (or Czekanowski) coefficient (Goodall 1973) calculated as:

$$S_{jk} = 1 - \frac{\sum_i |x_{ji} - x_{ki}|}{\sum_i (x_{ji} + x_{ki})} \tag{5}$$

where S_{jk} is the similarity between collections at stations j and k, x_{ji} is the abundance of the i-th species at station j, and x_{ki} the abundance of the i-th species at station k. To dampen the sensitivity of the Bray-Curtis index to the numerically dominant species, all absolute abundances were log-transformed as:

$$y = \ln (x + 1) \tag{6}$$

An advantage in using these two coefficients is that the Dice coefficient is the binary equivalent of the Bray-Curtis coefficient.

Numerical classification

15. Numerical classification was also used to evaluate changes in species composition at stations through time. The relationships between stations were studied by computing the Bray-Curtis index as given in equation (5). The stations were clustered based on the resulting resemblance matrix expressing relationships in the form of a dendrogram. The dendrogram graphically depicts the interrelationships among the samples in a hierarchial fashion. The clusters or groups produced by the clustering algorithm do not have an objective existence but are rather a property of the numerical process and data set (Williams 1971).

16. Cluster creation and interpretation must consider the above factors. Even though the technique is objective, its application and interpretation can be rather subjective. The flexible sorting strategy was chosen because of its mathematical properties and proven usefulness in ecology (Boesch 1973; Clifford and Stephenson 1975). The cluster intensity coefficient β was set at -0.25, which effects moderately intense clustering.

RESULTS

Sediments

Disposal operation

17. A hydraulic cutterhead dredge started maintenance dredging of the navigation channel above Windmill Point on 11 July 1976 and was in more or less continuous operation up to 25 July 1976. The dredge removed 219,810 cu yd of material, based on the log kept by the dredge operators, and disposed of it on a submerged shoal east of Bucklers Point (Figure 2). The movement of the dredge discharge pipe was confined to a circle approximately 100 m in diameter throughout the operation.

18. The disposal operation produced large quantities of fluid mud; roughly 676,000 m^2 was covered by more than 0.1 m and about 49,000 m^2 by more than 0.5 m of dredged material. The maximum depth of fluid mud, 2.1 m, was recorded 26 July, the day after the operation stopped (Nichols et al. 1977). By 21 September 1976 the maximum height of the mound of fluid mud was still 2 m.

Grain size

19. Pre-disposal sediments on the disposal shoal were mainly silt with small amounts of very fine sand. Only sites A2 and A6 had appreciable quantities of sand. The distribution of sand over the area prior to disposal was very patchy and variable. One day after the dredging operation was completed, 26 July, the sediments were finer grained, with clayey-silt and silt predominating over the disposal shoal. Sampling site S2 near site A2 was the sandiest, being classified as sandy-silt. About three weeks later, 13 August, the sediments were still finer grained than before the disposal operation. The sandiest site was B2 located in an area which received up to 1.6 m of dredged material. There was a decrease in average clay content from 16.9 percent on 26 July to 5.5 percent in August. Three months after the disposal operation, 20 October, the sediments were still different and finer grained than under pre-operation conditions. In October silt was predominant and

only sediment at site L8 was sandy-silt (Table 2). The grain-size change should be interpreted with caution. The grain-size determinations made after the disposal operation may be biased toward coarser sizes due to loss of fluid mud through the 0.5-mm screen in the top of the grab; thus, the sediment sample may have consisted of a mixture of fluid mud and the underlying substrate.

20. Sediments at the reference site were clayey-silt in July and became siltier in August and October. In general the sediments on the disposal shoal became finer and more homogeneous after the disposal operation. Mean sand, silt and clay percentages and their standard deviations for the disposal shoal for each sampling period are:

		Sand	Silt	Clay
Pre-operation:	$\overline{X}$	22.8	64.4	12.8
	SD	22.0	19.8	3.9
1 day after:	$\overline{X}$	9.8	73.3	16.9
	SD	8.0	9.2	5.6
3 weeks after:	$\overline{X}$	9.9	84.6	5.5
	SD	8.5	8.2	1.7
3 months after:	$\overline{X}$	11.3	82.2	6.4
	SD	11.2	11.6	1.2

21. When the sediment parameters were averaged within a sampling period and fluid mud thickness stratum, no apparent pattern of change occurred with increasing depth of fluid mud. The most obvious changes occurred between sampling periods (Table 3).

Total and volatile solids

22. Total and volatile solids measurements may not reflect the true solids content of the surface sediments. The Ponar grab penetrated deeply in the watery fluid mud disrupting the surface portions by squeezing them through the top screen, causing the total solids measurements to be higher than they really were. It is not known what effect this had on volatile solids.

23. Total solids concentrations were lowest 1 day after the dredging ended in areas that received a total thickness of 0.3 to 1.6 m of fluid mud. Three weeks later total solids had increased in these areas.

Three months after dredging there was no pattern in total solids measurements and the values were similar to those of 26 July in areas that received less than 0.3 m of fluid mud (Table 3).

24. Averaged volatile solids, a general indication of organic content, were homogeneous over the area, ranging from 10.0 to 12.3 percent. The highest value occurred in the area that received over 1.6 m of fluid mud. Volatile solids were slightly higher in October than in July.

25. The detrital content of the sediments ranged from 0.0 to 13.4 percent. The average amount of detritus increased with each sampling period but when averaged by thickness of fluid mud there appeared to be no pattern (Tables 2 and 3).

Dissolved Oxygen and Temperature

26. Bottom water temperature on the disposal shoal in July was 28°C; in August it had dropped one degree and was 14°C in October.

27. Pre-disposal dissolved oxygen levels on the disposal shoal were high, averaging 6.7 mg/l or 85 percent of the saturation value (American Public Health Association 1971). The first day after the dredging ended there was a horizontal gradient of dissolved oxygen with the lowest values in the area that received the most dredged material (Table 3). In August dissolved oxygen was 96 percent of saturation at the reference site and slightly lower over the disposal shoal averaging 81 percent of saturation.

Fauna

General

28. The 117 grabs from the entire pre- and post-dredging survey produced 10,537 individuals (Appendix A) representing 44 taxa (Appendix B). The breakdown by sampling period was as follows:

	Grabs	Taxa	Individuals	Ind./m^2
Pre-operation	30	29	3534	2356
1 day after	33	30	1882	1141
3 weeks after	27	19	2739	2029
3 months after	27	28	2382	1764

Oligochaetes were most numerous comprising 75 percent of all the individuals in the collections. The genus *Limnodrilus*, which was represented by at least 3 species, comprised 89 percent of all the oligochaetes. The most speciose group was the Chironomidae represented by 15 taxa and possibly more. Because of the difficulties in making species determination, several groups known to contain at least two species were lumped as one (i.e. *Chironomus* spp.). Even though the Chironomidae had the most species, it comprised only 9.5 percent of the individuals in the collections and one genus, *Coelotanypus*, comprised 62 percent of the chironomids. Bivalves had 5 taxa representing 11 percent of the individuals, and small (<10-mm) *Corbicula manilensis* made up 95 percent of the bivalves. In summary, oligochaetes, Chironomidae and bivalves comprised 99 percent of the individuals and 31 taxa (70 percent of the total taxa), with three genera (*Limnodrilus, Corbicula,* and *Coelotanypus*) making up 87 percent of the individuals while including only 7 taxa (16 percent of total). The percentage breakdown of major taxa and individuals is contained in Table 4 and of major taxa and species in Table 5.

29. The 9 species occurring at 18 (46 percent) or more of the 39 sites sampled were considered the overall dominants for the collections. The next 15 taxa were considered moderately common and the last 20 rare for the collection (Table 6). Only the distributions of the 24 dominant and moderately common taxa will be considered in detail.

Distribution of dominants

30. *Limnodrilus* spp., the most common taxon in the tidal freshwater James River (Koss et al. 1974; Diaz and Boesch 1977a), typified the response of the dominant species. At the reference site it averaged 2480 individuals/m^2 before disposal and 1265 individuals/m^2 for the four collection periods. The number of *Limnodrilus* spp. per grab was variable but always high at the reference site and in pre-disposal samples.

The day after the disposal operation ended, there was a decline in the number of *Limnodrilus* spp. in areas that had received a 0.3-m or greater thickness of fluid mud. In the area of greatest fluid mud accumulation *Limnodrilus* spp. were virtually absent the day after disposal with only 7 individuals/m^2. Three weeks after disposal *Limnodrilus* spp. had exhibited great recovery with average population densities only slightly lower than pre-disposal or reference densities. Three months after disposal average densities were very close to pre-disposal densities. The lowest densities of *Limnodrilus* spp. consistently occurred in the area overlain with 0.9-1.6 m of fluid mud (Table 7).

31. Densities of *Limnodrilus hoffmeisteri* before disposal were fairly uniform averaging 238 individuals/m^2. The first day after disposal ceased, densities had dropped at the reference site and areas that were covered with greater than 0.3 m of fluid mud. The low density at the reference site is difficult to explain, but could have been caused by spatial heterogeneity, biased samples, or errors in sample processing. Whatever the reason, 3 weeks later densities at the reference site were at pre-operation levels. The high density of *L. hoffmeisteri* in the area receiving a thickness of 0.9-1.6 m of fluid mud could also have several explanations. The worms may have been able to keep contact with the sediment surface by burrowing up through the fluid mud or at least have kept within 30-40 cm of the surface where they could be taken by the grab. Since the disposal operation took 15 days the actual "age" of the surface sediments could realistically be anywhere from 1 to 15 days at the time of sampling. So, if the area sampled on 26 July had been covered several days previously, the *L. hoffmeisteri* could have been recruited as adults. Densities 3 weeks after disposal were all high, the average being the highest of all four collections, indicating a rapid recovery or a higher proportion of *Limnodrilus* spp. (thought to be primarily immature *L. hoffmeisteri*) maturing for the fall spawning peak.

32. The average ratio of *L. hoffmeisteri* to *Limnodrilus* spp. was fairly constant in July at 0.25. In August (3 weeks after disposal), the ratio increased to 0.34, due to an increase in the population of

mature worms. By October the ratio had decreased to 0.07 from both a decrease in the population of mature worms, which had spawned, and an increase in the number of immature *Limnodrilus* (Table 8). Average population density was lowest 3 months after disposal in both the reference and disposal areas indicating a seasonal decline in adult *Limnodrilus*. The absence of *L. hoffmeisteri* from the >1.6-m stratum and decreased numbers in areas receiving fluid mud thickness of 0.3-1.6 m the first day after disposal are most certainly due to the disposal operation (Table 7).

33. *Ilyodrilus templetoni* responded in a manner similar to *L. hoffmeisteri* with high pre-operation densities and lowest densities 1 day after disposal in the reference area and areas receiving fluid mud thickness of >0.9 m. Three weeks after disposal, *Ilyodrilus* demonstrated substantial recovery but did not reach pre-operation densities even at the reference site (Table 7). Low densities in October reflect seasonality at both reference and disposal areas.

34. Small (<10-mm) *Corbicula manilensis*, the introduced Asiatic clam (Diaz 1974), was very variable in distribution. Pre-operation densities were low and very variable, possibly because of the summer attenuation of spawning. *Corbicula* larvae set all year round but there are two peaks, spring and fall, that correspond to spawning activity of adults. The first day after disposal the average density fell but the decline was completely attributable to lack of clams in areas that received more than 0.1 m of fluid mud. At the reference site and areas receiving less than 0.1 m, densities of clams increased greatly. Three weeks after disposal densities were uniformly high, possibly due to the beginning of the fall recruitment from planktonic larvae. There were still high population densities of newly set individuals in October even in areas with greater than 0.3 m of fluid mud (Table 7). The average shell length of small (2- to 10-mm) *Corbicula* was very similar for the July collections (3.29 mm for 1 July and 3.27 for 26 July), as indicated in Table 9. The average length of *Corbicula* from areas receiving 0.1 m or more fluid mud was only 2.48 mm, whereas the average for remaining areas was 3.37, slightly higher than the pre-operation average. The

increase of 0.08 mm in mean length 25 days after disposal is slower than the normal individual growth rate and thus reflects the addition of newly set clams, which were less than 2.0 mm, or an inhibition in growth due to the disposal operation. Three weeks after disposal the average length decreased to 2.72 mm because of the heavy influence of newly set clams in the areas with more than 0.1 m of fluid mud. By October there was another increase in the mean shell length to 3.08 mm indicating again both individual growth combined with recruitment (Table 9).

35. Larvae of *Coelotanypus scapularis*, the most abundant chironomid in the tidal James River (Diaz and Boesch 1977a), were moderately abundant during the pre-operation survey. The first day after disposal only areas receiving more than 0.3 m of fluid mud experienced a decline in abundance, and no *Coelotanypus* were found in areas receiving 1.6 m or more of fluid mud. Three weeks later, average density was high except in areas that received more than 0.9 m, indicating substantial recovery. The increased number of *Coelotanypus* was due mainly to the growth of larvae from the first to the larger second instar which is retained more effectively by the 0.5-mm screen. Only 4 presumed first instars were found in the collections (Figure 4). Most of larvae probably moved onto the new material by active crawling, passive drift with tidal currents or from newly hatched eggs. The single specimen from the area with 0.9-1.6 m of fluid mud the first day after disposal was in its fourth instar. By October the average abundance was still high but there was much more variability (Table 7). The average head capsule length was very consistent throughout the collections indicating that most of the recruitment onto the dredged material was by older larvae in the third and fourth instars (Table 10). *Coelotanypus* pupae were found only in October, occurring at 5 of 9 sampling sites.

36. *Chaoborus punctipennis*, the phantom midge larva, is the only dominant species that leaves the sediment to feed on zooplankton at night. During the day *Chaoborus* lives in the sediments preying on oligochaetes (Howmiller 1977). Pre-operation densities of *C. punctipennis* were low and very variable. The day after disposal there were higher, more uniform densities due to the settlement of the previous

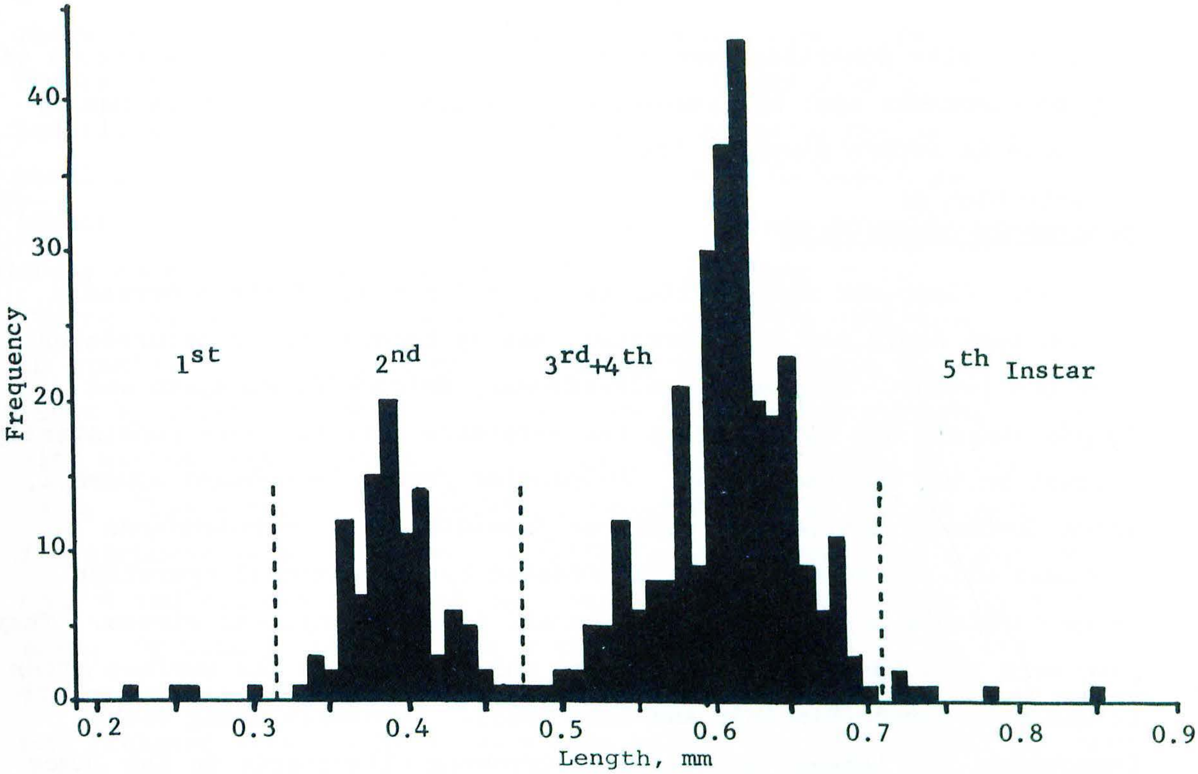

Figure 4. Head capsule length of *Coelotanypus scapularis* larvae from all the benthic samples

night's foragers. The newly deposited material did not seem to discourage the settlement of larvae although some larvae that returned to the sediments during the disposal operation must have been buried too deeply to escape. Densities were again very variable in August and October.

37. Pre-operation and reference site densities of the chironomid larvae, *Harnischia* spp. and *Procladius bellus*, were similar in pattern to *Coelotanypus scapularis*. The response of *Harnischia* spp. to the disposal operation was also similar to *Coelotanypus* except *Harnischia* was reduced in areas that received 0.1 m or more dredged material. *P. bellus* densities were reduced over the entire disposal area after the disposal operation ended and by October had not recovered. Reference site densities of *Procladius* were high in July and August and seasonally declined in October.

38. *Cryptochironomus* spp. response was similar to *Procladius* but more extreme in that up to 3 weeks after disposal *Cryptochironomus* spp. were virtually absent from the disposal area while pre-operation and

reference site densities were very variable. By October populations of *Cryptochironomus* spp. had recovered and average densities were nearly the same as before disposal (Table 7).

Distribution of
moderately common taxa

39. Clear-cut distribution patterns for most of the moderately common taxa could not be determined, mainly because their occurrences were too patchy. *Peloscolex multisetosus, Helobdella elongata* and *Rangia cuneata* did not occur at the reference site but were consistently present on the disposal shoal. *Peloscolex freyi, Branchiura sowerbyi,* large *Corbicula manilensis, Gammarus fasciatus,* and *Dicrotendipes nervosus* all seemed relatively unaffected by the disposal operation. Large *Corbicula* are very tolerant to all types of physical stress. They have even survived mixing in concrete and migrated to the surface after it has been pored (Sinclair and Isom 1963). *Corbicula* along with *Branchiura,* the largest and deepest burrowing oligochaete in the James River, is probably the species best able to cope with high rates of sedimentation associated with dredged material disposal. But when the density of sediment approaches that of fluid mud, the size and bulk of both are detrimental making support difficult.

40. *Chironomus* spp. and *Polypedilum* spp. seemed to respond to the disposal operation in a manner similar to the dominant chironomid species. The sphaerid clams *Sphaerium transversum* and *Pisidium* sp. seemed adversely affected. *Sphaerium* was reduced in occurrence and *Pisidium* was completely absent on the disposal shoal after the operation.

41. Not much can be said about the rare taxa except there were 11 insects, 1 bivalve, 3 gastropods, 4 oligochaetes, and 1 platyhelminth for a total of 20 species from all 4 collections. Of the taxa which only occurred, 2 species occurred only at two sample sites before the dredging, 4 species only after and 2 species both before and after disposal. There were 4 species had only one occurrence before dredging and 8 species that had only one occurrence after dredging.

Community structure

42. Diversity for the collections was moderate to low, a

characteristic typical of the tidal freshwater James River (Diaz 1977). The range of the species diversity index (H') was 0.93 to 2.56 bits/individual (Table 11). Average diversity decreased the day after disposal and increased above pre-operation levels in August and October (Table 12). Lowest diversity was recorded the day after disposal in areas receiving a total dredged material thickness of 0.1 to 0.9 m, but average values occurred in areas receiving a 0.9-m or greater thickness. An examination of other community parameters indicates the diversity index by itself presents a limited view of community structure. Diversity at the area receiving >1.6 m was 1.50, a low value but near the mean. This area had the highest evenness (0.95) in the collections and its richness of 1.44 was only slightly below average, but there were only 4 individuals representing 3 taxa in the 3 grabs taken in this area. Obviously, this was the most affected portion of the site. At the reference site on 1 July, the pre-operation sampling data, diversity and richness were slightly below mean values but were similar to those in the >1.6-m stratum, while evenness was much lower. However, there were 515 individuals representing 12 taxa in 3 grabs at the reference site. So it seems that in this study reliance on diversity and its components, evenness and richness, in interpreting effects of the disposal is of little value (Tables 11 and 12).

43. The average number of species/0.15 m^2 and individuals/m^2 did exhibit patterns attributable to the disposal operation. There was a decrease in species the day after disposal in areas that received 0.1 m or more dredged material. Three weeks later the entire area showed some recovery and by October the average number of species was near pre-operation levels. Macrofaunal density decreased the day after disposal in areas receiving more than 0.3 m of fluid mud, but by August density had recovered to near original levels, then experienced a seasonal decline in October (Table 12).

44. Similarity, both quantitative and qualitative coefficients, was high among the reference site collections, indicating that there were no major shifts or changes in community structure outside the area influenced by fluid mud during the course of the study (Table 13).

Pre-operation similarity was also high between the reference site and disposal shoal. The first day after disposal ended, similarity to pre-operational conditions declined at all areas receiving fluid mud with the greatest decrease occurring in quantitative similarity as calculated by equation (5). Quantitative similarity to pre-operational and reference conditions increased by August to near pre-operation levels and then declined slightly in October. Qualitative similarity to the reference site increased slightly by August and was unchanged in October (Table 13).

Classification results

45. Normal analysis of stations, including all species and collections, produced clear separation at the six-group level of pre-operation, unaffected, recovering and severely affected sites (Figure 5). Site group A consisted of the station that was most severely affected from the area receiving >1.6 m of fluid mud. The seven sites in Group B, mainly from the day after disposal, were also very affected by fluid mud. Site groups C, D, and E were made up of sites that were either recovering or unaffected by disposal. Group F represents the pre-operation conditions at the disposal and reference sites (Figure 5).

46. Inverse analysis (i.e., classification of species) did not demonstrate the effects of fluid mud because the general ubiquity and resilience of the fauna allowed for quick recovery with no species group being characteristic of any thickness of fluid mud.

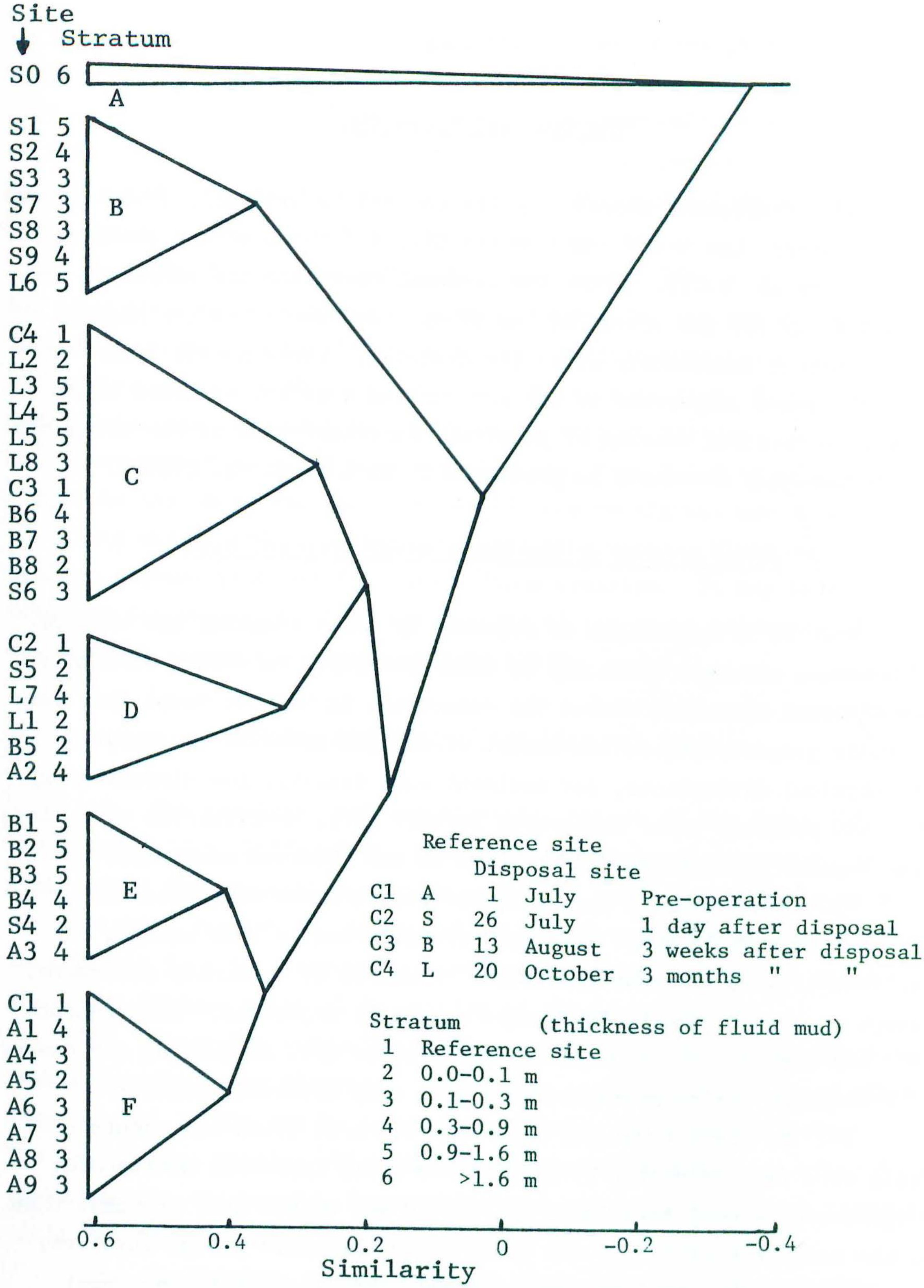

Figure 5. Normal analysis of all benthic sites

DISCUSSION

The Disposal Operation

47. Sediments removed from the channel by hydraulic dredging were finer grained than those found on the disposal shoal before dredging (Nichols et al. 1977). After the disposal operation the sediments remained finer for the course of the study. Sediments had the highest water content immediately after the dredging. Three months later water content seemed comparable to the surrounding area not affected by disposal. A detailed account of physical characteristics of the sediments and sedimentary movements is presented in Nichols et al. (1977).

Acute Effects at the James River Disposal Site

48. It is impossible to separate by field sampling the effects of numerous stresses which may be synergistically related. Certainly the disposal operation caused the reductions in benthic fauna that were directly proportional to the amount of dredged material accumulated, but the physical disturbance, low sediment bulk density, low dissolved oxygen, and possibly other unmeasured factors (i.e. mobilization of toxins, e.g. Kepone) all may have contributed to the observed acute effects.

49. Acute effects were most obvious in areas that received more than 0.3 m of fluid mud. All taxa were affected to some extent, but the insects were the most sensitive. Measures of community structure, except species diversity (H'), were generally depressed. This measure (H') was a poor reflection of community structure, suggesting the danger of evaluating environmental effects with only diversity indices.

50. In areas receiving less than 0.3 m of fluid mud, acute effects were felt primarily by insects and small *Corbicula manilensis*. Oligochaetes seemed relatively unaffected and became more abundant than at the reference site. Of the three major taxonomic groups involved, i.e. oligochaetes, molluscs, and insects, the oligochaetes are best suited to survive in a fluid mud environment. They are generally

subsurface deposit feeders with only the posterior end protruding to the surface for respiration. When environmental conditions become unsuitable oligochaetes can undergo a subsurface migration in search of more suitable conditions (Fisher and Beeton 1975). Oligochaetes also have a higher surface-to-volume ratio and lower bulk density than the other taxa, reducing the problem of support in fluid mud.

51. The insects, in particular the chironomids, from the area all have special respiratory structures whose function may be impaired by the fluid mud. They also have a lower surface-area-to-volume ratio and higher density than oligochaetes. The Asiatic clam, *Corbicula manilensis*, the species with the greatest support problem, declined in abundance except in areas that received less than 0.1 m of fluid mud. *Corbicula* has short siphons so it would have to migrate upward through the fluid mud in order to reach the overlying water. Fluid mud does present support problems for such a dense organism. It may have survived in the shallower fluid mud because of its great tolerance of environmental stress (Sinclair and Isom 1963).

General Recovery of the Disposal Area

52. The resilient and opportunistic nature of the fauna (Diaz and Boesch 1977a) buffered the impact of the disposal operation. Three weeks after the disposal operation ended all but a few of the more sensitive insect species had recovered, mainly through the migration of individuals from the surrounding unaffected areas. *Corbicula* recolonized the dredged material by setting of planktonic larvae.

53. Generally community structure had recovered to pre-operation levels 3 weeks after disposal. A few rare species did not occur after disposal but little can be inferred from their distribution patterns. The only common species which had not recovered in abundance after 3 weeks was the chironomid, *Cryptochironomus* spp., which did not recover until October, 3 months after disposal.

54. By October, normal seasonal changes in all the community parameters had taken place. The ratio of mature to immature *Limnodrilus*

had decreased greatly, indicating their peak spawning had occurred. The average size of *Corbicula* increased, indicating a decline in the number of newly set individuals.

General Observations on Effects of Fluid Mud

55. Fluid mud presents some unique biological problems that are not associated with turbidity, either natural or man-induced, or burial by more consolidated materials. Turbidity, whether generated by dredging operations or naturally, tends to be short-lived, although there are conflicting reports on its environmental effects (Herbich 1975, Windom 1972, Gustafson 1972, Oschwald 1972). The main potential effects of increased turbidity are interference with respiration and food collection. Depending on stamina of the species exposed and duration of exposure to excess turbidity, the outcome could range from minor irritation to death for nonmotile forms unable to escape, or benefit to motile forms that enter turbidity in search of food or protection.

56. Impacts of burial are the most obvious potential effects of dredged material disposal on benthic organisms, and depend on the ability of organisms to withstand rapid sedimentation and migrate to the new sediment surface. Surprisingly little attention has been devoted to upward migratory abilities of benthic fauna. Hamilton and La Plante (1972) and Frey and Howard (1972) have demonstrated the ability of several species to migrate through overlying sand. It is reasonable to suppose a species' ability to migrate vertically depends on factors such as its size, oxygen requirements, burrowing behavior, and physical characteristics of the sediment under which it is buried.

57. In terms of its environmental impact, fluid mud could conceptually be regarded as intermediate between turbidity and burial, although it may have the potential for unique impacts. Unlike turbidity, which is moved by local currents, fluid mud movement is controlled by gravity and tidal action and unlike consolidated sediments, which have concentrations greater than 175 g/l and do not flow, fluid mud starts to form at 10 g/l concentration and will flow up to concentrations of

175 g/l when consolidation and settlement begin (Masch and Espey 1967).

58. Nichols et al. (1977) have found the fluid mud produced by the dredged material disposal activity in the Windmill Point area to be very persistent and consolidation to occur slowly. Fluid mud thus poses a more formidable threat to respiration and feeding activities of benthos than temporary increases in turbidity. Because of its unconsolidated state and low bulk density, fluid mud may spread over a broader area and be less able to support the weight of benthic organisms than more consolidated dredged material. Fluid mud may separate many organisms, particularly bivalves and chironomid larvae, from the overlying water upon which they depend for respiration and food. Such organisms would be killed unless they were able to reestablish contact with the overlying water before these physiological stresses became overpowering. Figure 6 depicts in a schematic way the disruption that fluid mud had on the benthic communities of the study site.

59. Dissolved oxygen, which is vital to most aquatic life forms, was reduced in the immediate vicinity of the discharge pipe during and shortly after dredging. There was a horizontal gradient from lowest

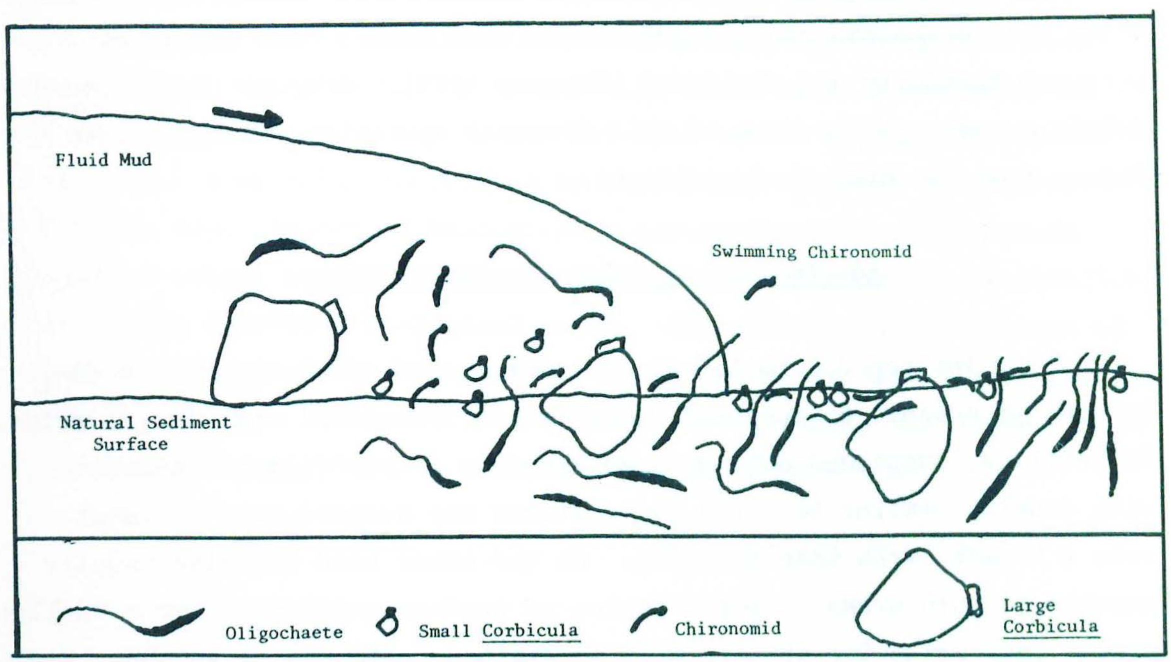

Figure 6. Schematic depiction of the effects of fluid mud on Windmill Point benthic communities

dissolved oxygen, in areas that received the most dredged material, to highest at the reference site and areas farthest from the outfall. Oxygen values before and 3 weeks after dredging were all higher than the day after disposal ended. The temporary decrease in dissolved oxygen, which seems typical for disposal operations in fine-grained environments (May 1973, Brown and Clark 1968, Lee unpublished data), is caused mainly by the oxidation of reduced compounds in the sediments which are released during dredging and disposal operation.

60. The depression in oxygen levels was short-lived, probably lasting on the order of days, and by itself would have little effect on the benthos of this environment. However, when the stress is added to that of burial by fluid mud, it may be very important in determining the survival of organisms in the affected area and may delay recolonization by new individuals.

61. The remobilization of buried toxic materials by dredging and their subsequent incorporation into fluid mud may have added to the impact of fluid mud. Although there is poor understanding of the biological effects of sediment-associated toxic materials, field evidence indicates that organisms can accumulate toxic materials from dredging-produced turbidity and fluid mud (Gregory 1977). Gregory (1977) found *Rangia cuneata* in the area of this disposal operation to concentrate Kepone from the disturbed sediments.

Adaptations to Substrate Instability

62. The top 0.5 to 1.0 cm of sediments of tidal rivers and estuaries is subject to frequent resuspension from tidal and wind energies. On settling, suspended sediments may produce a thin film of sediment with density similar to fluid mud. Storms may suspend more sediment over a broader area than dredging. On the other hand dredging usually results in more dramatic mobilization of surface sediments over a smaller area. Thus while instability of fine-grained sediments is common, thick fluid mud layers are rare natural phenomena.

63. Organisms cope with soft and unstable substrates by a series

of support, feeding and respiratory adaptations. Many organisms overcome the problem of sinking in soft sediment by 1) reduced body density, 2) reduced linear dimension, 3) increased surface area but not volume, and 4) increased buoyancy (Rhoads 1974). The species composing the benthic communities in the tidal freshwater James River exhibit these basic adaptations. The organisms that must maintain contact with the sediment surface, for the most part the insects and molluscs, are small and have high surface-area-to-volume ratios, except for the large unionids (only one small *Elliptio* was taken in this study but many large specimens do occur near the disposal site) which overcome the problem by sitting on the more consolidated deep sediments (10 to 20 cm). Other species which can burrow below the sediment surface for extended periods, such as oligochaetes and some chironomids, have in addition to the size adaptation specialized blood pigments (e.g. hemoglobin) to aid in respiration at the low dissolved oxygen levels found below the sediment surface (Brinkhurst and Jamieson 1971).

64. The benthic community at the James River study site recovered rapidly from the perturbation of burial or inundation by fluid mud. Less resistant and/or resilient communities would probably have been more persistently affected by burial with fluid mud. Potentially more susceptible communities are those that tend toward biological accommodation rather than being controlled by physically rigorous conditions. After the acute impact, a biologically accommodated community would require a longer period of time to recover depending on the reestablishment of its intricate biological order. The successful recruitment of opportunistic species, which might not have been previous members of the community, into a disturbed area could alter community development such that it might not return to its predisturbance condition.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

65. The disposal operation resulting from the maintenance dredging of the Jordan Point - Windmill Point channel altered the physical environment of the disposal site making it shallower and its sediments finer grained.

66. There was a detrimental acute impact on the macrobenthos attributed to the disposal operation. Due to the resilience and opportunistic nature of the fauna the site was recolonized within 3 months.

67. The fluid mud produced from the disposal operation probably had both physical and physiological effects on the fauna. The responses of different species to the fluid mud were not similar; some species were more susceptible than others. Insects were the most sensitive and oligochaetes were the least affected by fluid mud.

68. The phenomenon of fluid mud produced by dredged material disposal seems different from natural phenomena of sediment suspension. Its unique physical properties have deleterious effects on benthic fauna that warrant further investigation.

Recommendations

69. The potential for the creation of fluid mud from different types of dredged material and dredging methods needs to be assessed, so that practices which minimize the formation of fluid mud can be established.

70. In situations where large quantities of fluid mud would be formed, and subaqueous disposal is the only alternative, the disposal site should be chosen to minimize its spread. Particular attention should be placed on topography and tidal currents which will control the flow of fluid mud.

71. Since the acute impact of fluid mud will be directly related to the environmental constancy and community persistence and stability

(Boesch 1974), future studies should be conducted to determine the relative susceptibility of various benthic communities to the effects of fluid mud. Disposal site selection could then consider likely community responses and impacts on the most sensitive or valuable communities could be avoided.

72. Further research is needed under more controlled conditions, including laboratory and field experiments, on the effects of fluid mud on benthos. These should consider assessments of physical effects and the effects of reduced oxygen availability and mobilization of toxic materials.

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Table 1

Stratification of Sample Sites

Stratum	Sampling Date							
	1 July		26 July		13 August		20 October	
	Sample Site	Number of Replicates	Sample Site	Number of Replicates	Sample Site	Number of Replicates	Sample Site	Number of Replicates
Reference or Control	C1	3	C2	3	C3	3	C4	3
0.0-0.1 m*	A5	3	S4,5	6	B5,8	6	L1,2	6
0.1-0.3 m	A4,6,7,8,9	15	S3,6,7,8	12	B7	3	L8	3
0.3-0.9 m	A1,2,3	9	S2,9	6	B4,6	6	L7	3
0.9-1.6 m	**	--	S1	3	B1,2,3	9	L3,4,5,6	12
>1.6 m	**	--	S0	3	**	--	**	--

* Thickness of fluid mud above the bottom.
** No data.

Table 2

Sediment Parameter, Dissolved Oxygen, and Temperature Measurements at Each Site by Sampling Date

Date	Site	Grain-Size Distribution, Percent				Percent Solids		D.O.	Temp.	Sediment
		Sand	Silt	Clay	Detritus	Total	Volatile	mg/l	°C	Classification
1 July	C1	5.4	73.6	21.0	1.4	ND*	ND	7.4	28	clayey-silt
	A1	0.7	84.1	15.2	3.0	ND*	ND	7.0	28	silt
	2	68.6	26.0	5.4	1.0	ND*	ND	6.0	28	silty-sand
	3	9.6	74.0	16.4	0.8	ND*	ND	6.5	28	clayey-silt
	4	7.0	75.4	17.6	0.3	ND*	ND	6.5	28	silt
	5	30.3	54.4	15.3	1.2	ND*	ND	6.8	28	sandy-silt
	6	46.4	40.2	13.4	5.2	ND*	ND	7.0	28	silty-sand
	7	12.7	78.4	8.9	1.8	ND*	ND	6.8	28	silt
	8	19.0	70.7	10.3	1.1	ND*	ND	6.5	28	sandy-silt
	9	10.9	76.4	12.7	0.8	ND*	ND	6.5	28	silt
26 July	C2	7.0	63.7	29.3	0.8	44.5	10.7	5.7	28	clayey-silt
	S1	15.9	67.3	16.8	0.6	39.2	10.6	3.8	28	clayey-silt
	2	26.7	59.0	14.3	2.5	41.6	11.7	4.2	28	sandy-silt
	3	10.7	78.0	11.3	0.0	48.2	9.2	4.6	28	silt
	4	16.0	68.9	15.1	1.9	43.7	10.2	4.9	28	clayey-silt
	5	0.4	80.3	19.4	5.1	57.1	10.5	4.5	28	silt
	6	6.5	65.8	27.7	3.4	46.5	10.4	4.3	28	clayey-silt
	7	5.7	72.5	21.8	2.9	42.9	10.0	4.6	28	clayey-silt
	8	9.9	70.1	20.0	2.6	40.8	10.6	3.8	28	clayey-silt
	9	5.0	79.8	15.2	1.5	38.9	11.9	4.1	28	silt
	0	1.4	91.0	7.6	1.5	36.2	12.3	3.2	28	silt

(Continued)

* No data.

Table 2 (Concluded)

Date	Site	Grain-Size Distribution, Percent: Sand	Silt	Clay	Detritus	Percent Solids: Total	Volatile	D.O. mg/l	Temp. °C	Sediment Classification
13 Aug	C3	10.7	82.3	7.0	2.7	ND	ND	7.8	27	silt
	B1	2.2	92.1	5.7	2.4	ND	ND	7.1	27	silt
	2	26.3	69.8	3.9	2.0	44.0	ND	7.2	27	sandy-silt
	3	0.0	93.2	6.8	3.6	ND	ND	6.9	27	silt
	4	12.5	83.7	3.8	1.6	ND	ND	5.5	27	silt
	5	3.0	92.2	4.8	3.7	ND	ND	6.0	27	silt
	6	14.7	80.1	5.2	2.4	ND	ND	6.7	27	silt
	7	8.4	87.1	4.5	2.2	ND	ND	6.8	27	silt
	8	12.1	78.9	9.0	6.1	ND	ND	6.4	27	silt
20 Oct	C4	0.0	90.8	9.2	3.0	39.5	11.2	ND	14	silt
	L1	0.0	95.6	4.4	13.4	51.9	10.2	ND	14	silt
	2	0.0	92.3	7.4	5.0	36.5	12.4	ND	14	silt
	3	7.5	85.3	7.2	4.6	46.2	12.6	ND	14	silt
	4	9.8	83.8	6.4	1.5	46.4	11.9	ND	14	silt
	5	13.7	78.4	7.9	1.6	43.6	11.1	ND	14	silt
	6	9.1	85.5	5.4	3.3	47.4	10.5	ND	14	silt
	7	14.9	79.7	5.4	2.8	55.5	43.8	ND	14	silt
	8	35.6	57.4	6.9	0.8	42.0	3.3	ND	14	sandy-silt

Table 3

Sediment Parameters and Dissolved Oxygen Measurements Averaged by Stratum for Each Sampling Period

Stratum	Percent Sand				Percent Total Solids			
	P.O.*	1 day	3 weeks	3 months	P.O.	1 day	3 weeks	3 months
Reference	5.4	7.0	10.7	0.0	**	44.5	**	39.5
0.0-0.1 m	30.3	8.2	7.6	0.0	**	50.4	**	44.2
0.1-0.3 m	19.2	8.2	8.4	35.6	**	44.6	**	42.0
0.3-0.9 m	26.3	15.8	13.6	14.9	**	40.2	**	55.5
0.9-1.6 m	**	15.9	9.5	10.0	**	39.2	44.0	45.9
>1.6 m	**	1.4	**	**	**	36.2	**	**
	Percent Silt				Percent Volatile Solids			
Reference	73.6	63.7	82.3	90.8	**	10.7	**	11.2
0.0-0.1 m	54.4	74.6	85.6	94.0	**	10.4	**	11.3
0.1-0.3 m	68.2	71.6	87.1	57.4	**	10.0	**	3.3
0.3-0.9 m	61.4	69.4	81.9	79.7	**	11.8	**	43.8
0.9-1.6 m	**	67.3	85.0	83.2	**	10.6	**	11.5
>1.6 m	**	91.0	**	**	**	12.3	**	**
	Percent Clay				Dissolved Oxygen mg/l			
Reference	21.0	29.3	7.0	9.2	7.4	5.7	7.8	**
0.0-0.1 m	15.3	17.2	6.9	5.9	6.8	4.7	6.2	**
0.1-0.3 m	12.6	20.2	4.5	6.9	6.7	4.3	6.8	**
0.3-0.9 m	12.3	14.8	4.5	5.4	6.5	4.2	6.1	**
0.9-1.6 m	**	16.8	5.5	6.7	**	3.8	7.1	**
>1.6 m	**	7.6	**	**	**	3.2	**	**

(Continued)

* P.O. indicates pre-operational or prior to disposal.

** No data.

Table 3 (Concluded)

Stratum	Percent Detritus P.O.	Percent Detritus 1 day	Percent Detritus 3 weeks	Percent Detritus 3 months	Dissolved Oxygen Percent of Saturation P.O.	Dissolved Oxygen Percent of Saturation 1 day	Dissolved Oxygen Percent of Saturation 3 weeks	Dissolved Oxygen Percent of Saturation 3 months
Reference	1.4	0.8	2.7	3.0	94	72	96	**
0.0-0.1 m	1.2	3.5	4.9	9.2	86	59	76	**
0.1-0.3 m	1.8	2.2	2.2	0.8	85	54	84	**
0.3-0.9 m	1.6	2.0	2.0	2.8	82	53	75	**
0.9-1.6 m	**	0.6	2.7	2.8	**	48	88	**
>1.6 m	**	1.5	**	**	**	40	**	**

** No data.

Table 4

Breakdown of Major Taxa and Individuals

Taxonomic Group	1 July		26 July		13 August		20 October		Total	
	Inds.	Percent of Total	Inds.	Percent of Total	Inds.	Percent of Total	Inds.	Percent of Total	Inds.	Percent of Total
Platyhelminthes	3	0.1	0	0.0	0	0.0	0	0.0	3	0.0
Annelida	2927	82.8	1450	77.0	1919	70.1	1620	68.0	7916	75.1
Oligochaeta	2922	82.7	1443	76.7	1919	70.1	1612	67.7	7896	74.9
Hirudinea	5	0.1	7	0.4	0	0.0	8	0.3	20	0.2
Mollusca	350	9.9	233	12.4	512	18.7	424	17.8	1519	14.4
Gastropoda	1	0.0	0	0.0	0	0.0	4	0.2	5	0.0
Bivalvia	349	9.9	233	12.4	512	18.7	420	17.6	1514	14.4
Arthropoda	254	7.2	199	10.6	308	11.2	338	14.2	1099	10.4
Amphipoda	2	0.0	9	0.5	36	1.3	0	0.0	47	0.4
Insecta	252	7.2	190	10.1	272	9.9	338	14.2	1052	10.0
Chironomidae	249	7.0	169	9.0	266	9.7	313	13.1	997	9.5
Totals	3534	100.0	1882	100.0	2739	100.0	2382	100.0	10,537	100.0

Table 5

Breakdown of Major Taxa and Species

Taxonomic Group	1 July		26 July		13 August		20 October		Total	
	Spp.	Percent of Total	Spp.	Percent of Total	Spp.	Percent of Total	Spp.	Percent of Total	Spp.	Percent of Total
Platyhelminthes	1	3.4	0	0.0	0	0.0	0	0.0	1	2.3
Annelida	10	34.5	9	30.0	7	35.0	8	27.6	12	27.3
Oligochaeta	9	31.0	8	26.7	7	35.0	7	24.1	11	25.0
Hirudinea	1	3.4	1	3.3	0	0.0	1	3.4	1	2.3
Mollusca	6	20.7	4	13.3	3	20.0	7	27.6	8	18.2
Gastropoda	1	3.4	0	0.0	0	0.0	2	6.9	3	6.8
Bivalvia	5	17.2	4	13.3	3	20.0	5	20.7	5	11.4
Arthropoda	12	41.4	17	56.7	9	45.0	13	44.8	23	52.3
Amphipoda	1	3.4	1	3.3	1	5.0	0	0.0	1	2.3
Insecta	11	37.9	16	53.3	8	40.0	13	44.8	22	50.0
Chironomidae	9	31.0	11	36.7	6	30.0	9	31.0	15	34.1
Totals	29	100.0	30	100.0	19	100.0	28	100.0	44	100.0

Table 6

Occurrence of Taxa at All 39 Collection Sites

	Taxon	Taxonomic Group*	Occurrences Number	Occurrences Percent
1	*Limnodrilus* spp.	O	39	100
2	*Ilyodrilus templetoni*	O	38	97
3	*Corbicula manilensis* (<10 mm)	B	38	97
4	*Limnodrilus hoffmeisteri*	O	37	95
5	*Coelotanypus scapularis*	C	36	92
6	*Procladius bellus*	C	23	59
7	*Harnischia* spp.	C	23	59
8	*Chaoborus punctipennis*	I	19	49
9	*Cryptochironomus* spp.	C	18	46
10	*Polypedilum* spp.	C	14	36
11	*Corbicula manilensis* (>10 mm)	B	12	31
12	*Peloscolex multisetosus*	O	11	28
13	*Peloscolex freyi*	O	10	26
14	*Sphaerium transversum*	B	10	26
15	*Chironomus* spp.	C	8	21
16	*Gammarus fasciatus*	A	7	18
17	*Branchiura sowerbyi*	O	7	18
18	*Helobdella elongata*	L	6	15
19	*Dicrotendipes nervosus*	C	5	13
20	*Coelotanypus pupae*	C	5	13
21	*Pisidium* sp.	B	4	10
22	*Rangia cuneata*	B	3	8
23	Odonata	I	3	8
24	Cyclorrahapha larvae	I	3	8
25	*Limnodrilus profundicola*	O	2	5
26	Chironomid sp. 2	C	2	5
27	*Tubifex* sp.	O	2	5
28	*Limnodrilus cervix*	O	2	5
29	*Tanypus neopunctipennis*	C	2	5
30	*Hexagenia mingo*	I	2	5
31	*Ablebesmyia* sp. E Roback	C	2	5
32	*Nais* spp.	O	2	5
33	*Hydrolimax grisea*	P	1	3
34	*Stictochironomus devinctus*	C	1	3
35	Gastropod	G	1	3
36	*Coelotanypus concinnus*	C	1	3
37	*Valvata sincera*	G	1	3

(Continued)

* O - Oligochaete
B - Bivalve
C - Chironomidae
I - Insect
L - Leech
A - Amphipod
P - Platyhelminth
G - Gastropod

Table 6 (Concluded)

	Taxon	Taxonomic Group	Occurrences Number	Occurrences Percent
38	*Ferrissia* sp.	G	1	3
39	*Elliptio complanata*	B	1	3
40	Coleopteran larvae	I	1	3
41	Chironomid sp. 1	C	1	3
42	Tricopteran A	I	1	3
43	Tricopteran B	I	1	3
44	*Psectrocladius* sp.	C	1	3

Table 7

Distribution of Dominant Species by Stratum and Collection Period. Average Abundance Estimated to Individuals/m^2

	Collection Period			
		After Disposal		
Limnodrilus spp.				
Stratum	Pre-Op	1 day	3 weeks	3 months
Reference	2480	647	807	1127
0.0-0.1 m	1140	1153	977	1070
0.1-0.3 m	1529	768	960	747
0.3-0.9 m	1056	410	1373	2673
0.9-1.6 m	---*	180	618	588
>1.6 m	---*	7	---	---
Collection Mean	1443	639	924	1004
Limnodrilus hoffmeisteri				
Stratum	Pre-Op	1 day	3 weeks	3 months
Reference	220	93	213	93
0.0-0.1 m	180	233	440	70
0.1-0.3 m	231	242	233	0
0.3-0.9 m	276	60	250	287
0.9-1.6 m	---	93	336	32
>1.6 m	---	0	---	---
Collection Mean	238	158	315	72
Ilyodrilus templetoni				
Stratum	Pre-Op	1 day	3 weeks	3 months
Reference	380	20	67	60
0.0-0.1 m	227	147	303	57
0.1-0.3 m	231	67	40	153
0.3-0.9 m	176	43	153	33
0.9-1.6 m	---	7	82	37
>1.6 m	---	0	---	---
Collection Mean	229	61	141	56

(Continued)

* No data.

Table 7 (Continued)

Corbicula manilensis (small)

Stratum	Pre-Op	1 day	3 weeks	3 months
	Collection Period			
		After Disposal		
Reference	20	260	233	173
0.0-0.1 m	147	493	360	247
0.1-0.3 m	88	45	200	193
0.3-0.9 m	491	3	730	953
0.9-1.6 m	---	7	229	232
>1.6 m	---	13	---	---
Collection Mean	208	132	367	304

Coelotanypus scapularis

Stratum	Pre-Op	1 day	3 weeks	3 months
Reference	133	100	253	433
0.0-0.1 m	40	60	127	57
0.1-0.3 m	69	70	293	73
0.3-0.9 m	42	17	233	0
0.9-1.6 m	---	7	58	218
>1.6 m	---	0	---	---
Collection Mean	65	49	160	166

Chaoborus punctipennis

Stratum	Pre-Op	1 day	3 weeks	3 months
Reference	0	13	7	20
0.0-0.1 m	7	3	3	10
0.1-0.3 m	1	15	0	0
0.3-0.9 m	0	7	10	0
0.9-1.6 m	---	7	0	23
>1.6 m	---	7	---	---
Collection Mean	1	10	4	15

Harnischia spp.

Stratum	Pre-Op	1 day	3 weeks	3 months
Reference	13	13	67	33
0.0-0.1 m	27	7	20	3
0.1-0.3 m	13	2	33	0
0.3-0.9 m	22	0	37	0

(Continued)

Table 7 (Concluded)

	Collection Period			
		After Disposal		
Harnischia spp. (Continued)				
Stratum	Pre-Op	1 day	3 weeks	3 months
0.9-1.6 m	---	0	4	32
>1.6 m	---	0	---	---
Collection Mean	17	3	25	18
Procladius bellus				
Stratum	Pre-Op	1 day	3 weeks	3 months
Reference	67	60	47	13
0.0-0.1 m	47	0	7	3
0.1-0.3 m	64	5	0	0
0.3-0.9 m	20	7	7	7
0.9-1.6 m	---	7	2	3
>1.6 m	---	0	---	---
Collection Mean	49	9	9	4
Cryptochironomus spp.				
Stratum	Pre-Op	1 day	3 weeks	3 months
Reference	7	40	0	7
0.0-0.1 m	0	0	3	7
0.1-0.3 m	15	0	0	13
0.3-0.9 m	20	0	0	40
0.9-1.6 m	---	0	0	12
>1.6 m	---	0	---	---
Collection Mean	14	4	1	13

Table 8

Ratio of *Limnodrilus hoffmeisteri* to *Limnodrilus* spp.

Averaged by Stratum and Collection Period

	Collection Period			
		After Disposal		
Stratum	Pre-Op	1 day	3 weeks	3 months
Reference	0.09	0.14	0.26	0.08
0.0-0.1 m	0.16	0.20	0.45	0.06
0.1-0.3 m	0.15	0.32	0.24	0.00
0.3-0.9 m	0.26	0.15	0.18	0.11
0.9-1.6 m	*	0.52	0.54	0.05
>1.6 m	*	0.00	*	*
Collection Mean	0.16	0.25	0.34	0.07

* No data.

Table 9

Average Shell Length of *Corbicula manilensis*

Between 2 and 10 mm

Stratum	Collection Period			
		After Disposal		
	Pre-Op	1 day	3 weeks	3 months
Reference	6.00	2.00	2.50	3.40
0.0-0.1 m	4.00	3.44	3.14	3.38
0.1-0.3 m	3.48	2.73	2.27	2.00
0.3-0.9 m	2.80	2.20	2.41	3.12
0.9-1.6 m	*	*	2.91	2.79
>1.6 m	*	2.00	*	*
Collection Mean	3.29	3.27	2.72	3.08

* No data.

Table 10

Average Head Capsule Lengths for Larvae of *Coelotanypus scapularis*

Stratum	Pre-Op	Collection Period: After Disposal 1 day	3 weeks	3 months
Reference	0.54	0.50	0.55	0.49
0.0-0.1 m	0.61	0.49	0.53	0.61
0.1-0.3 m	0.56	0.57	0.54	0.51
0.3-0.9 m	0.62	0.63	0.57	0.0
0.9-1.6 m	*	0.63	0.55	0.57
>1.6 m	*	0.0	*	*
Collection Mean	0.58	0.55	0.55	0.56

* No data.

Table 11

Community Structure Parameters Calculated from Sum of Three 0.05-m^2 Grab Samples

Date	Station	Diversity	Evenness	Individuals	Richness	Species
1 July	C1	1.54	0.43	515	1.76	12
	A1	1.91	0.52	315	2.09	13
	A2	2.55	0.59	407	3.16	20
	A3	2.11	0.66	293	1.43	9
	A4	2.42	0.63	321	2.26	14
	A5	1.91	0.58	277	1.60	10
	A6	1.72	0.48	293	1.94	12
	A7	1.56	0.52	274	1.25	8
	A8	1.48	0.47	284	1.42	9
	A9	1.60	0.43	555	1.90	13
26 July	C2	2.56	0.63	203	3.01	17
	S1	1.69	0.56	47	1.82	8
	S2	1.60	0.53	104	1.51	8
	S3	1.47	0.57	128	1.03	6
	S4	1.77	0.51	322	1.73	11
	S5	2.40	0.58	401	2.84	18
	S6	2.07	0.60	250	1.81	11
	S7	1.68	0.56	222	1.30	8
	S8	0.93	0.36	138	1.02	6
	S9	0.94	0.36	63	1.21	6
	S0	1.50	0.95	4	1.44	3
13 August	C3	2.46	0.66	267	2.14	13
	B1	1.91	0.64	254	1.26	8
	B2	1.79	0.64	199	1.13	7
	B3	2.05	0.68	152	1.39	8
	B4	2.01	0.67	550	1.11	8
	B5	2.44	0.73	429	1.48	10
	B6	1.84	0.58	303	1.40	9
	B7	1.88	0.73	264	0.90	6
	B8	2.39	0.67	321	1.91	12
20 October	C4	2.15	0.57	309	2.27	14
	L1	1.87	0.42	322	3.46	21
	L2	1.92	0.54	170	2.14	12
	L3	2.17	0.72	103	1.51	8
	L4	2.04	0.61	235	1.65	10
	L5	2.26	0.59	266	2.33	14
	L6	1.68	0.56	120	1.46	8
	L7	1.72	0.50	669	1.54	11
	L8	1.81	0.64	188	1.15	7

Table 12

Community Structure Parameters Averaged

by Stratum and Collection Period

Stratum	Collection Period			
		After Disposal		
	Pre-Op	1 day	3 weeks	3 months
		a. Diversity		
Reference	1.54	2.56	2.46	2.15
0.0-0.1 m	1.91	2.08	2.42	1.90
0.1-0.3 m	1.76	1.54	1.88	1.81
0.3-0.9 m	2.19	1.27	1.92	1.72
0.9-1.6 m	*	1.69	1.92	2.04
>1.6 m	*	1.50	*	*
Collection Mean	1.88	1.69	2.09	1.96
		b. Richness		
Reference	1.76	3.01	2.14	2.27
0.0-0.1 m	1.60	2.28	1.70	2.80
0.1-0.3 m	1.75	1.29	0.90	1.15
0.3-0.9 m	2.23	1.36	1.26	1.54
0.9-1.6 m	*	1.82	1.26	1.74
>1.6 m	*	1.44	*	*
Collection Mean	1.88	1.70	1.41	1.95
		c. Individuals/m^2		
Reference	3433	1353	1780	2060
0.0-0.1 m	1847	2410	2500	1640
0.1-0.3 m	2303	1230	1760	1253
0.3-0.9 m	2256	557	2843	4460
0.9-1.6 m	*	313	1344	1207
>1.6 m	*	27	*	*
Collection Mean	2356	1141	2029	1764

(Continued)

* No data.

Table 12 (Concluded)

Stratum	Collection Period: Pre-Op	After Disposal: 1 day	3 weeks	3 months
		d. Evenness		
Reference	0.43	0.63	0.66	0.57
0.0-0.1 m	0.58	0.54	0.70	0.48
0.1-0.3 m	0.51	0.52	0.73	0.64
0.3-0.9 m	0.59	0.44	0.62	0.50
0.9-1.6 m	*	0.56	0.65	0.62
>1.6 m	*	0.95	*	*
Collection Mean	0.53	0.56	0.67	0.57
		e. Species/0.15 m^2		
Reference	12	17	13	14
0.0-0.1 m	10	14	11	16
0.1-0.3 m	11	8	6	7
0.3-0.9 m	14	7	8	11
0.9-1.6 m	*	8	8	10
>1.6 m	*	3	*	*
Collection Mean	12	9	9	12

* No data.

Table 13

Similarity Between the Reference Site and the Disposal Shoal

(a) Reference site only

	Quantitative Bray-Curtis coefficient X 100			Qualitative Dice coefficient X 100		
	After Disposal			After Disposal		
	3 months	3 weeks	1 day	3 months	3 weeks	1 day
Pre-Op	68	71	68	69	72	69
1 day	59	73		71	73	
3 weeks	79			82		
Mean	71			73		

(b) Average similarity of fluid mud stratum with reference site

Stratum	Pre-Op	After Disposal			Pre-Op	After Disposal		
		1 day	3 weeks	3 months		1 day	3 weeks	3 months
0.0-0.1 m	72	58	70	69	64	53	62	68
0.1-0.3 m	77	60	81	63	74	56	63	57
0.3-0.9 m	66	40	73	56	65	46	65	64
0.9-1.6 m	--	52	71	66	--	64	65	68
>1.6 m	--	16	--	--	--	30	--	--
Collection Mean	73	52	73	66	70	52	64	64

APPENDIX A: SPECIES TAKEN AT BENTHIC SITES

1 July Pre-operation collection

Site C1

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex freyi	2		2	4
Branchiura sowerbyi	3	5	3	11
Limnodrilus spp.	146	107	119	372
Limnodrilus hoffmeisteri	16	14	3	33
Ilyodrilus templetoni	17	20	20	57
Naididae			1	1
Corbicula manilensis (>10 mm)		1		1
Corbicula manilensis (<10 mm)		1	2	3
Coelotanypus scapularis		8	12	20
Procladius bellus		5	5	10
Cryptochironomus	1			1
Harnischia		2		2

Site A1

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex multisetosus			1	1
Limnodrilus spp.	57	42	87	186
Limnodrilus hoffmeisteri	12	7	22	41
Limnodrilus profundicola		1		1
Ilyodrilus templetoni	27	14	11	52
Corbicula manilensis (<10 mm)	5	6	3	14
Gammarus fasciatus		1		1
Chironomid sp. 2		1		1
Coelotanypus scapularis	1	2	3	6
Procladius bellus	5		1	6
Cryptochironomus		1	1	2
Polypedilum	1			1
Harnischia	2	1		3

Site A2

Taxon	Grab 1	Grab 2	Grab 3	Total
Hydrolimax grisea			3	3
Peloscolex freyi	3	2	2	7
Limnodrilus spp.	52	59	55	166
Limnodrilus hoffmeisteri	18	10	14	42
Ilyodrilus templetoni	2	4	3	9
Helobdella elongata		4		4
Corbicula manilensis (>10 mm)		1	1	2

Site A2 (continued)

Taxon	Grab 1	Grab 2	Grab 3	Total
Corbicula manilensis (<10 mm)	22	48	46	116
Rangia cuneata			1	1
Sphaerium transversum	5	4	16	25
Pisidium			1	1
Gammarus fasciatus	1			1
Coelotanypus scapularis	3	1		4
Procladius bellus	1		2	3
Chironomus	4	4		8
Cryptochironomus	2		2	4
Polypedilum		3	3	6
Harnischia			1	1
Stictochironomus devinctus		1		1
Dicrotendipes nervosus			3	3

Site A3

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	30	14	79	123
Limnodrilus hoffmeisteri	2	15	24	41
Ilyodrilus templetoni	7	1	10	18
Corbicula manilensis (<10 mm)	26	30	35	91
Sphaerium transversum			1	1
Coelotanypus scapularis	6		3	9
Cryptochironomus	1		2	3
Polypedilum	1			1
Harnischia	1		5	6

Site A4

Taxon	Grab 1	Grab 2	Grab 3	Total
Tubificidae			3	3
Peloscolex multisetosus	21			21
Peloscolex freyi	2			2
Limnodrilus spp.	76	23	68	167
Limnodrilus hoffmeisteri	5	10	4	19
Ilyodrilus templetoni	10		27	37
Gastropoda	1			1
Corbicula manilensis (>10 mm)		1	1	2
Corbicula manilensis (<10 mm)	16	5	3	24
Odonata	1			1
Coelotanypus scapularis	8	2	9	19
Procladius bellus	8	2	8	18
Cryptochironomus		2	2	4
Harnischia		3		3

Site A5

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	101	57	13	171
Limnodrilus hoffmeisteri	10	9	8	27
Ilyodrilus templetoni	20	11	3	34
Corbicula manilensis (<10 mm)	7	14	1	22
Sphaerium transversum	2			2
Chaoborus punctipennis	1			1
Coelotanypus scapularis	3	3		6
Procladius bellus	3	4		7
Polypedilum	1	1	1	3
Harnischia	3	1		4

Site A6

Taxon	Grab 1	Grab 2	Grab 3	Total
Tubifex			1	1
Peloscolex multisetosus		1		1
Branchiura sowerbyi			1	1
Limnodrilus spp.	59	14	125	198
Limnodrilus hoffmeisteri	6	5	15	26
Ilyodrilus templetoni	10		24	34
Corbicula manilensis (<10 mm)		1	8	9
Coelotanypus scapularis	3		8	11
Procladius bellus	2		4	6
Cryptochironomus	1			1
Polypedilum			1	1
Harnischia	1		3	4

Site A7

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	18	86	83	187
Limnodrilus hoffmeisteri	6	8	20	34
Ilyodrilus templetoni	16		15	31
Helobdella elongata			1	1
Corbicula manilensis (<10 mm)	2	2	1	5
Coelotanypus scapularis		5	2	7
Procladius bellus	4		3	7
Polypedilum			2	2

Site A8

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	49	49	103	201
Limnodrilus hoffmeisteri	2	13	24	39
Ilyodrilus templetoni	2		19	21
Corbicula manilensis (>10 mm)		1		1
Corbicula manilensis (<10 mm)	1	3	8	12
Coelotanypus scapularis		1	1	2
Procladius bellus	2	1	2	5
Cryptochironomus	2			2
Harnischia		1		1

Site A9

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex multisetosus	1		2	3
Limnodrilus spp.	230	80	84	394
Limnodrilus hoffmeisteri	26	16	13	55
Ilyodrilus templetoni	21	15	14	50
Corbicula manilensis (>10 mm)		1		1
Corbicula manilensis (<10 mm)	8	4	4	16
Chaoborus punctipennis	1			1
Coelotanypus scapularis		9	4	13
Procladius bellus	5	5	2	12
Chironomus		1		1
Cryptochironomus	1	2	1	4
Polypedilum		2	1	3
Harnischia	1	1		2

26 July first day after end of disposal collection

Site C2

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex freyi	4	1	2	7
Limnodrilus spp.	33	16	48	97
Limnodrilus hoffmeisteri	7	2	5	14
Ilyodrilus templetoni	1	1	1	3
Corbicula manilensis (>10 mm)	3			3
Corbicula manilensis (<10 mm)	6	26	7	39
Sphaerium transversum	1			1
Pisidium			1	1
Gammarus fasciatus			1	1
Chaoborus punctipennis	1		1	2

Site C2 (continued)

Taxon	Grab 1	Grab 2	Grab 3	Total
Chironominae sp. 1			1	1
Chironominae sp. 2	1			1
Coelotanypus scapularis	8	1	6	15
Procladius bellus	4		5	9
Chironomus			1	1
Cryptochironomus			6	6
Harnischia			2	2

Site S1

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	16	11		27
Limnodrilus hoffmeisteri	12	2		14
Ilyodrilus templetoni	1			1
Corbicula manilensis (>10 mm)	1			1
Corbicula manilensis (<10 mm)		1		1
Chaoborus punctipennis		1		1
Coelotanypus scapularis		1		1
Procladius bellus		1		1

Site S2

Taxon	Grab 1	Grab 2	Grab 3	Total
Branchiura sowerbyi	1			1
Limnodrilus spp.	30	11	29	70
Limnodrilus hoffmeisteri	9	4	3	16
Ilyodrilus templetoni	1	2	5	8
Odonata	1			1
Chaoborus punctipennis			2	2
Coelotanypus scapularis	3		2	5
Procladius bellus	1			1

Site S3

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	27	20	32	79
Limnodrilus hoffmeisteri	14	9	13	36
Ilyodrilus templetoni	2			2
Corbicula manilensis (<10 mm)		6		6
Chaoborus punctipennis		2		2
Coelotanypus scapularis	2	1		3

Site S4

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex multisetosus	3		2	5
Limnodrilus spp.	70	44	93	207
Limnodrilus hoffmeisteri	12	15	15	42
Ilyodrilus templetoni	10	5	20	35
Helobdella elongata		2		2
Corbicula manilensis (<10 mm)		3	6	9
Sphaerium transversum		1		1
Cyclorrahapha larvae	1			1
Coelotanypus scapularis	3	1	13	17
Tanypus neopunctipennis			1	1
Harnischia			2	2

Site S5

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex multisetosus	1			1
Peloscolex freyi	2	5	1	8
Limnodrilus spp.	36	66	37	139
Limnodrilus hoffmeisteri	4	13	11	28
Ilyodrilus templetoni	1	5	3	9
Naididae		1		1
Helobdella elongata		3	2	5
Corbicula manilensis (>10 mm)	1	3		4
Corbicula manilensis (<10 mm)	3	120	16	139
Rangia cuneata	1			1
Sphaerium transversum		1		1
Gammarus fasciatus		7	1	8
Tricopteran A		1		1
Tricopteran B		1		1
Chaoborus punctipennis		1		1
Coelotanypus scapularis		1		1
Dicrotendipes nervosus		52		52
Psectrocladius		1		1

Site S6

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	62	46	31	139
Limnodrilus hoffmeisteri	11	13	15	39
Ilyodrilus templetoni	10	5		15
Corbicula manilensis (>10 mm)	1			1
Corbicula manilensis (<10 mm)	5	7		12
Sphaerium transversum			1	1
Chaoborus punctipennis	2		1	3

Site S6 (continued)

Taxon	Grab 1	Grab 2	Grab 3	Total
Coelotanypus scapularis	9	8	15	32
Procladius bellus		1	2	3
Polypedilum			4	4
Harnischia		1		1

Site S7

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	63	52	13	128
Limnodrilus hoffmeisteri	24	19	15	58
Limnodrilus profundicola	1	1	1	3
Ilyodrilus templetoni	12	8	2	22
Corbicula manilensis (<10 mm)	2			2
Chaoborus punctipennis	2	1		3
Coelotanypus scapularis	1	4		5
Tanypus neopunctipennis	1			1

Site S8

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.		56	59	115
Limnodrilus hoffmeisteri	1	3	8	12
Ilyodrilus templetoni			1	1
Corbicula manilensis (<10 mm)	3	3	1	7
Chaoborus punctipennis			1	1
Coelotanypus scapularis	2			2

Site S9

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	24	24	5	53
Limnodrilus hoffmeisteri	2			2
Ilyodrilus templetoni	3	2		5
Corbicula manilensis (<10 mm)	1			1
Cyclorrahapha larvae			1	1
Procladius bellus		1		1

Site S0

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	1			1
Corbicula manilensis (<10 mm)	2			2
Chaoborus punctipennis		1		1

13 August 3 weeks after disposal collection

Site C3

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex freyi			1	1
Branchiura sowerbyi			1	1
Limnodrilus spp.	40	35	46	121
Limnodrilus hoffmeisteri	12	11	9	32
Ilyodrilus templetoni	3	1	6	10
Corbicula manilensis (<10 mm)	19	8	8	35
Sphaerium transversum	9			9
Pisidium		1		1
Chaoborus punctipennis		1		1
Coelotanypus scapularis	15	15	8	38
Procladius bellus	1	5	1	7
Polypedilum			1	1
Harnischia	3	5	2	10

Site B1

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex freyi			1	1
Limnodrilus spp.	8	67	31	106
Limnodrilus hoffmeisteri		82	12	94
Ilyodrilus templetoni	2	22	1	25
Corbicula manilensis (>10 mm)		1		1
Corbicula manilensis (<10 mm)	1	11	5	17
Coelotanypus scapularis		9		9
Harnischia		1		1

Site B2

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex multisetosus	2		1	3
Limnodrilus spp.	80	8	11	99
Limnodrilus hoffmeisteri	25	3	1	29

Site B2 (continued)

Taxon	Grab 1	Grab 2	Grab 3	Total
Ilyodrilus templetoni			1	1
Corbicula manilensis (<10 mm)	46	9	2	57
Coelotanypus scapularis	9			9
Harnischia	1			1

Site B3

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex freyi			1	1
Limnodrilus spp.	8	46	19	73
Limnodrilus hoffmeisteri	10	11	7	28
Ilyodrilus templetoni	10	1		11
Corbicula manilensis (<10 mm)		26	3	29
Cyclorrahapha larvae		1		1
Coelotanypus scapularis	2	5	1	8
Procladius bellus		1		1

Site B4

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex multisetosus	1	1	5	7
Limnodrilus spp.	22	64	136	222
Limnodrilus hoffmeisteri	5	26	30	61
Ilyodrilus templetoni	6	10	21	37
Corbicula manilensis (<10 mm)	9	74	112	195
Gammarus fasciatus			3	3
Coelotanypus scapularis	1	13	10	24
Procladius bellus		1		1

Site B5

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex multisetosus	1	1	5	7
Limnodrilus spp.	43	47	75	165
Limnodrilus hoffmeisteri	18	33	40	91
Limnodrilus cervix	14	4	16	34
Ilyodrilus templetoni	21	11	34	66
Corbicula manilensis (<10 mm)	5	9	19	33
Gammarus fasciatus	6	2	20	28
Coelotanypus scapularis			3	3
Coelotanypus concinnus		1		1
Cryptochironomus		1		1

Site B6

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	55	73	62	190
Limnodrilus hoffmeisteri	2	5	7	14
Ilyodrilus templetoni	6	2	1	9
Corbicula manilensis (<10 mm)	15	9		24
Gammarus fasciatus	5			5
Chaoborus punctipennis	2	1		3
Coelotanypus scapularis	30	16		46
Procladius bellus		1		1
Harnischia	5	5	1	11

Site B7

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	1	104	39	144
Limnodrilus hoffmeisteri		27	8	35
Ilyodrilus templetoni		6		6
Corbicula manilensis (<10 mm)	16	14		30
Coelotanypus scapularis	27	17		44
Harnischia		3	2	5

Site B8

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex multisetosus			1	1
Limnodrilus spp.	36	35	57	128
Limnodrilus hoffmeisteri	3	23	15	41
Ilyodrilus templetoni	9	9	7	25
Corbicula manilensis (>10 mm)	1	1		2
Corbicula manilensis (<10 mm)	26	3	46	75
Sphaerium transversum	2		2	4
Chaoborus punctipennis			1	1
Coelotanypus scapularis	12	6	17	35
Procladius bellus	1		1	2
Polypedilum		1		1
Harnischia	5		1	6

20 October 3 months after disposal collection

Site C4

Taxon	Grab 1	Grab 2	Grab 3	Total
Branchiura sowerbyi		3	2	5
Limnodrilus spp.	56	55	58	169
Limnodrilus hoffmeisteri	12		2	14
Ilyodrilus templetoni	1		8	9
Corbicula manilensis (<10 mm)	9	13	4	26
Pisidium	2		2	4
Chaoborus punctipennis			3	3
Coelotanypus scapularis	19	15	31	65
Procladius bellus		2		2
Chironomus	1	1		2
Cryptochironomus		1		1
Polypedilum		1	2	3
Harnischia	4	1		5
Dicrotendipes nervosus		1		1

Site L1

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex multisetosus	5		1	6
Limnodrilus spp.	53	62	99	214
Limnodrilus hoffmeisteri	3	6	8	17
Ilyodrilus templetoni			5	5
Helobdella elongata	3	2	2	7
Valvata sincera			1	1
Ferrissia		3		3
Elliptio complanata		1		1
Corbicula manilensis (>10 mm)	1			1
Corbicula manilensis (<10 mm)	26	13	13	52
Rangia cuneata			1	1
Hexagenia mingo			1	1
Coleoptera	1			1
Chironomidae	1			1
Coelotanypus scapularis			3	3
Procladius bellus			1	1
Chironomus	1		1	2
Cryptochironomus			1	1
Dicrotendipes nervosus	3			3
Ablebesmyia sp. E			1	1

Site L2

Taxon	Grab 1	Grab 2	Grab 3	Total
Branchiura sowerbyi			2	2
Limnodrilus spp.	17	55	35	107
Limnodrilus hoffmeisteri	2	2		4
Ilyodrilus templetoni		7	5	12
Helobdella elongata			1	1
Corbicula manilensis (<10 mm)	4	9	9	22
Chaoborus punctipennis	1	1	1	3
Coelotanypus scapularis	8	6		14
Chironomus		1		1
Cryptochironomus	1			1
Polypedilum	2			2
Harnischia		1		1

Site L3

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	18	10	6	34
Limnodrilus hoffmeisteri			2	2
Ilyodrilus templetoni			1	1
Corbicula manilensis (<10 mm)	3	8	2	13
Chaoborus punctipennis	1	1	1	3
Coelotanypus scapularis	16	17	7	40
Cryptochironomus			3	3
Harnischia	2	5		7

Site L4

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	43	47	35	125
Limnodrilus hoffmeisteri	1	1	2	4
Ilyodrilus templetoni	1	9		10
Corbicula manilensis (<10 mm)	8	13	23	44
Chaoborus punctipennis	2	4		6
Chironomidae	1			1
Coelotanypus scapularis	1	14	21	36
Chironomus	1		1	2
Cryptochironomus			1	1
Harnischia	3		3	6

Site L5

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex freyi	1			1
Branchiura sowerbyi	5			5
Limnodrilus spp.	32	31	50	113
Limnodrilus hoffmeisteri	1	1	2	4
Ilyodrilus templetoni	1	1		2
Corbicula manilensis (<10 mm)	10	25	35	70
Sphaerium transversum	2			2
Chaoborus punctipennis	1	3	1	5
Chironomidae		1		1
Coelotanypus scapularis	28	15	7	50
Procladius bellus		2		2
Chironomus		1	1	2
Cryptochironomus	1	2		3
Harnischia		2	4	6

Site L6

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	34	33	14	81
Limnodrilus hoffmeisteri	2	7		9
Ilyodrilus templetoni	7	2		9
Corbicula manilensis (<10 mm)	6	6		12
Hexagenia mingo	2			2
Chironomidae		1		1
Coelotanypus scapularis	2	3		5
Ablebesmyia sp. E	1			1

Site L7

Taxon	Grab 1	Grab 2	Grab 3	Total
Peloscolex freyi	2	1		3
Limnodrilus spp.	87	56	258	401
Limnodrilus hoffmeisteri	19	9	15	43
Limnodrilus cervix	14	13	34	61
Ilyodrilus templetoni	2	1	2	5
Corbicula manilensis (<10 mm)	33	34	76	143
Chironomidae			1	1
Procladius bellus			1	1
Cryptochironomus	1	1	4	6
Polypedilum	1		1	2
Dicrotendipes nervosus	1		2	3

Site L8

Taxon	Grab 1	Grab 2	Grab 3	Total
Limnodrilus spp.	74	34	4	112
Ilyodrilus templetoni	13	6	4	23
Corbicula manilensis (<10 mm)	17	8	4	29
Odonata	1			1
Coelotanypus scapularis	5	6		11
Cryptochironomus	2			2
Polypedilum	6	4		10

APPENDIX B: TAXONOMIC LIST OF ALL BENTHIC SPECIES

Phylum: Platyhelminthes
- Class: Turbellaria
  - Family: Plagiostomidae
    - *Hydrolimax grisea* Haldeman

Phylum: Mollusca
- Class: Pelecypoda
  - Family: Corbiculidae
    - *Corbicula manilensis* (Phillippi)
  - Family: Sphaeriidae
    - *Sphaerium transversum*
    - *Pisidium* sp.
  - Family: Mactridae
    - *Rangia cuneata* Sowerby
  - Family: Unionidae
    - *Elliptio complanata* Lightfoot
- Class: Gastropoda
  - Family: Ancylidae
    - *Ferrissia* sp.
  - Family: Valvatidae
    - *Valvata sincera* Say

Phylum: Annelida
- Class: Oligochaeta
  - Family: Tubificidae
    - *Tubifex* sp.
    - *Branchiura sowerbyi* Beddard
    - *Ilyodrilus templetoni* (Southern)
    - *Limnodrilus cervix* Brinkhurst
    - *Limnodrilus hoffmeisteri* Claparede
    - *Limnodrilus profundicola* Smith
    - *Limnodrilus* spp.
    - *Peloscolex multisetosus* Brinkhurst
    - *Peloscolex freyi* Brinkhurst, 1965
  - Family: Naididae
- Class: Hirudinea
  - Family: Piscicolidae
    - *Helobdella elongata* (Castle) 1899

Phylum: Arthropoda
- Class: Crustacea
  - Order: Amphipoda
    - Family: Gammaridae
      - *Gammarus fasciatus* Say
- Class: Insecta
  - Order: Ephemeroptera
    - Family: Ephemeridae
      - *Hexagenia mingo* Walsh

Phylum: Arthropoda (continued)

- Order: Tricoptera
- Order: Odonata
- Order: Diptera
  - Suborder: Cyclorrahapha
    - Cyclorrahapha larvae
    - Family: Culcidae
      - *Chaoborus punctipennis* Lichtenstein
    - Family: Chironomidae
      - Chironomid sp. 1
      - Chironomid sp. 2
      - *Ablebesmyia* sp. E Roback
      - *Chironomus* spp.
      - *Coelotanypus scapularis* (Loew)
      - *Coelotanypus concinnus* (Coquillett)
      - *Cryptochironomus* spp.
      - *Dicrotendipes nervosus* (Staeg.)
      - *Polypedilum* spp.
      - *Procladius bellus* (Loew)
      - *Stictochironomus devinctus* (Say)
      - *Tanypus neopunctipennis*
      - *Psectrocladius* sp.
      - *Harnischia* spp.
- Order: Coleoptera
  - Coleopteran larvae

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.

Diaz, Robert J

Impact of fluid mud dredged material on benthic communities of the tidal James River, Virginia / by Robert J. Diaz and Donald F. Boesch, Virginia Institute of Marine Science, Division of Biological Oceanography, Gloucester Point, Va. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.

38, [38] p. : ill. ; 27 cm. (Technical report - U. S. Army ngineer Waterways Experiment Station ; D-77-45)

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Special report in Applied Marine Science and Ocean Engineering No. 153.

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(Continued on next card)

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4. James River. 5. Mud. I. Boesch, Donald F., joint author. II. United States. Army. Corps of Engineers. III. Virginia Institute of Marine Science, Gloucester Point. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-45.

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