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THE SIGNIFICANCE OF DREDGING AND DREDGED MATERIAL DISPOSAL AS A SOURCE OF NITROGEN AND PHOSPHORUS FOR ESTUARINE WATERS

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ABSTRACT: Several hundred million cubic meters of waterway sediment are dredged each year in the United States to maintain adequate navigation depth. A significant part of this dredging and dredged sediment disposal takes place in freshwater tidal, estuarine, and marine waters. U.S. waterway sediments contain sufficient quantities of nitrogen and phosphorus compounds which, if released in available forms during dredged material disposal, could stimulate the growth of excessive amounts of algae and other aquatic plants in estuaries. This paper discusses the results of that portion of a comprehensive study conducted by the authors that assessed the significance of dredged sediments as a source of nutrients for U.S. estuarine waters.

Laboratory studies were conducted on waterway sediments from over 20 marine, estuarine, and freshwater tidal areas to evaluate the suitability of the elutriate test for estimating contaminant release from dredged sediments during open water disposal. Disposal operations involving sediments from nine of these areas were monitored for nutrient release to the water column.

Sediment Kjeldahl nitrogen concentration generally ranged from ~ 200 to 4,000 mgN/kg with a mean concentration of ~1,550 mgN/kg. Elutriate tests generally showed a release of soluble nitrogen (ammonia plus nitrate) to 0.5 to 35 mgN/1. Total phosphorus concentrations of the sediments studied averaged ~950 mgP/kg and ranged from ~100 to 3,750 mgP/kg. Response of sediment-associated and soluble phosphorus to elutriation ranged from a decrease in soluble ortho P concentration by 0.6 mgP/l to an increase by 1.6 mgP/l. Generally, relatively small amounts of nitrogen and phosphorus are released during elutriation and would be expected to be released during open water disposal of hydraulically dredged sediments; this was substantiated by intensive field monitoring of disposal operations. While there is no relationship between the bulk sediment content of N or P and the amounts of available forms released in elutriate tests, the maximum

sediment nitrogen released in available forms was about 1 percent; maximum soluble orthophosphate released was less than 0.1 percent of the total P content of the sediment. Even less release would be expected during barge-scow disposal of mechanically dredged sediment.

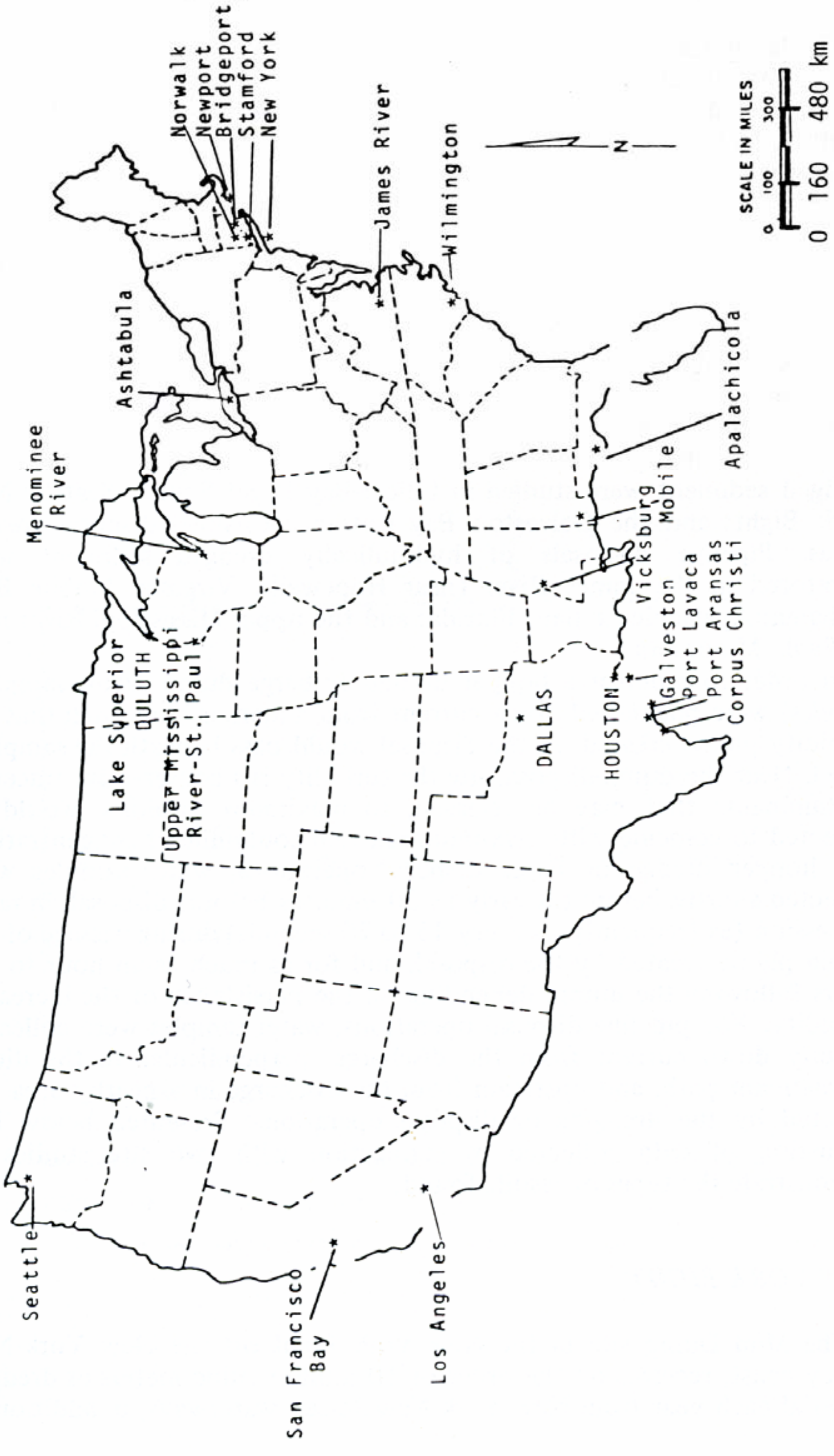
This study demonstrated that modified elutriate tests provide an indication of sediment-associated contaminant behavior during open water disposal of hydraulically dredged sediment. The key to the proper use of these procedures is having a knowledge of the hydrodynamic characteristics of the disposal area, the limiting nutrient in the area of concern, and, for phosphorus, a knowledge of the iron system in the sediments being dumped.

INTRODUCTION

One of the potential sources of nutrients which has been of concern in the eutrophication of surface waters is dredged sediment. On the order of 400 million cubic yards of sediments are dredged each year in the development and maintenance of United States waterways. A substantial part of this material is dredged from and disposed of in freshwater tidal and estuarine areas. U.S. waterway sediments contain highly variable levels of nutrients, typically on the order of several hundred to several thousand mg/kg N and P. These quantities are sufficient to stimulate the growth of excessive amounts of algae and other aquatic plants if they were released in available forms during dredging and disposal.

Because of the concern about algal available nutrient release associated with dredged sediment disposal, this topic was included as one aspect of a five-year study undertaken by the authors under sponsorship of the Corps of Engineers Dredged Material Research Program (DMRP). This study consisted of two parts. One part was devoted to evaluating the release of a wide variety of chemical contaminants including available forms of nutrients (ammonia, nitrate, and soluble orthophosphate) in the laboratory using bulk sediment analysis and the elutriate test. The second part involved determination of the amounts of these contaminants released to the water column during a number of dredged material disposal operations. The second part was also designed to assess the ability of the laboratory tests to predict contaminant release. The detailed results of these studies and discussion of their significance to dredged material disposal have been presented in a number of reports and papers (1, 2, 3, 5, 6, 7, 8). This paper discusses the results of that portion of the study conducted by the authors designed to determine the significance of dredged sediments as a source of nutrients for U.S. estuarine waters. Data obtained from parts of the James River and New York Bight studies are discussed herein to illustrate the types of information collected.

FIGURE 1. Sampling locations.



LABORATORY AND FIELD STUDIES

The laboratory studies were conducted on over 50 sediments from the approximately 20 areas across the U.S. shown in Figure 1. Freshwater tidal and estuarine systems investigated included areas on the Gulf coast, North Atlantic coast, and the western U.S. coast. More than 325 elutriate tests were conducted during this study in evaluating and refining this test procedure, which consists of combining one volume of sediment with four volumes of water, mixing for 30 minutes using vigorous aeration or bubbling with nitrogen gas, settling for one hour, decanting and filtering the supernatant through a half micron pore size filter, and analyzing the filtrate. Each sediment processed through the elutriate test was also analyzed for about 30 bulk chemical parameters.

Field studies were conducted during about 20 disposal operations at nine of the areas shown in Figure 1. Hopper dredge dumping of hydraulically dredged sediment and/or barge dumping of mechanically dredged sediment were studied in Elliott-Bay Puget Sound, Seattle; New York Bight; and the Galveston Bay Entrance Channel disposal area in Texas. Pipeline disposals of hydraulically dredged sediment were monitored in the James River (near Hopewell), Virginia; Mobile Bay, Alabama; Apalachicola Bay, Florida; and the upper Mississippi River near St. Paul., Minnesota.

In order to monitor a hopper dredge or barge dump event, sampling vessel(s) were positioned down current from a marker buoy such that the turbidity plume created by the disposal would pass beneath the sampling vessel. Near the dump-disposal site the turbidity is a conservative tracer of contaminants that may be released, so maximum turbidity would be expected to coincide with maximum released contaminant concentration. For hopper dredge or barge disposal operations, water samples were collected shortly before (as early as 30 minutes before) disposal, in rapid succession (as frequently as every 15 to 20 seconds) during passage of the turbid plume created by the disposal, and for as much as an hour to 1.5 hours following the dump, depending on the persistence of the increased turbidity. For pipeline disposal operations, water samples were collected directly down current from the discharge, perpendicular to the direct downstream path, and upstream from the discharge in a nearby area not affected by the dredging or disposal operations. Presented below is a discussion of data collected in connection with two site studies to demonstrate the types of results found.

NEW YORK BIGHT

The Mud Dump site in the New York Bight off the New York-New Jersey coast, receives on the order of 10 million cubic meters of dredged material each year from New York-New Jersey waterways, in addition to chemical and other waste materials. As discussed by Lee and Jones (4), this region had experienced a massive fish die-off due to low dissolved oxygen water resulting from algal growth and death.

Monitoring vessels were positioned downcurrent from the dump site as shown in Figure 2, such that the turbid plume of dredged sediment would pass beneath them for sampling. Figure 3 shows changes in turbidity in the bottom waters at the Mud Dump site at the position of the sampling vessel Hatton during disposals of sediment from Perth Amboy channel (No. 1 - hopper disposal), and Perth Amboy Anchorage (No. 2 - barge disposal); the dump events are obvious. Turbidity in the bottom waters decreased to ambient levels within about one hour after the dump. At this location the ammonia concentrations (which include ammonium and unionized ammonia) were found to increase coincident with the increase

FIGURE 2. Positions of sampling vessels at Mud Dump Site during monitoring of New York Bight Dump No. 1.

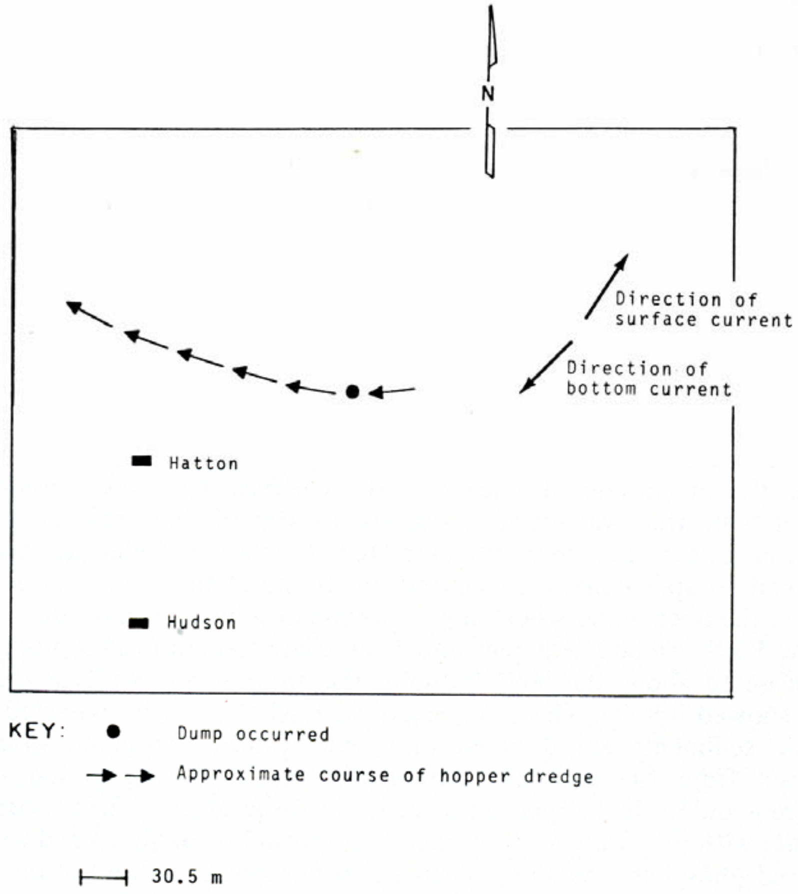
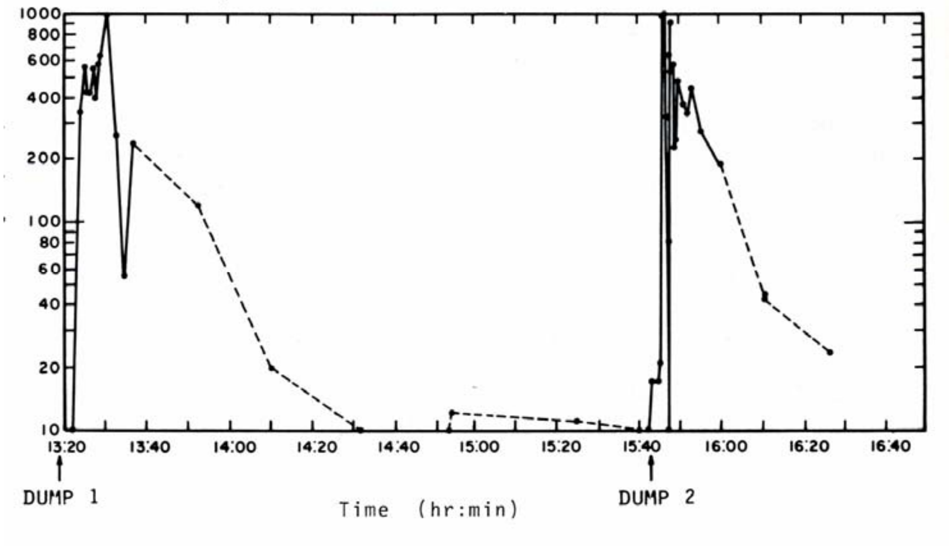


FIGURE 3. Turbidity in near bottom water during New York Bight Dump Nos. 1 and 2.

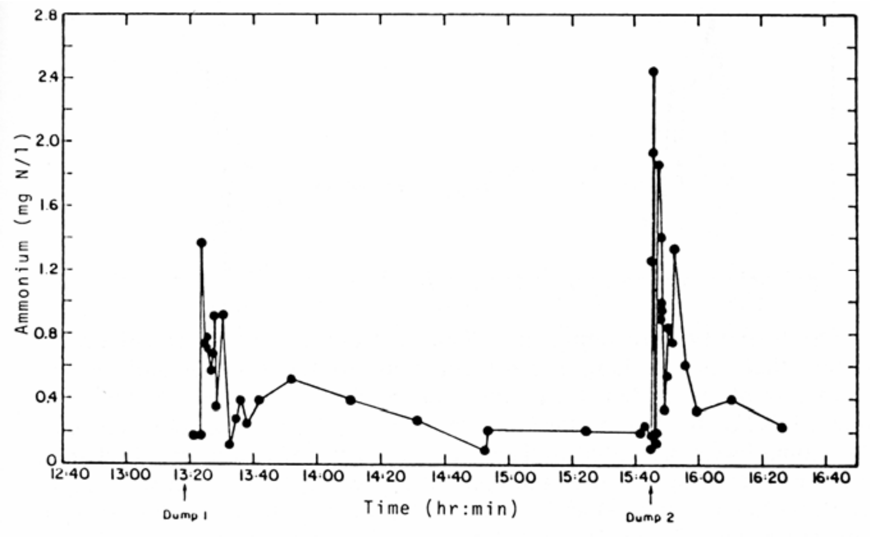


in turbidity (Figure 4). Concentrations reached about l.5 mg/l N and ~2.5 mg/l N in association with the two dumps and returned to ambient at the dump site within 10 to 20 minutes of the dump. Soluble orthophosphate concentrations (Figure 5) increased to about 200 to 250 µg/l P from a baseline of about 50 µg/l P. With the first dump, concentrations decreased to baseline within 10 minutes or so; after the second dump they remained elevated for the duration of sampling.

Elutriate tests run on the sediments being dumped in the New York Bight during the monitored dumps (Perth Amboy Channel and Anchorage) showed releases of ammonia on the order of 15 to 30 mgN/l. While the magnitude of release in the elutriate test was considerably greater than what was found during the passage of the turbid plume, the fact that release occurred was predicted. Further, the elutriate test was designed to approximate concentrations found in the hopper bins rather than in the open water where large amounts of dilution can occur.

The Perth Amboy sediment anoxic elutriate tests showed soluble ortho P release to about the level found at the disposal site, whereas the oxic ones showed uptake. This is in accord with what could be expected when anoxic sediments are dumped into oxic waters. Phosphate would be released from the sediment during the anoxic mixing period during dredging and in the hopper in transit to the disposal site. When it comes in contact with oxic waters, the reduced iron would be oxidized and sorb the released phosphate, causing a decrease in phosphate concentration in the water. This seemed to be the case with the New York Bight dumps, as evidenced by the rapid decrease in concentration of soluble ortho P between two sampling vessels about 100 m apart, both downcurrent from another New York Bight dump.

FIGURE 4. Ammonia concentrations in near bottom water during New York Bight Dump Nos. 1 and 2.

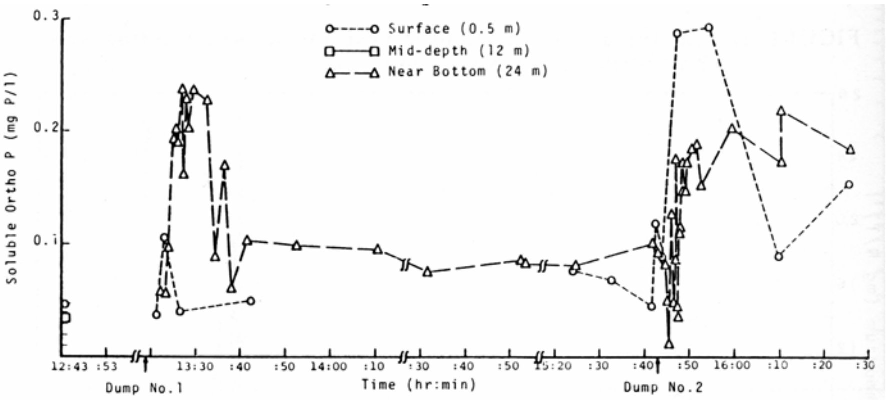


Similar nutrient release patterns were found at other hopper dredge disposal sites; there was typically an increase in concentration followed by a rapid decrease to ambient levels. At the Galveston Bay Entrance Channel disposal site (7) a number of water samples were collected over a several year period in order to detect long term contaminant release from the deposited sediments. There was no indication that there was sufficient release of contaminants from the deposited dredged sediments to affect water quality in the disposal area.

JAMES RIVER

The primary concern at the James River dredging-disposal area near Hopewell, Virginia, was the release of sediment-associated kepone during dredging. Monitoring of this pipeline disposal of hydraulically dredged sediments, however, included measurement of aquatic plant nutrients as well. Figure 6 shows the dredging-disposal area and sampling locations. A drogue designed to move with the near bottom current was released at the discharge point. Samples of water were collected both in the path of the drogue to measure variations in concentrations with time-distance, and also in a number of other areas perpendicular to the path of the drogue and upstream from the discharge to determine the extent of the impact of the disposal.

FIGURE 5. Soluble ortho P concentrations in near bottom water during New York Bight Dump Nos. 1 and 2.



The turbidity with depth and distance from the discharge (Figure 7) shows that the discharged sediment sank to the bottom and flowed downcurrent as a density current, decreasing in intensity from over 60,000 NTU to the background level by 350 m or so downcurrent. Ammonia levels presented in Table l were also elevated at the discharge, Station 8, reaching 20 to 25 mg/l N, but decreasing to ambient within 200 or so meters (Station 9) and remaining below detection. Soluble ortho P concentrations (Table 2) were also elevated in the area of the discharge, reaching levels of 35 µg/l P in the bottom waters and dispersing downcurrent.

FIGURE 6. James River study area.

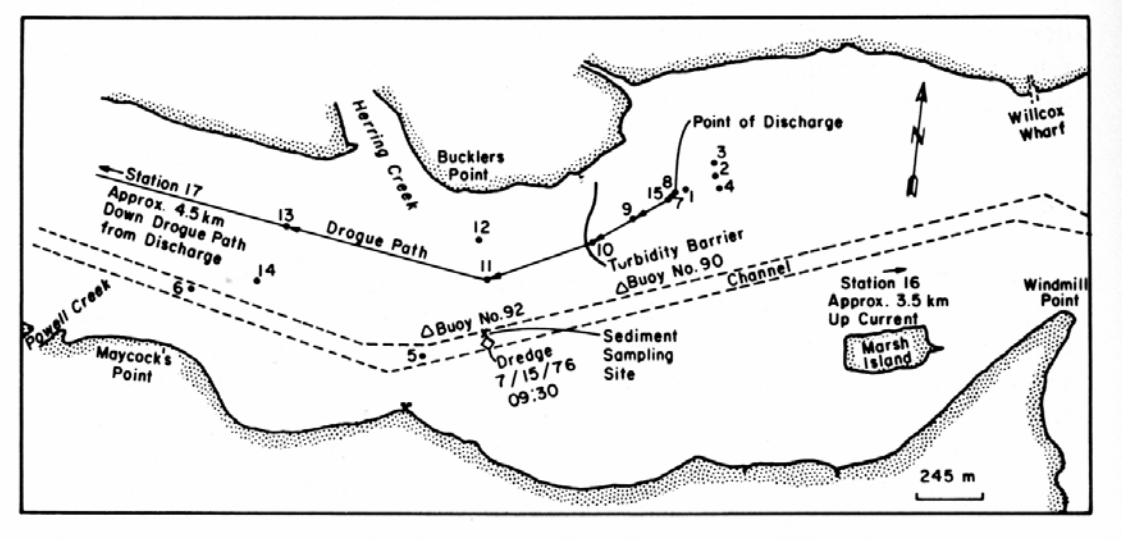
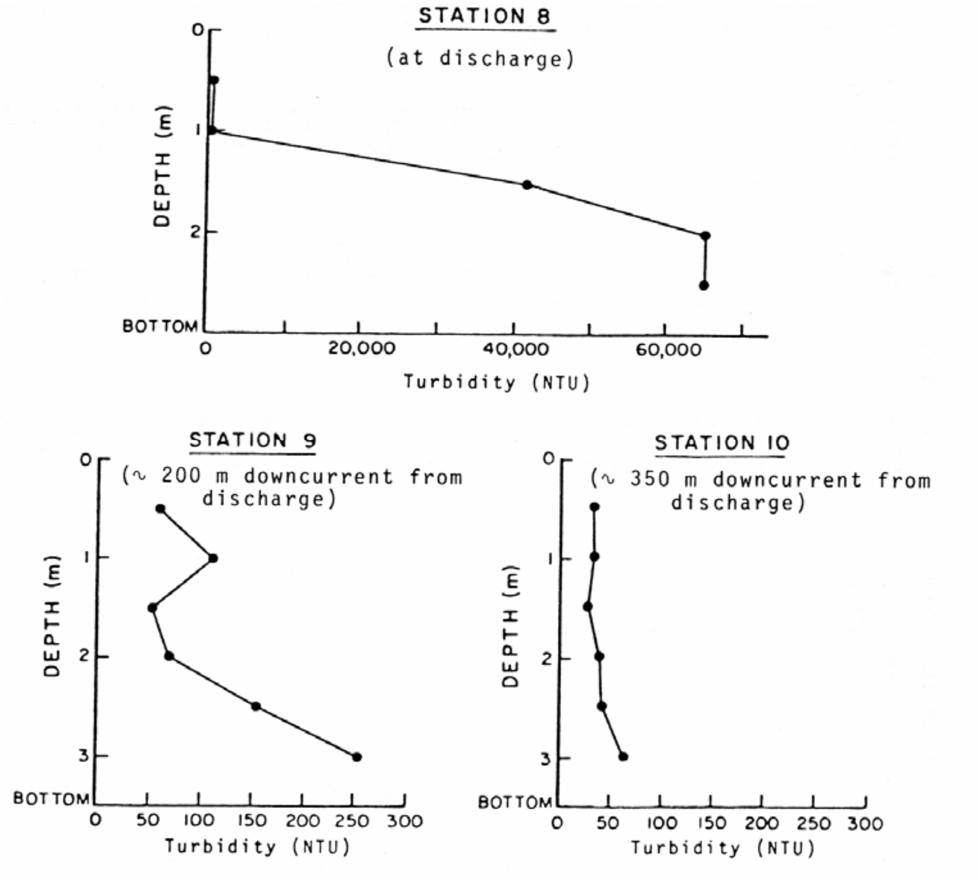


FIGURE 7. Turbidity near James River disposal area.

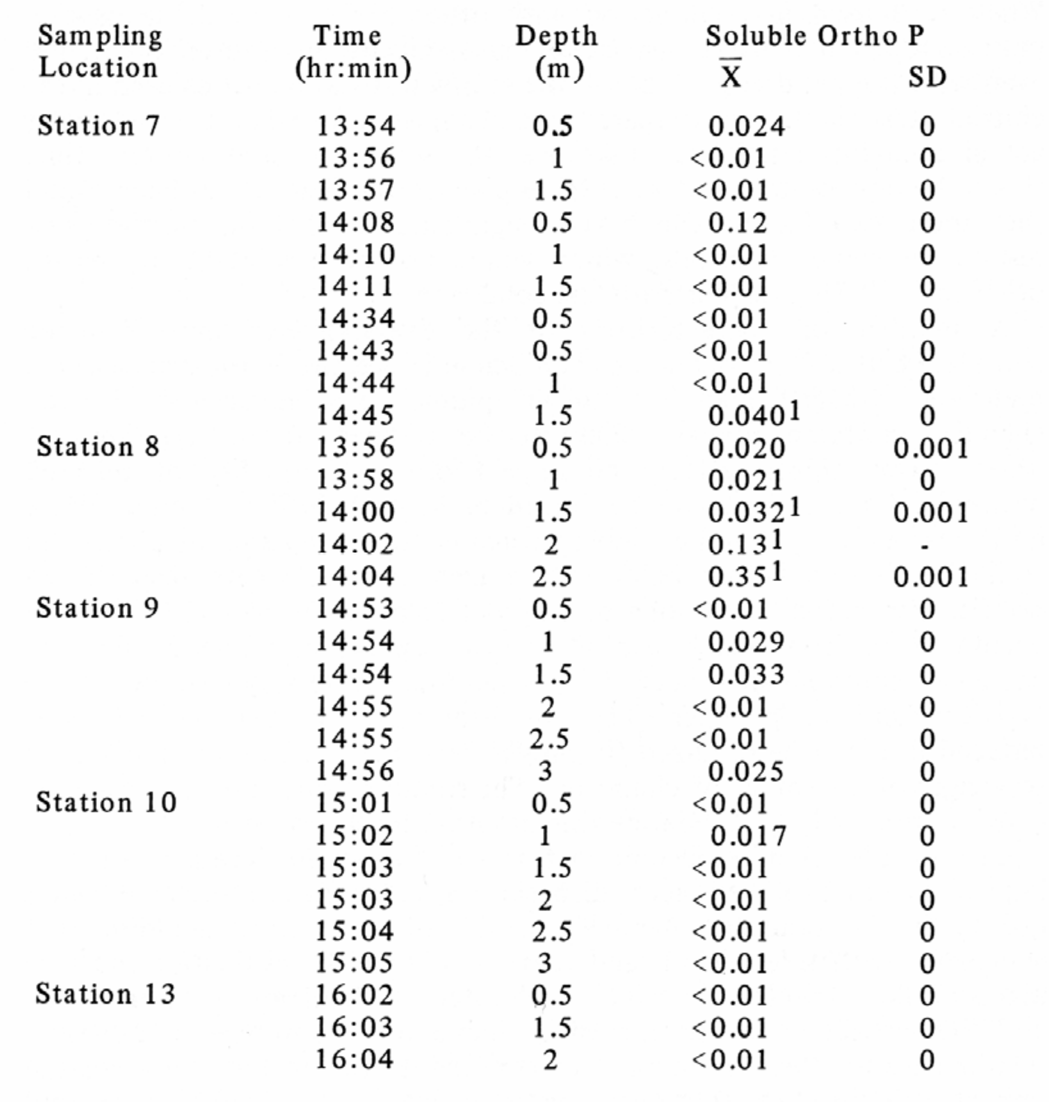


Elutriate tests run on the James River sediments showed ammonia release on the order of 5 to 6 mgN/l. This level is considerably below that found in the disposal site water column. Elutriation also resulted in a small uptake of soluble ortho P, whereas some release was found near the discharge point. These seemingly deviant results point to the importance of proper interpretation and use of the data in terms of the disposal operation characteristics. In the case of the James River disposal operation, these results may have been due in part to the fact that the elutriate test, which was designed for hopper dredge operations, had a considerably longer sediment-water contact time than was found in the field. Also, there were large amounts of finely divided (<0.45 µ diameter) particulate matter in the discharge. The additional sediment-water contact time in the elutriate test may have allowed a greater amount of soluble ortho phosphate to sorb onto the fine materials, thereby showing a lower soluble ortho P concentration than actually found in the field. The factors to be considered in interpretation of elutriate test results are discussed below.

TABLE 1. Concentrations of ammonia near James River disposal area. (After Lee *et al.*[8])

Sampling Location	Time (hr:min)	Depth (m)	Ammonium (mg N/l)	
			$\bar{x}$	SD
Station 5	12:19	0.5	<0.05	∿0
	12:40	3.0	<0.05	∿0
	12:41	6.0	<0.05	∿0
	12:43	8.5	<0.05	∿0
Station 6	13:09	2.0	<0.05	∿0
	13:10	0.5	<0.05	∿0
Station 7	13:54	0.5	<0.05	∿0
	13:56	1.0	<0.05	∿0
	13:57	1.5	<0.05	∿0
	14:08	0.5	<0.05	∿0
	14:10	1.0	<0.05	∿0
	14:11	1.5	0.43	0
	14:34	Surface	<0.05	∿0
	14:43	0.5	<0.05	∿0
	14:44	1.0	<0.05	∿0
	14:45	1.5	1.66	0.05
Station 8	13:56	0.5	<0.05	∿0
	13:58	1.0	<0.05	∿0
	14:00	1.5	16.45	0.64
	14:02	2.0	23.40	0.42
	14:04	2.5	24.15	0.21
Station 9	14:53	0.5	<0.05	∿0
	14:54	1.0	<0.05	∿0
	14:54	1.5	<0.05	∿0
	14:55	2.0	<0.05	∿0
	14:55	2.5	<0.05	∿0
	14:56	3.0	<0.05	∿0
Station 10	15:01	0.5	<0.05	∿0
	15:02	1.0	<0.05	∿0
	15:03	1.5	<0.05	∿0
	15:03	2.0	<0.05	∿0
	15:04	2.5	<0.05	∿0
	15:05	3.0	<0.05	∿0
Station 11	15:27	0.5	<0.05	∿0
	15:27	1.5	<0.05	∿0
	15:28	2.5	<0.05	∿0
	15:29	3.5	<0.05	∿0
	15:31	4.0	<0.05	∿0
Station 12	15:39	0.5	<0.05	∿0
	15:40	1.5	<0.05	∿0
	15:41	2.5	<0.05	∿0
	15:42	3.5	<0.05	∿0
Station 13	16:02	0.5	<0.05	∿0
	16:03	1.5	<0.05	∿0
	16:04	2.0	<0.05	∿0
Station 14	16:14	0.5	<0.05	∿0
	16:16	2.5	<0.05	∿0
	16:18	4.5	<0.05	∿0
	16:19	6.0	<0.05	∿0
Station 15	16:42	0.5	<0.05	∿0
	16:43	1.0	<0.05	∿0
	16:44	1.5	0.29	0.01
	16:46	1.75	2.93	0.06

TABLE 2. Soluble ortho P concentrations at James River disposal site.



Sampling Location	Time (hr:min)	Depth (m)	Soluble Ortho P $\overline{X}$	SD
Station 7	13:54	0.5	0.024	0
	13:56	1	<0.01	0
	13:57	1.5	<0.01	0
	14:08	0.5	0.12	0
	14:10	1	<0.01	0
	14:11	1.5	<0.01	0
	14:34	0.5	<0.01	0
	14:43	0.5	<0.01	0
	14:44	1	<0.01	0
	14:45	1.5	0.040[1]	0
Station 8	13:56	0.5	0.020	0.001
	13:58	1	0.021	0
	14:00	1.5	0.032[1]	0.001
	14:02	2	0.13[1]	-
	14:04	2.5	0.35[1]	0.001
Station 9	14:53	0.5	<0.01	0
	14:54	1	0.029	0
	14:54	1.5	0.033	0
	14:55	2	<0.01	0
	14:55	2.5	<0.01	0
	14:56	3	0.025	0
Station 10	15:01	0.5	<0.01	0
	15:02	1	0.017	0
	15:03	1.5	<0.01	0
	15:03	2	<0.01	0
	15:04	2.5	<0.01	0
	15:05	3	<0.01	0
Station 13	16:02	0.5	<0.01	0
	16:03	1.5	<0.01	0
	16:04	2	<0.01	0

[1] Sample contained fine particulate matter after 0.45 µ pore-size filtration. Samples were refiltered through a 0.2 µ pore-size membrane filter prior to analysis. After Lee et al.[8]

INTERPRETATION OF ELUTRIATE TEST RESULTS

In order to effectively use elutriate test results, they must be interpreted in terms of the characteristics of the disposal operation and the disposal site. Without such interpretation, elutriate test concentrations are of very limited value in making a decision about the potential impact on water quality associated with disposal of dredged sediment in a particular location.

The elutriate test was designed to predict contaminant release associated with hopper-dredge disposal of hydraulically dredged sediment. When it is used in conjunction with other types of dredging-disposal operations, such as barge disposal of mechanically dredged sediment, and even with hopper dredge disposal, the sediment-to-water ratios used in the elutriate test should be compared to and adjusted for what is found under actual dredging conditions. Likewise, the sediment-water contact time should be representative of what takes place in the field. It has been found that these two factors can have a significant impact on elutriate test results for some chemicals, impacts which would not be predictable by means other than altering the elutriate test conditions.

A number of characteristics of the disposal area must also be considered. If a thermocline or chemocline is present at the disposal site, then the dredged material "turbid plume" and associated released chemical contaminants are likely to be trapped in the hypolimnetic waters. This would affect the impact on water quality of released nutrients, since there could be considerable time during which available nutrients released could be made unavailable for use by aquatic plants and could be diluted before being mixed into an area where algal uptake occurs. The redox conditions of disposal area waters will influence the chemistry of iron, which can affect the uptake and release of some chemical contaminants such as phosphorus. Waterway sediments are typically anoxic, so when they are disposed of in oxic open waters, reduced iron can be oxidized forming a ferric hydroxide floc, an effective scavenger of a number of chemicals. The running of both oxic and anoxic elutriate tests may better define this situation for a system.

One of the most important factors to consider in defining potential impact of dredged sediment disposal on eutrophication-related water quality is the dilution character of the disposal area, including that associated with tides, wind, and current mixing. An evaluation must be made of the expected duration of elevated contaminant concentrations and the critical concentration of available forms—duration of exposure relationship for the contaminant of concern. In the case of predicting the impact of released phosphorus on water quality, as discussed by Jones and Lee (2), the dilution as expressed as the hydraulic residence time is a crucial component. It must be noted that as currently designed, the elutriate test does not give consideration to dilution and therefore typically represents a worst case with respect to contaminant release.

When release of nutrients is of concern with respect to dredged material disposal, the nutrient limiting algal growth in the disposal area during the time of year of concern must be determined. If, as is the case with many coastal marine waters, the disposal area waters are nitrogen-limited, then the release of phosphorus from dredged sediment may be of little consequence. Further, highly turbid water, such as is typical of many estuarine and freshwater tidal waters, may preclude growth limitation by nutrients. If a nutrient of potential concern is expected to be released with dredged material, other sources of this nutrient should be evaluated for their relative significance in stimulating algal growth.

Finally, it may be determined that the water quality significance of other contaminants released during disposal, such as toxic materials, may dwarf the overall water quality significance of increased aquatic plant growth.

CONCLUSIONS

The results presented here are typical of sediment-associated nutrient behavior at the seven other disposal sites studied. Sediment Kjeldahl nitrogen concentration generally ranged from ~ 200 to 4,000 mgN/kg with a mean concentration of ~ 1,550 mgN/kg. Elutriate tests generally showed a release of soluble nitrogen (ammonia plus nitrate) to 0.5 to 35 mgN/l. Total phosphorus concentrations of the sediments studied averaged ~ 950 mgP/kg and ranged from ~ 100 to 3,750 mgP/kg. Response of sediment-associated and soluble phosphorus to elutriation ranged from a decrease in soluble ortho P concentration by 0.6 mgP/1 to an increase by l.6 mgP/l. Detailed data presentation and discussion of the study results are presented by Lee et al. (8) and Jones and Lee (2). Conclusions that can be drawn based on these studies include the following:

Based on total amounts of N and P, dredged sediments appear to be a potentially significant source of nutrients if the nutrients are released in available forms during disposal.

No general relationship can be developed between bulk composition of a sediment and the amounts of contaminant release either in the laboratory elutriate test or in the field. This was based on intensive study of contaminant release from over 50 sediments from across the country.

The elutriate test can provide a prediction of the behavior of available nitrogen and phosphorus during open water dredged material disposal and will also provide an estimate of the concentrations if interpreted properly in light of disposal operation characteristics.

Based on the results of this study as well as a review of the literature, it appears that in general, dredged sediment-associated nutrients will rarely have an adverse effect on eutrophication-related water quality at the disposal site mainly because the events are short-lived, there is typically fairly rapid dilution of the disposed-of sediment, and, relative to the dilution, nutrient release is small. The potential impact must be evaluated on a site-by-site basis.

For several contaminants, including phosphorus, elutriate test results must be interpreted in terms of the aqueous environmental chemistry of iron. Iron present in the anoxic dredged sediment is oxidized when it comes in contact with oxic disposal area water, forming a ferric hydroxide floc which is an effective scavenger for phosphate.

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