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Water Resources
Support Center

Management of Bottom Sediments Containing Toxic Substances

Proceedings of the 13th U.S./Japan
Experts Meeting

3-5 November 1987
Baltimore, Maryland

Thomas R. Patin, Editor

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The 13th U.S./Japan Meeting on Management of Bottom Sediments Containing Toxic Substances was held 3-5 November 1987 in Baltimore, Maryland. The meeting is held annually through an agreement with the U.S. Army Corps of Engineers and the Japan Ministry of Transport to provide a forum for presentation of papers and in-depth discussions on dredging and disposal of contaminated sediment.

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PREFACE

The 13th U.S./Japan Experts Meeting on Management of Bottom Sediments Containing Toxic Substances was held 3-5 November 1987 in Baltimore, Maryland. The meeting is held annually through an agreement with the U.S. Army Corps of Engineers and the Japan Ministry of Transport to provide a forum for presentation of papers and in-depth discussions on dredging and disposal of contaminated sediment.

COL Richard G. Rothblum, Commander and Director of the Water Resources Support Center, was the U.S. Chairman. Mr. Takao Nishimura, Ministry of Transport, Tokyo, Japan, was the Japanese Chairman.

Coordinator of the organizational activities and editor of this report was Mr. Thomas R. Patin, current Program Manager, Dredging Operations Technical Support (DOTS) Program, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. Mr. Charles C. Calhoun, Jr., was Program Manager, DOTS, at the time of the meeting. Dr. Robert M. Engler is the Program Manager of the Environmental Effects of Dredging Program, of which the DOTS Program is a part.

CONTENTS

ATTENDEES

13TH U.S./JAPAN EXPERTS MEETING ON MANAGEMENT
OF BOTTOM SEDIMENTS CONTAINING
TOXIC SUBSTANCES

Baltimore, Maryland
3-5 November 1987

Japanese Delegation

Mr. Takao Nishimura Co-Chairman	Director, Environment Division Port & Harbor Bureau, Ministry of Transport
Dr. Motoo Fujiki	Professor, Institute of Community Environmental Medicine, Tsukuba University
Dr. Mitsumasa Okada	Professor, Agriculture and Technology, Chemical Engineering, Tokyo University
Mr. Masaaki Hosomi	Researcher, Freshwater Environmental Studies Section, National Institute for Environmental Pollution Research
Mr. Miyoji Konae	Port Development Department, Port and Harbor Bureau, City of Osaka
Mr. Makoto Natori	Japan Sediments Management Association
Mr. Tatsuro Kotake	Japan Sediments Management Association
Mr. Kazuhiro Yoshida	Japan Sediments Management Association
Mr. Kiyoshi Nikaidou	Japan Sediments Management Association
Mr. Tohru Mishima	Japan Sediments Management Association
Mr. Koichiro Irie	Japan Sediments Management Association
Mr. Hiroshi Shinsha	Japan Dredging and Reclamation Engineering Association
Mr. Kunikazu Fujii	Japan Dredging and Reclamation Engineering Association
Mr. Takeo Haekawa	Japan Dredging and Reclamation Engineering Association

Mr. Naoshi Ishimatsu	Japan Work Vessel Association

<u>U.S. Delegation</u>

COL Richard Rothblum Co-Chairman	Commander/Director, Water Resources Support Center, US Army Corps of Engineers
Mr. William Murden	US Army Corps of Engineers Water Resources Support Center
Mr. Thomas R. Patin	US Army Corps of Engineers Waterways Experiment Station
Mr. Frank Hamons	Maryland Port Administration
Mr. Glenn Earhart	US Army Corps of Engineers, Baltimore District
Mr. Vyto Andreliunas	US Army Corps of Engineers, New England Division
Mr. John Tavolaro	US Army Corps of Engineers, New York District
Mr. John Adams	US Army Corps of Engineers, Buffalo District
Mr. Kenneth Kamlet	URS Corporation, Washington, D.C.
Mr. Richard Gorini	Director of Planning & Development Vancouver, Washington
Dr. Thomas Hart	US Army Corps of Engineers Waterways Experiment Station
Mr. Anthony Kizlauskas	US Environmental Protection Agency, Region 5
Dr. Richard Peddicord	Battelle Ocean Science, Massachusetts
Mr. Norman Francingues	US Army Corps of Engineers Waterways Experiment Station
Dr. Robert Morton	Science Applications International Corp. Rhode Island
Dr. Robert Engler	US Army Corps of Engineers Waterways Experiment Station

AGENDA

13TH U.S./JAPAN EXPERTS MEETING ON MANAGEMENT
OF BOTTOM SEDIMENTS CONTAINING
TOXIC SUBSTANCES

Baltimore, Maryland
3-5 November 1987

Tuesday, November 3, 1987

8:00 - 9:00	Welcome-Deputy District Engineer, Baltimore District, LTC Joel M. Sauer
	Opening remarks-Deputy Division Engineer, North Atlantic Division, COL Richard G. Riordan
	Cochairman - COL Richard Rothblum, Director, Water Resources Support Center
	Cochairman - Mr. Takao Nishimura, Director, Environment Division, Ministry of Transport
9:00 - 9:30	"Treatment of Bottom Sediments Containing Mercury and Watching Method Using Fishes" presented by Dr. Motoo Fujiki
9:30 - 10:00	"Strategies and Techniques for Handling Contaminated Sediments in the Marine Environment" presented by Mr. Kenneth Kamlet
10:00 - 10:30	"Rehabilitation of the Amenity of Urban Rivers--Introduction of Secondary Treated Domestic Wastewater Into the Nobidome Channel" presented by Dr. Mitsumasa Okada
10:30 - 10:45	BREAK
10:45 - 11:15	"The Corps Management Strategy for Highly Contaminated Bottom Sediments" presented by Mr. Norman Francingues
11:15 - 11:45	"Sequencing Batch Treatment of Municipal Landfill Leachate--Removal of Nitrogen and Refractory Organic Compounds" presented by Mr. Masaaki Hosomi

12:30 - 2:00	Luncheon at OMNI Hotel Guest speaker-Mr. David Wagner, Port Administrator, Maryland Port Administration
2:30 - 3:00	"Regional Efforts Through IJC for Managing Contaminated Bottom Sediments Within the Great Lakes Area" presented by Mr. Anthony Kizlauskas
3:00 - 3:30	"Removal and Disposal of Accumulated Organic Sludge in the Port and Harbor Area" presented by Mr. Miyoji Konae
3:30 - 4:00	"The No-Dredging Option for Highly Contaminated In-Place Sediments" presented by Dr. Thomas Hart
4:00 - 4:15	BREAK
4:15 - 4:45	"The Synthetic Purification System of Lakes and Ports" presented by Mr. Tatsuro Kotake
4:45 - 5:15	"Updating the U.S. Experience with Aquatic Capping of Contaminated Sediments" presented by Dr. Robert Morton
7:00 - 9:00	U.S. Reception at World Trade Center

Wednesday, November 4, 1987

8:00 - 8:30	"The Consideration of the Relationship Between the Sediment Pollution and the Benthic Communities in the Closed Basin" presented by Mr. Kazuhiro Yoshida
8:30 - 9:00	"The Planned Pilot Dredging Demontration for the New Bedford Superfund Project" presented by Mr. Vyto Andreliunas
9:00 - 9:30	"Rehabilitation of Estuaries in Takamatsuko Harbor" presented by Mr. Kiyoshi Nikaido
9:30 - 10:00	"Toledo Harbor as a Case Study of Dredged Material Management" presented by Mr. John Adams
10:00 - 10:15	BREAK
10:15 - 10:45	"Bio-Filter System--A Water Area Purification System Utilizing Aquatic Plants" presented by Mr. Tohru Mishima

10:45 - 11:15	"The Results of the Corps' Field Verification Program" presented by Dr. Richard Peddicord
11:15 - 11:45	"On the Correlationships of the Natural Environment and the Park Located Adjacent to the Inner Area of Tokyo Bay" presented by Mr. Koichiro Irie
11:45 - 12:15	"Hart/Miller Island" presented by Mr. Frank Hamons
12:15 - 5:00	Field Trip to Hart/Miller Island
6:00 - 8:00	Japan Reception at OMNI Hotel

Thursday, November 5, 1987

8:00 - 8:30	"Volume Change Prediction of Pump Dredged Clay Soils" presented by Mr. Hiroshi Shinsha
8:30 - 9:00	"Subaqueous Borrow Pit Disposal" presented by Mr. John Tavolaro
9:00 - 9:30	"Disposition and Treatment of Noxious Sludge" presented by Mr. Takao Maekawa
9:30 - 10:00	BREAK
10:00 - 10:30	"Lake Restoration by Dredging" presented by Mr. Richard Gorini
10:30 - 11:00	"London Dumping Convention" presented by Dr. Robert Engler
11:00 - 11:30	"Recent Beneficial Uses of Dredged Material in Baltimore" presented by Mr. Glenn Earhart
11:30 - 12:30	Closing Remarks
1:00 - 4:00	Dundalk Marine Terminal Tour (Lunch provided by MPA)

TREATMENT OF BOTTOM SEDIMENT CONTAINING MERCURY AND MONITORING METHOD USING FISHES

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ABSTRACT

In Minamata Bay, sediment containing mercury higher than 25 ppm has accumulated on the bottom, and dredging work continues. The dredging has been conducted carefully, and secondary pollution as a result of disturbance of the bottom sediment has been prevented.

The mercury concentration in fishes was investigated to determine the conditions before dredging. As a result, a good correlation between the mercury concentration in fishes and the body length was found. Six kinds of fishes were chosen for monitoring. These were selected because they were present in sufficient numbers, the mercury concentration in them was adequate, and there was good correlation between mercury concentration and body length.

The monitoring work has been successful, based on the results obtained.

INTRODUCTION

Minamata Bay is located near the southern tip of Kumamoto Prefecture. The Port of Minamata, which is on Yatsushiro Sea, is an important port. A chemical factory on Minamata Bay used mercury as a catalyst in making acetaldehyde and vinyl chloride for 40 years, from 1932 to March 1971. It has been estimated that 70 to 150 tons, or more, of mercury was discharged to the bay. As a result, most of the bay demonstrated mercury concentrations higher than 25 ppm. The thickness of polluted sediment reached 4 m at some points of the inner part of thickness of the bay.

Some of the mercury used as the catalyst was changed into methyl mercury by a secondary reaction in the acetaldehyde reaction plant. Methyl mercury in wastewater from the plant was discharged to the bay, and from the seawater, accumulated into fish tissue. Many inhabitants who ate the polluted fishes were poisoned. The total mercury concentration in fishes has been investigated for many years and was found to be approximately 20 ppm in 1960. Since the factory has discontinued the use of mercury, the total mercury concentration in fish has decreased to 1 ppm or less. The mercury concentration in fish from the bay, however, is higher than that of fish from other districts. Furthermore, the total mercury concentration found in some fish from the bay is higher than 0.4 ppm (the safety guideline for fishes).

In Japan, the required level for removal is 25 ppm. So, the government of Kumamoto Prefecture decided to remove the sediment with a mercury concentration higher than 25 ppm. This work was begun in October 1977. The inner part of the bay (582,000 m^2, 726,000 m^3), which had a thick bottom layer of sediment with a high concentration of mercury, was chosen as the disposal area for the dredged sediment. Sediments in the other parts of the bay (1,510,000 m^2, 784,000 m^3) have been dredged and pumped directly to the disposal area. Dredging has continued to the present (Figure 1).

A cutterless pump has been used, and the work has been conducted carefully to prevent secondary pollution from disturbance of the bottom sediment. Also, the water quality and marine products have been monitored to detect any further deterioration caused by the work in the bay. When further pollution is found, the dredging work is suspended by the government of Kumamoto Prefecture until the origin of the pollution is traced; then, the dredging work is resumed after removal of the origin.

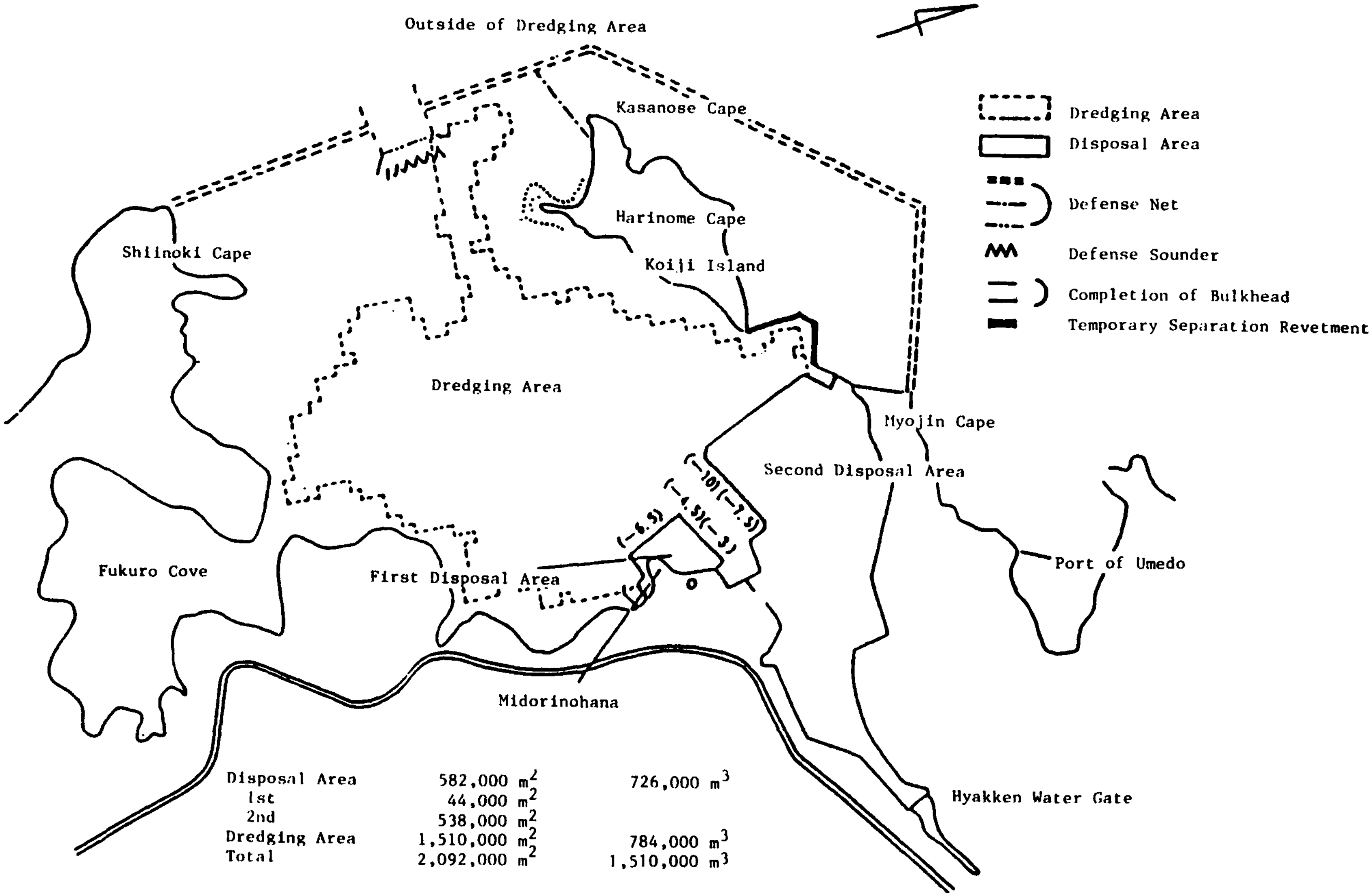
The water quality monitoring was described in detail by Nakayama et al. at the 12th US/Japan Experts Meeting on Management of Bottom Sediments Containing Toxic Substances, November 1986, Yokohama, Japan. In this paper, the authors will report on the monitoring method using fishes.

TREATMENT OF SEDIMENT

Defense nets and sounders to detect fishes moving into or out of the bay were set along the border of the dredging area. As a result, fishes containing mercury were kept within the bay.

A temporary separation revetment (length, 430 m) was constructed between Koiji Island and Myojin Cape to prevent the diffusion of pollutants by decreased current in the bay working area.

The cutterless pump was used for dredging in the bay because it did not stir the bottom sediment. The bottom sediment containing mercury was pumped



Disposal Area	582,000 m^2	726,000 m^3
1st	44,000 m^2	
2nd	538,000 m^2	
Dredging Area	1,510,000 m^2	784,000 m^3
Total	2,092,000 m^2	1,510,000 m^3

Figure 1. Work plan for Minamata Bay

directly to the disposal area. After primary sedimentation in the disposal area, the effluent was pumped into the treatment plant and treated with a coagulant. The effluent from the plant was discharged into the bay.

Dredging in the first area was done from 1980 to 1985. This was an experimental area, and new harbor facilities will be constructed to replace those existing. During dredging in the first area, no further pollution was confirmed. Therefore, the same dredging method has been applied to the second (main dredging) area.

In the second dredging area, sand-compaction work, construction of a bulkhead, and construction of the effluent treatment plant have been completed, and dredging continues. When dredging is finished, the seawater in the disposal area will be drained. The sediment in the disposal area will be covered with sand or soil from the mountains. The work in Minamata Bay is scheduled for completion by March 1990.

MONITORING METHOD USING FISHES

It is well known that the ratio of accumulation of mercury into fishes is significant. It is said that the ratio of accumulation of total mercury from water into fishes is a thousand times. It has also been reported that the ratio of accumulation of methyl mercury from water into fishes is ten thousand to a million times. Moreover, mercury intake from water to fishes is quick. Therefore, fishes in water containing mercury as an undetectable concentration take up mercury for the short term; as a result, mercury in fishes increases to a detectable concentration. Based on these facts, a monitoring program using fishes (Table 1, Figure 2) was designed and implemented.

Confinement of Fishes Within the Bay

The defense net was set along the dredging area borderline to keep fishes containing mercury within the bay. The defense net could not be set on a part of the waterway; thus, sounders were set on that part of the waterway.

Five collection nets have been set in the dredging area, and fishes have been caught in the bay. These were incinerated.

Mercury Concentrations in Fishes

Outside Dredging Area

To confirm the mercury concentration in fishes from outside the dredging area, an investigation of 10 principal fish species has been carried out four times a year. The appraisal was based on the safety guidelines for fishes (total mercury concentration, 0.4 ppm).

Within Dredging Area

It is thought that the mercury concentration in fishes depends upon the mercury concentration in water, the feeding habit of fishes, the physiological properties of fishes, the seasonal condition, the body length, and the ecological characteristics of fishes. The mercury concentration in fishes from the dredging area was investigated to determine their conditions before dredging.

TABLE 1. MONITORING PROGRAM (FISHES AND PLANKTON)

Monitoring	Area	Contents
Defense for moving fish	Defense net	Nets were set along the dredging area borderline.
	Collection net	Five collection nets were set in the dredging area; fishes caught were disposed.
Monitoring of fish	Outside of dredging area	11 kinds of fishes T-mercury: 4 times/year
	Dredging area	Mebaru, marble rock fish, perch, gilthead, sasanohabera, ishimochi T-mercury: 1 time/month
Monitoring of plankton	Outside of dredging area	Zooplankton T-mercury: 6 times/year
	Dredging area	Zooplankton T-mercury: 6 times/year
Fish-rearing test	Dredging area	Red sea bream, mejina T-mercury: 3 times/month

From the above results, fishes were grouped into three classes based on mercury concentration. In the first class, the mercury concentration was constantly over 0.4 ppm as total mercury; the second class fluctuated about the 0.4-ppm level, and the third class was constantly lower than 0.4 ppm. It became clear that there was a good correlation between the mercury concentration in fishes and body length (Table 2, Figures 3-8).

Six kinds of fishes were chosen for monitoring based on the criteria of being sufficient in number, having an adequate mercury concentration to discriminate the variation, and good correlation between mercury concentration and body length. The fishes selected were: mebaru, marble rock fish, perch, gilthead, sasanohabera, and ishimochi. The mercury concentration in these fishes was investigated once a month.

Fish Rearing Test

To determine as quickly as possible the effect of mercury bioaccumulation into the fish as a result of dredging, red sea bream and mejina obtained from an unpolluted area were reared in fish-rearing cages in the dredging area. The total mercury concentration in these was measured every 10 days.

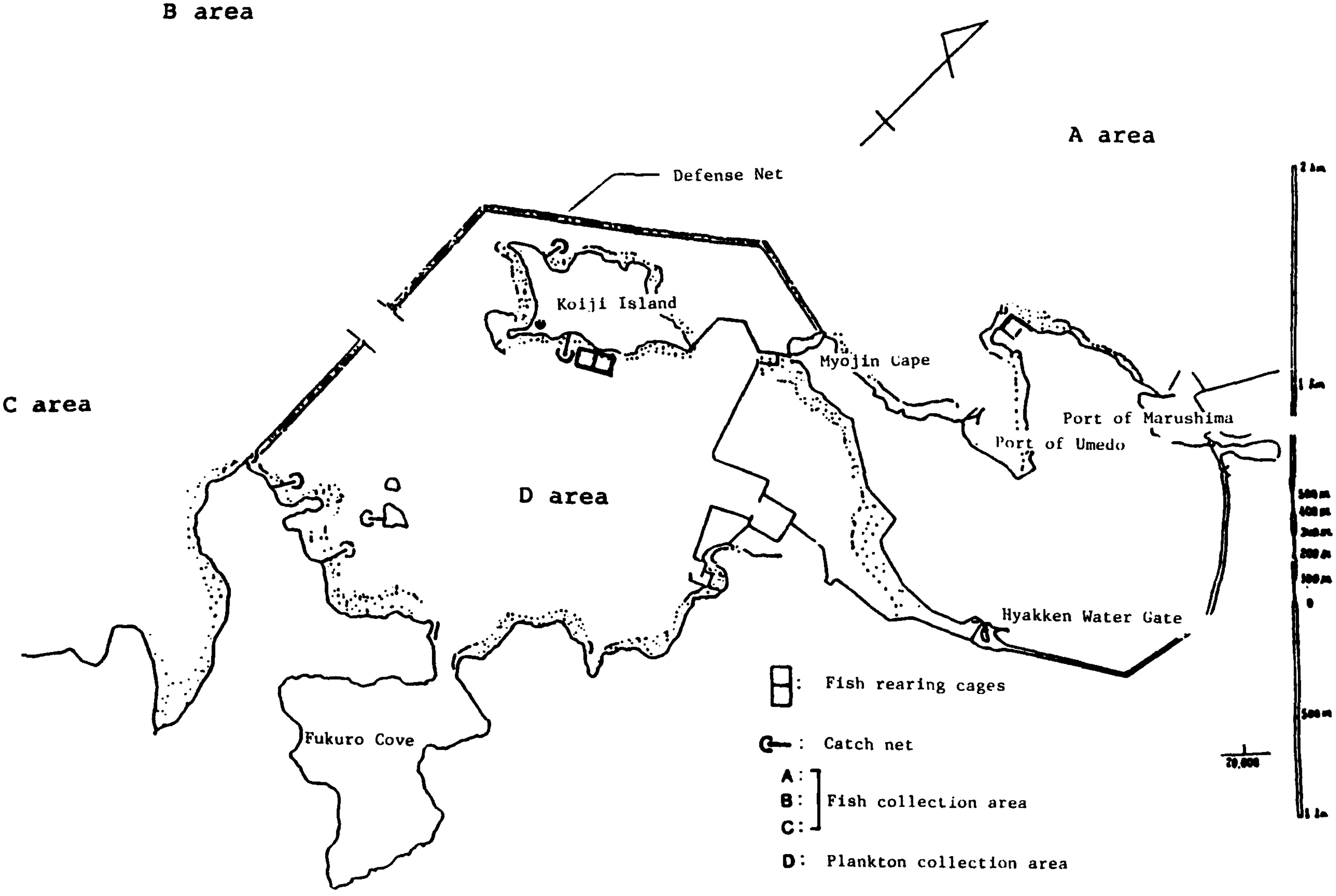


Figure 2. Collection points for fishes and plankton

TABLE 2. CORRELATION BETWEEN TOTAL MERCURY CONCENTRATION AND THE BODY LENGTH OF THE FISHES (1974 - MARCH 1980)

		Mebaru	Marble Rock Fish	Perch	Gilthead	Sasanohabera	Ishimochi
Sampling number	(n)	283	302	252	228	171	191
Regression line	(a)	0.02922	0.03887	0.01705	0.04738	0.01282	0.06410
log (100 y) = ax + b	(b)	0.9770	1.4045	0.9117	0.4919	1.5458	0.4231
Correlation	(r)	0.419	0.563	0.625	0.748	0.241	0.766
	(t)	7.745	11.80	12.65	16.933	3.228	16.366
	(p)	<0.001	<0.001	<0.001	<0.001	$0.0005 < p < 0.001$	<0.001
Body length, cm	($\bar{x}$)	16.14	15.02	36.26	25.01	15.58	22.12
	(Sx)	2.593	2.511	10.87	6.298	1.693	2.900
Total mercury concentration, ppm	($\bar{y}$)	0.281	0.974	0.339	0.475	0.556	0.693
	(Sy)	0.01516	0.01491	0.01981	0.02506	0.01230	0.01749

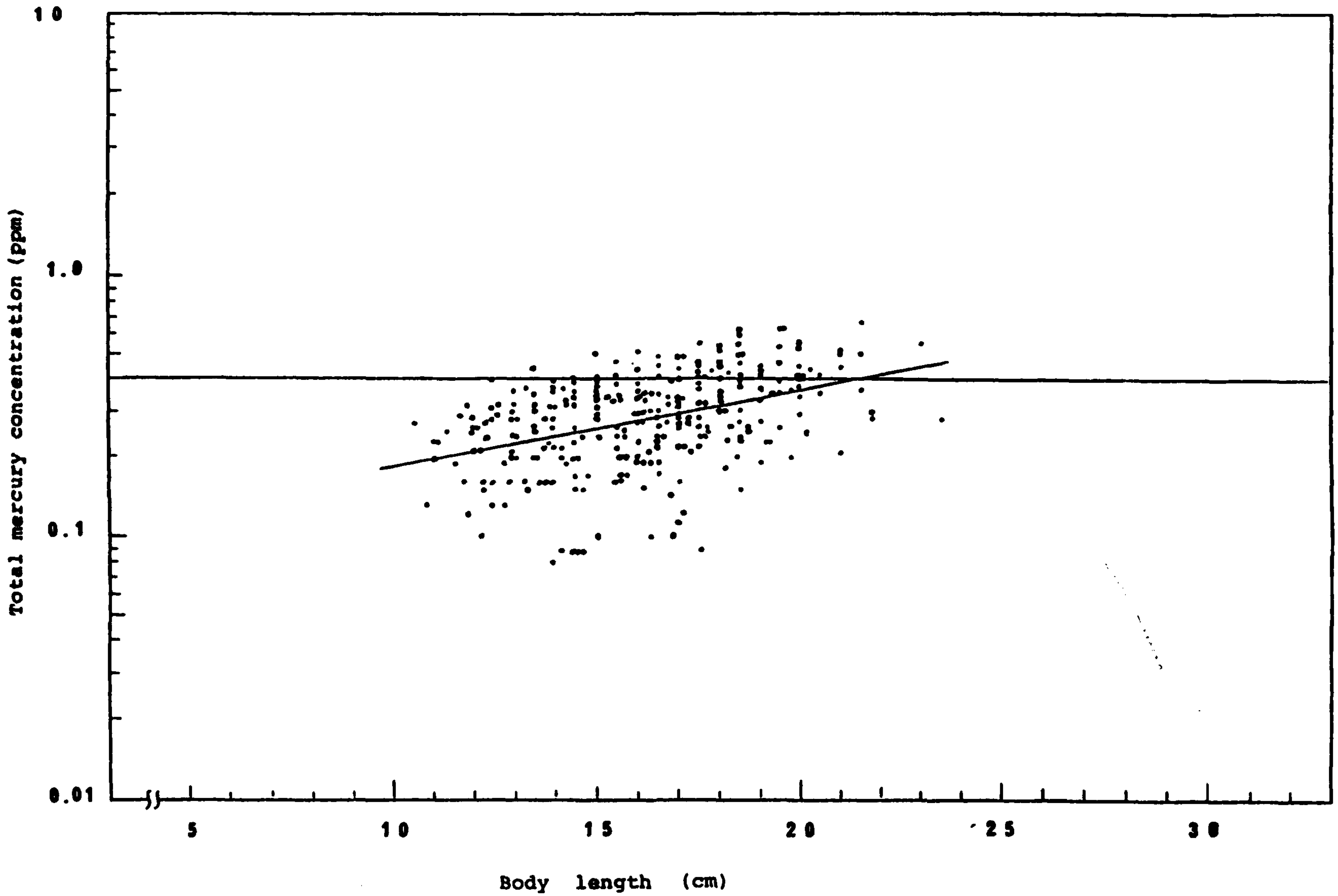


Figure 3. Correlation between total mercury concentration and fish body length (mebaru)

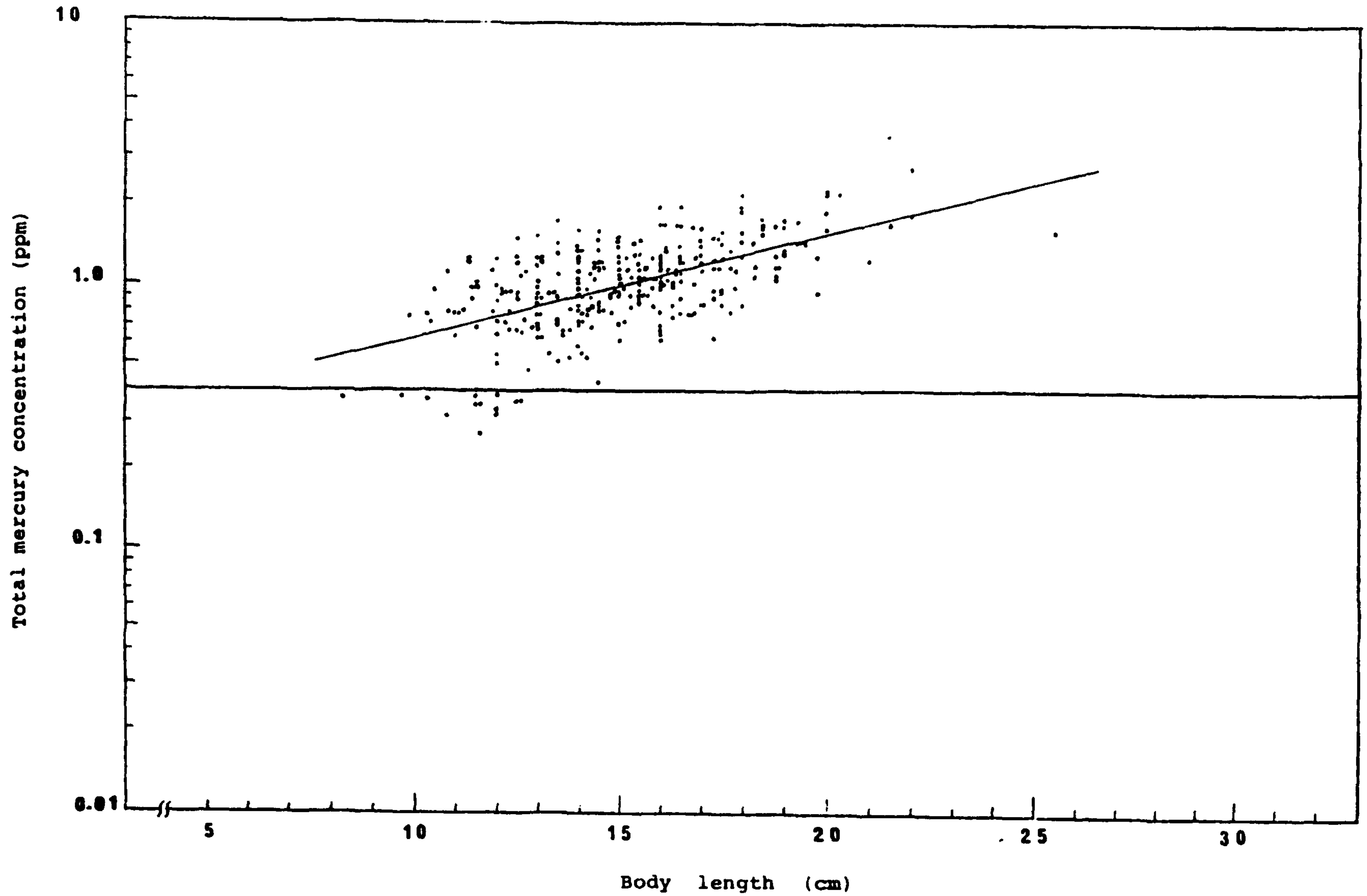


Figure 4. *Correlation between total mercury concentration and fish body length* (marble rock fish)

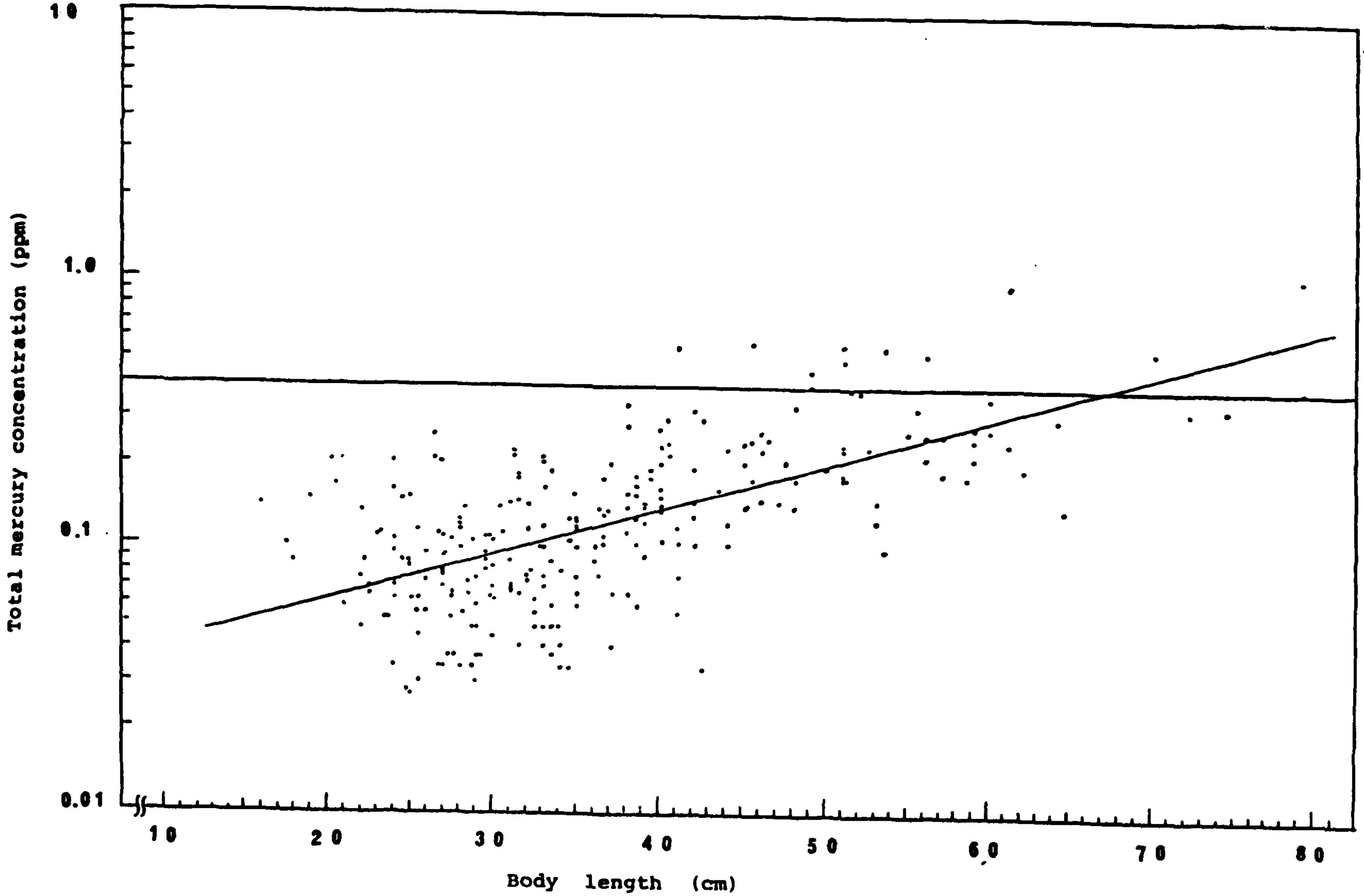


Figure 5. Correlation between total mercury concentration and fish body length (perch)

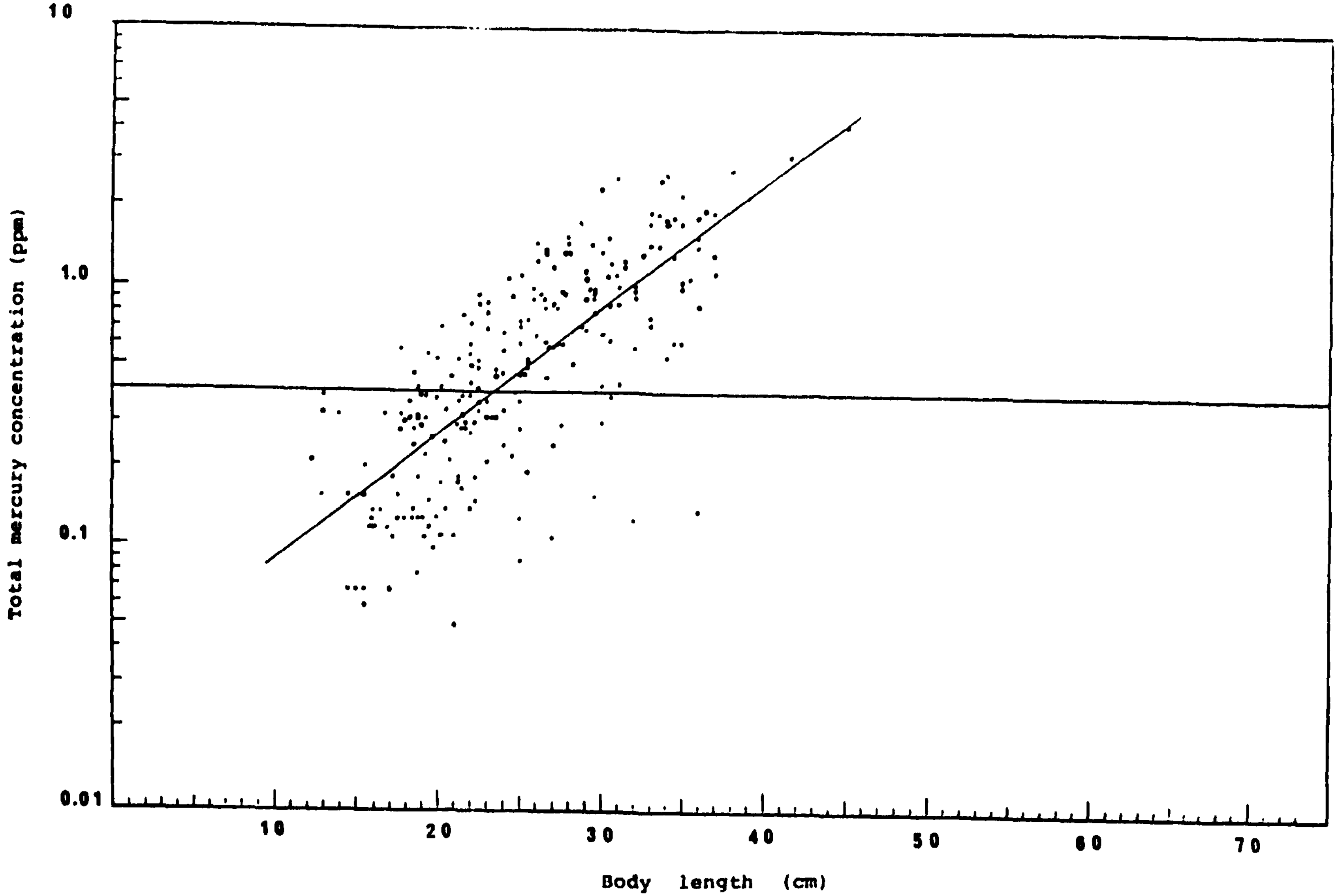


Figure 6. Correlation between total mercury concentration and fish body length (gilthead)

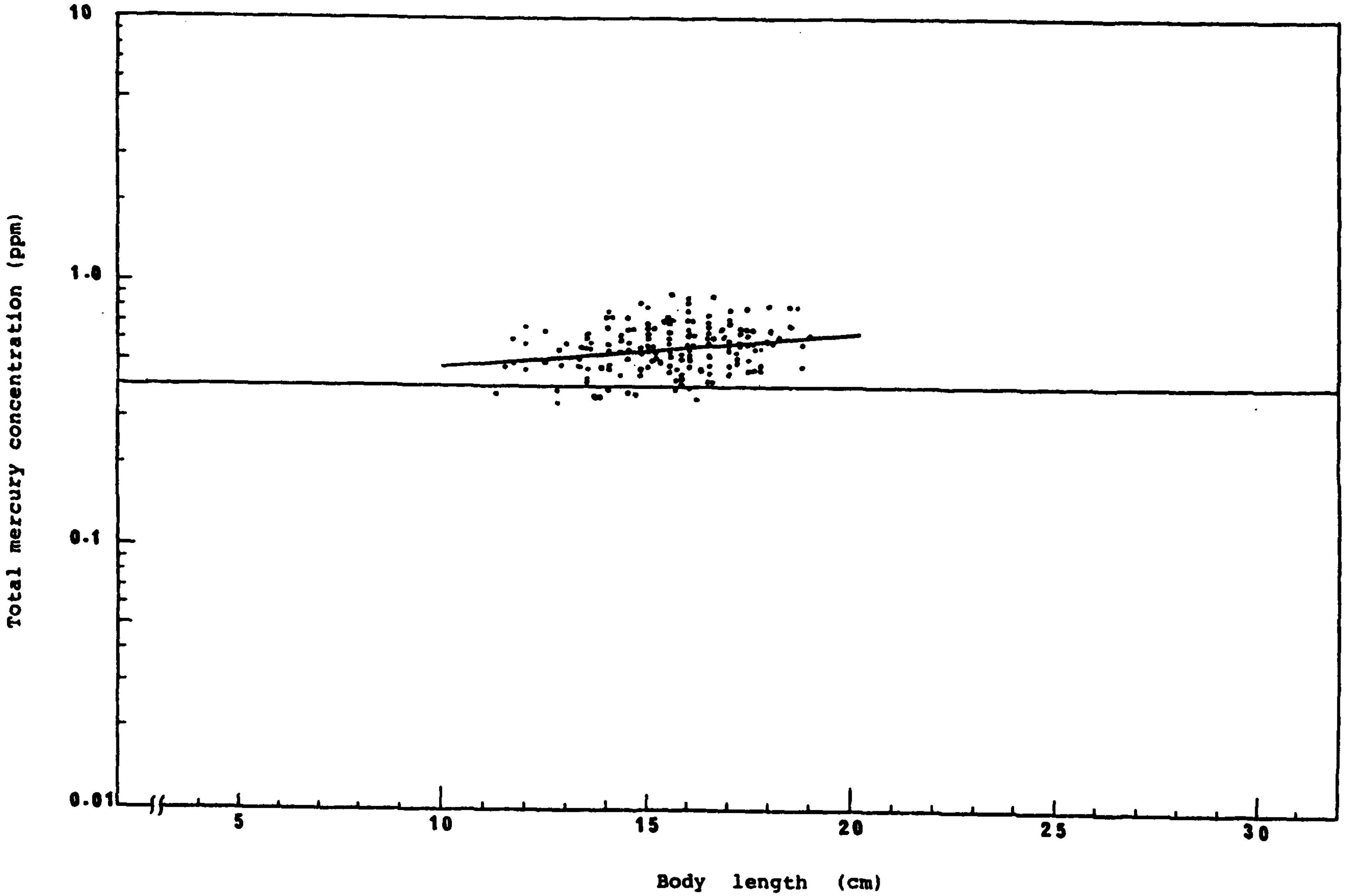


Figure 7. Correlation between total mercury concentration and fish body length (sasanohabera)

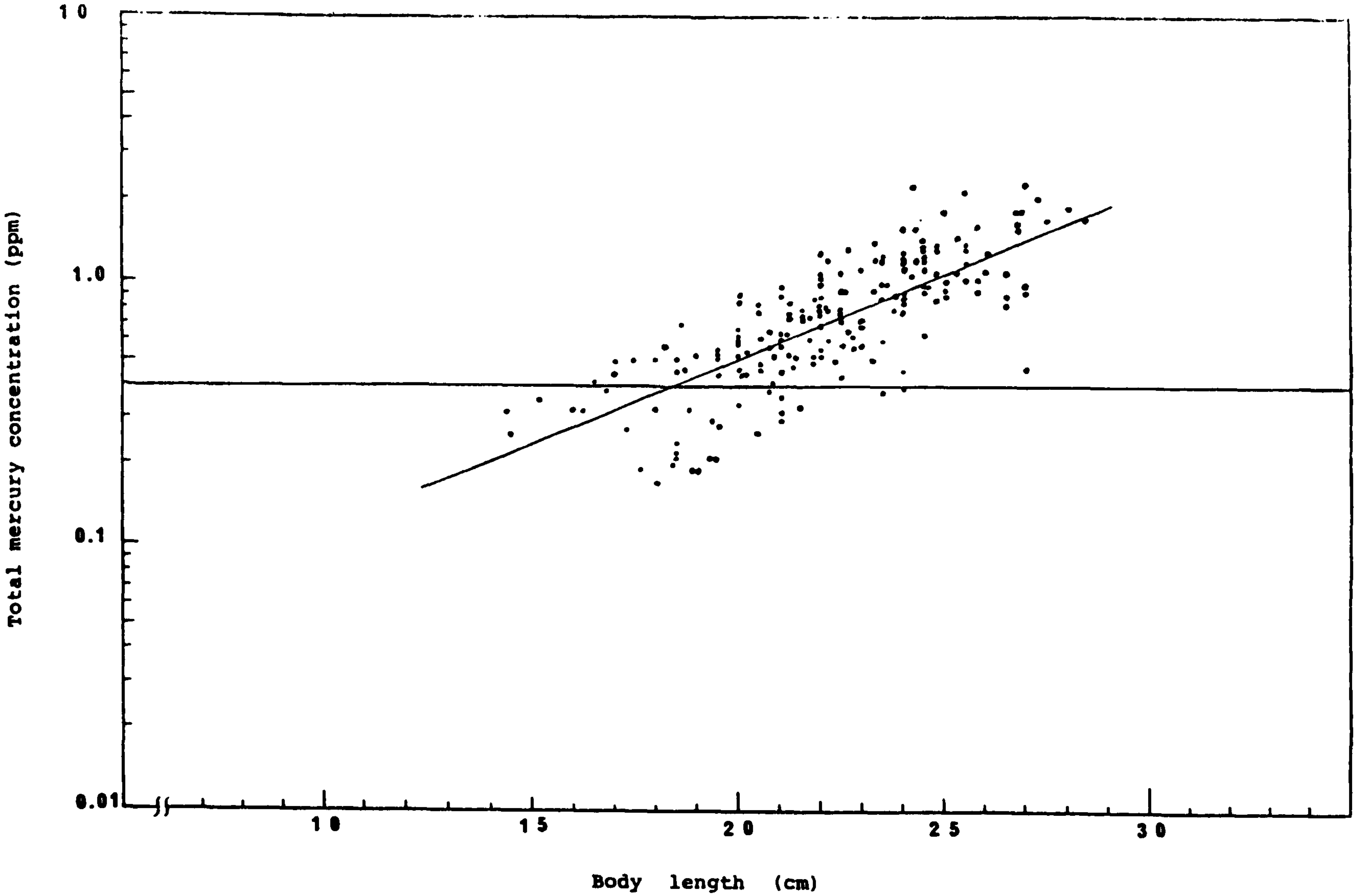


Figure 8. Correlation between total mercury concentration and fish body length (ishimochi)

Mercury Concentration in Plankton

Zooplankton were collected within and outside the dredging area, and total mercury concentration was measured every 2 months.

MONITORING RESULTS

Fishes Outside the Dredging Area

Ten fish species were investigated four times a year. The mercury concentration in all fishes has been lower than 0.4 ppm (safety guideline for fishes).

Fishes Within the Dredging Area

To minimize the deviation in mercury concentration in fishes caused by the body length, the value of the mercury concentration was corrected as follows. From the mercury concentrations and body lengths obtained in investigations of fishes of the same species for the past 3 years, a linear regression was calculated by the method of the least squares. A mean of the body length was also calculated, and it was used as a standard body length. The value of the mercury concentration and the body length of fishes were plotted, and a line was drawn parallel to the linear regression line and through the plotted point. Then, a corrected value of the mercury concentration was obtained from an intersection of the drawn line and the standard body length line. In practice, the corrected value of the mercury concentration was obtained by the calculation using the linear regression formula of each fish species.

Six principal fishes have been investigated one time a month, and it was confirmed that the transition of the mercury concentration in these fishes has been normal (Figures 9-14). These results indicate no effects from the dredging.

Fish Rearing Test

The 6-month fish rearing test has been conducted repeatedly. The transition of the mercury concentration in red sea bream and mejina was similar to the results of the past rearing test (Figure 15). From these results, no effects of the dredging have been found.

Plankton Investigation

The transition of the mercury concentration in the zooplankton within and outside the dredging area has been normal, and no effects of the dredging have been found.

DISCUSSION

From the investigation of the mercury concentration in fishes over the past several years, a good correlation between the mercury concentration and body length of fishes was found in all kinds of fish. In the monitoring of fishes, the results obtained from the larger fishes must not be compared directly with the results from the smaller fishes to determine the transition of the mercury concentration in fishes. Therefore, the value of the mercury

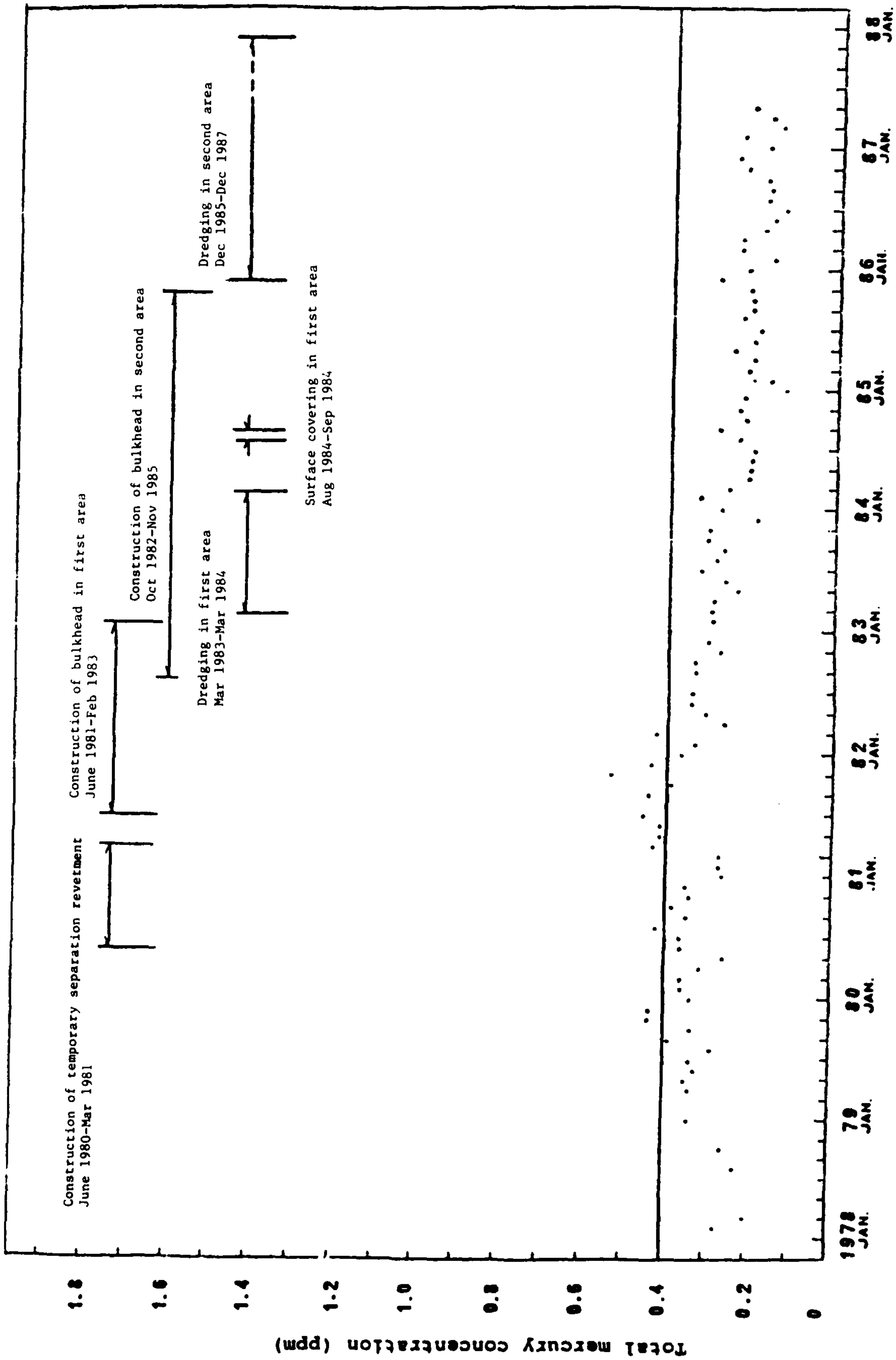


Figure 9. Transition of total mercury concentration (mebaru)

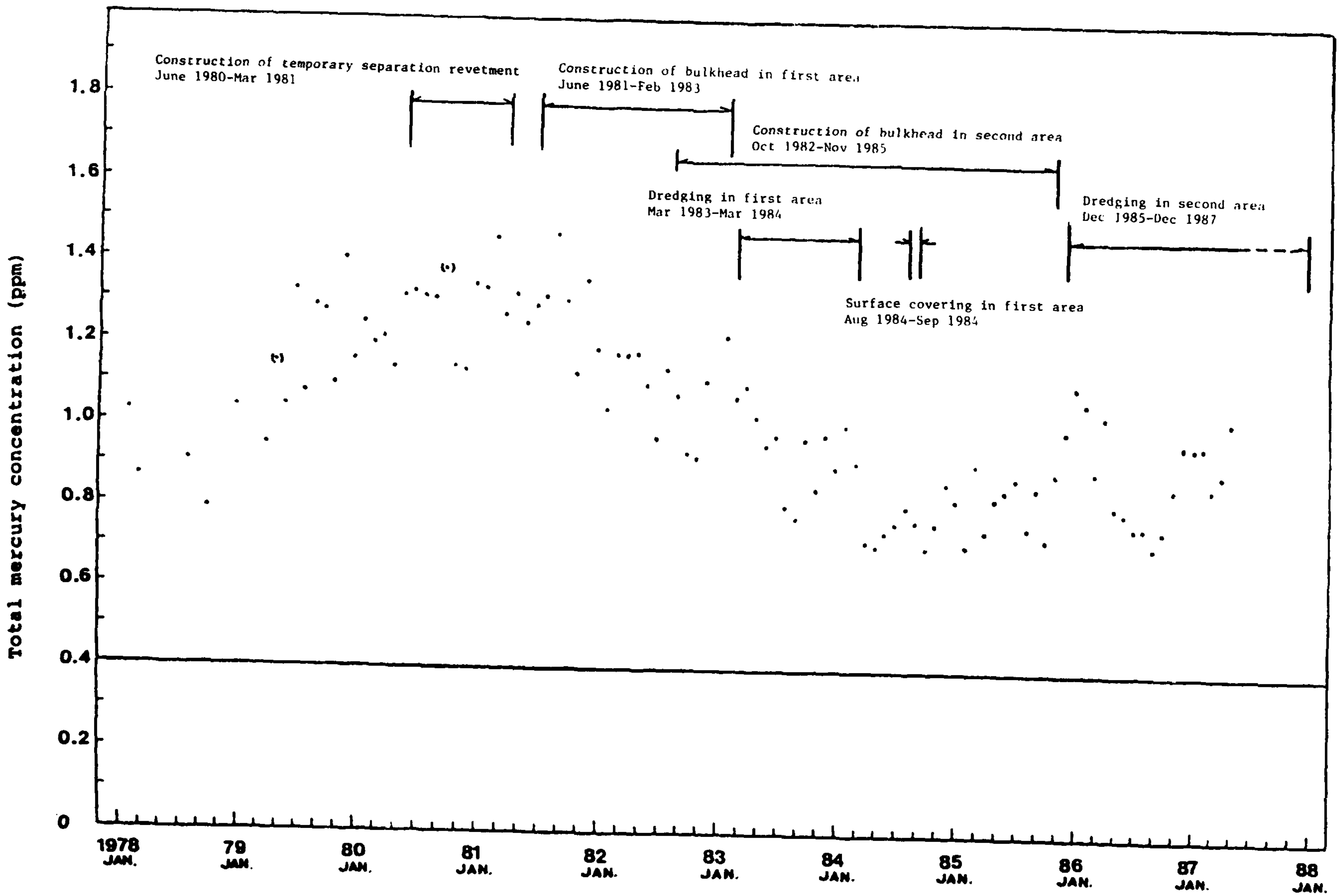


Figure 10. Transition of total mercury concentration (marble rock fish)

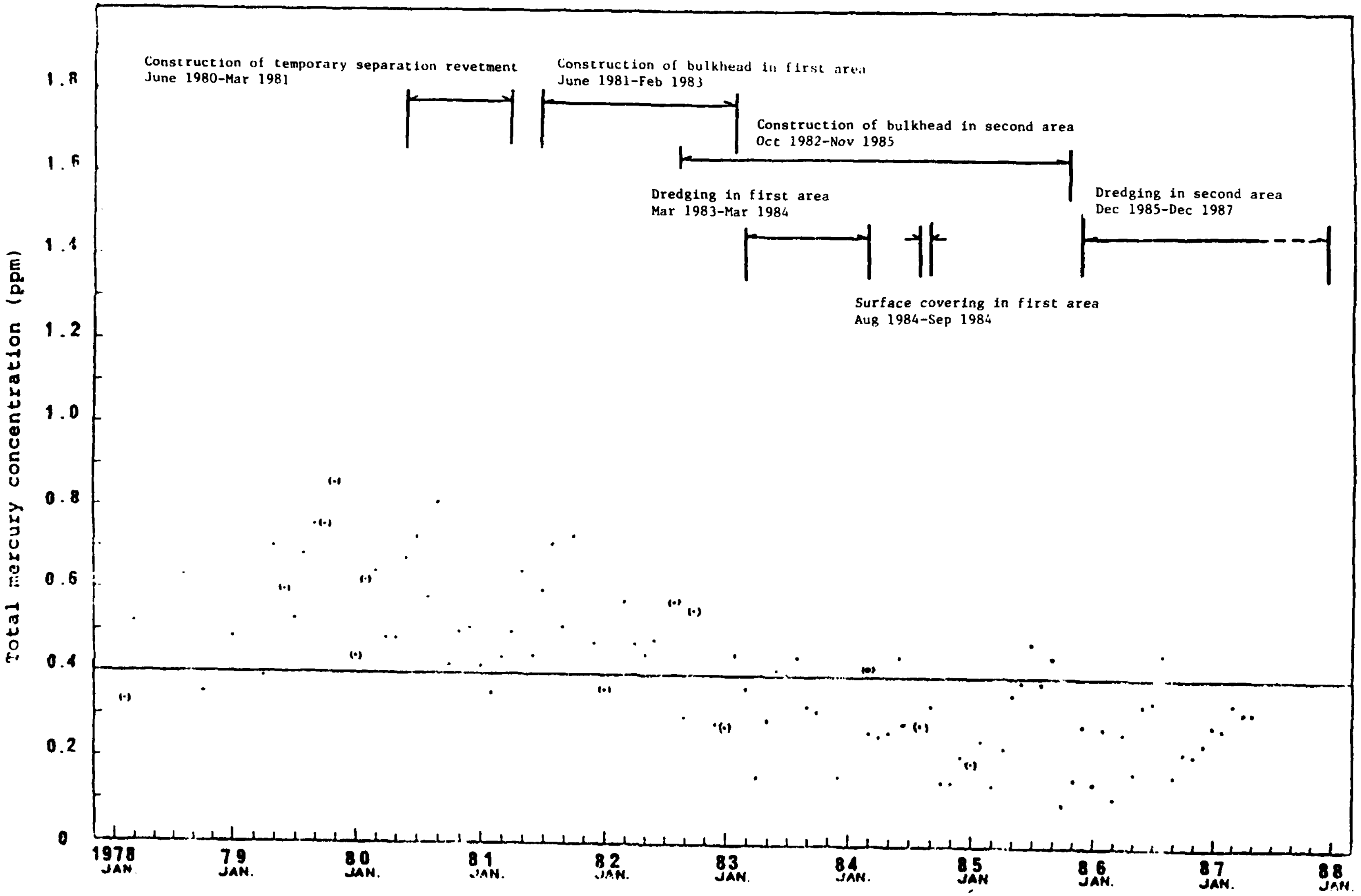


Figure 11. Transition of total mercury concentration (perch)

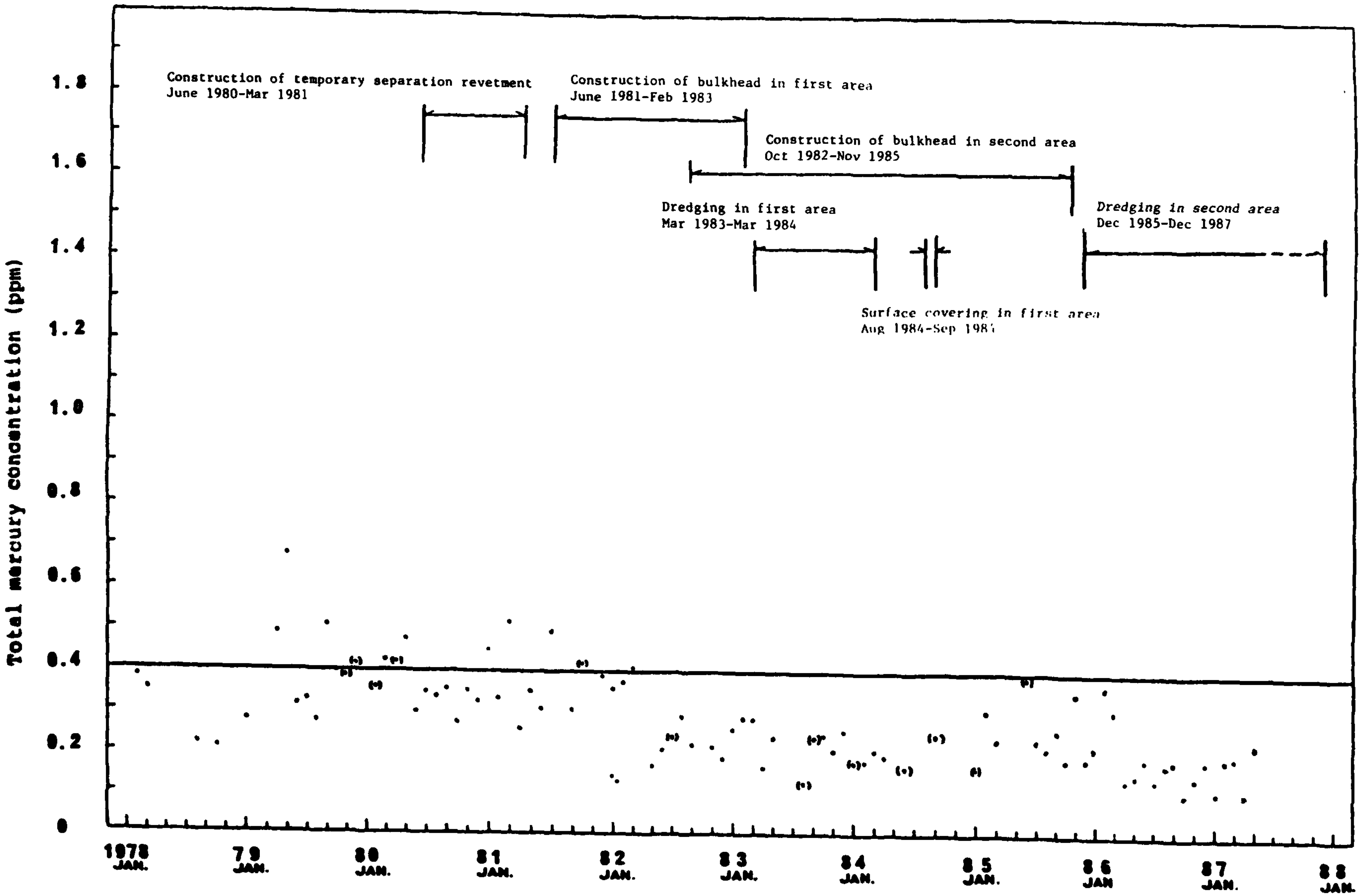


Figure 12. Transition of total mercury concentration (gilthead)

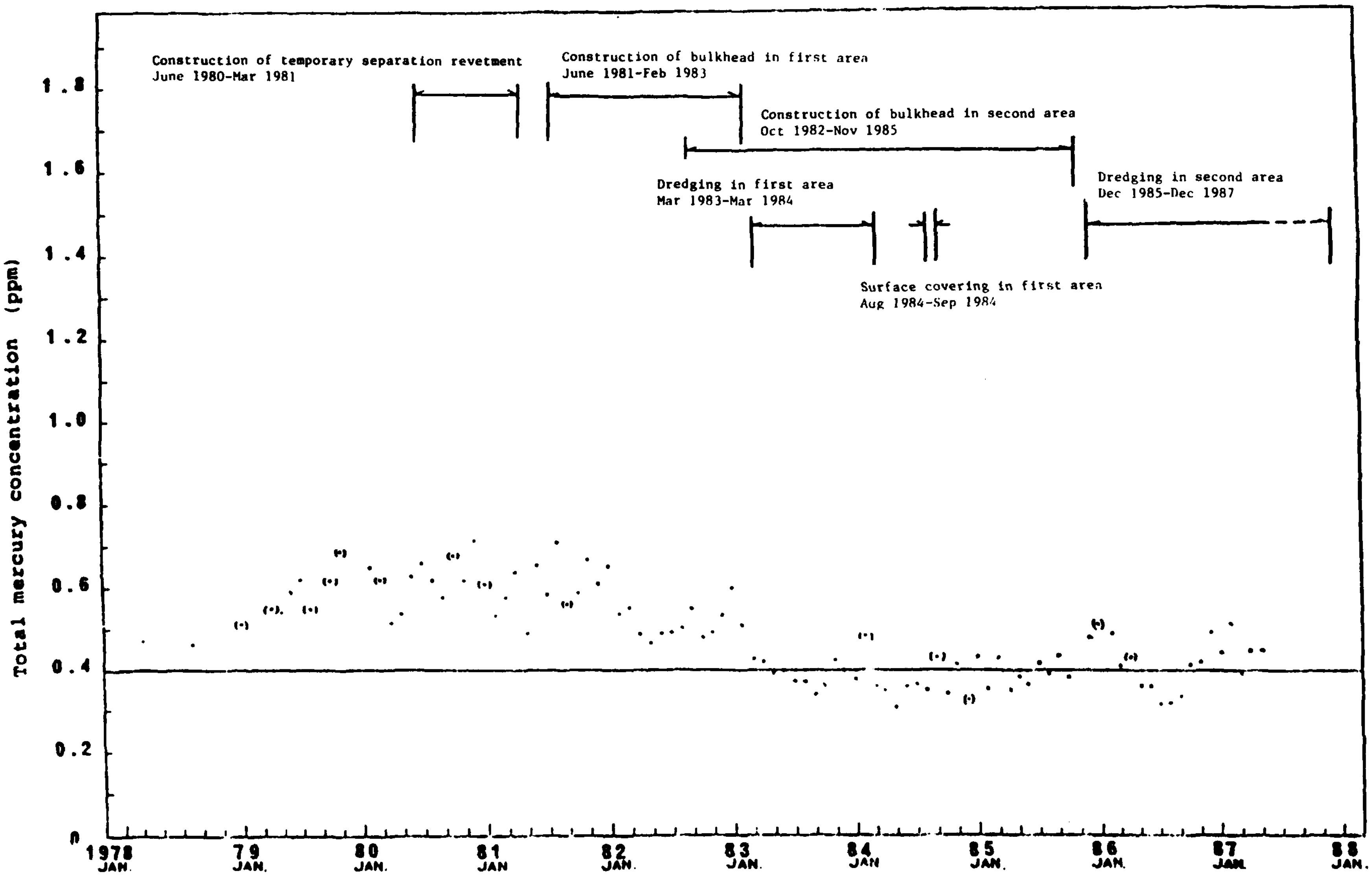


Figure 13. Transition of total mercury concentration (sasanohabera)

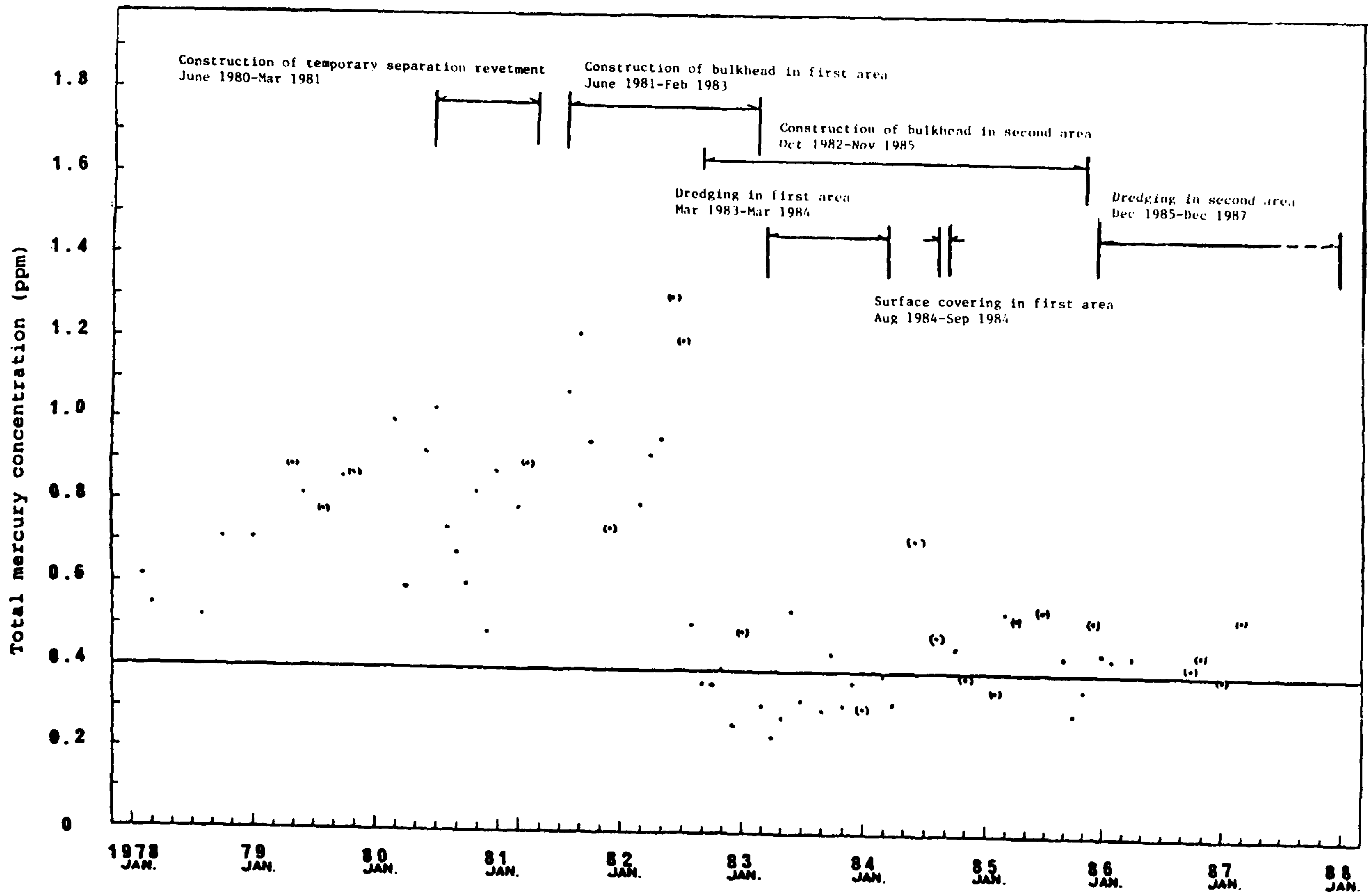


Figure 14. Transition of total mercury concentration (ishimochi)

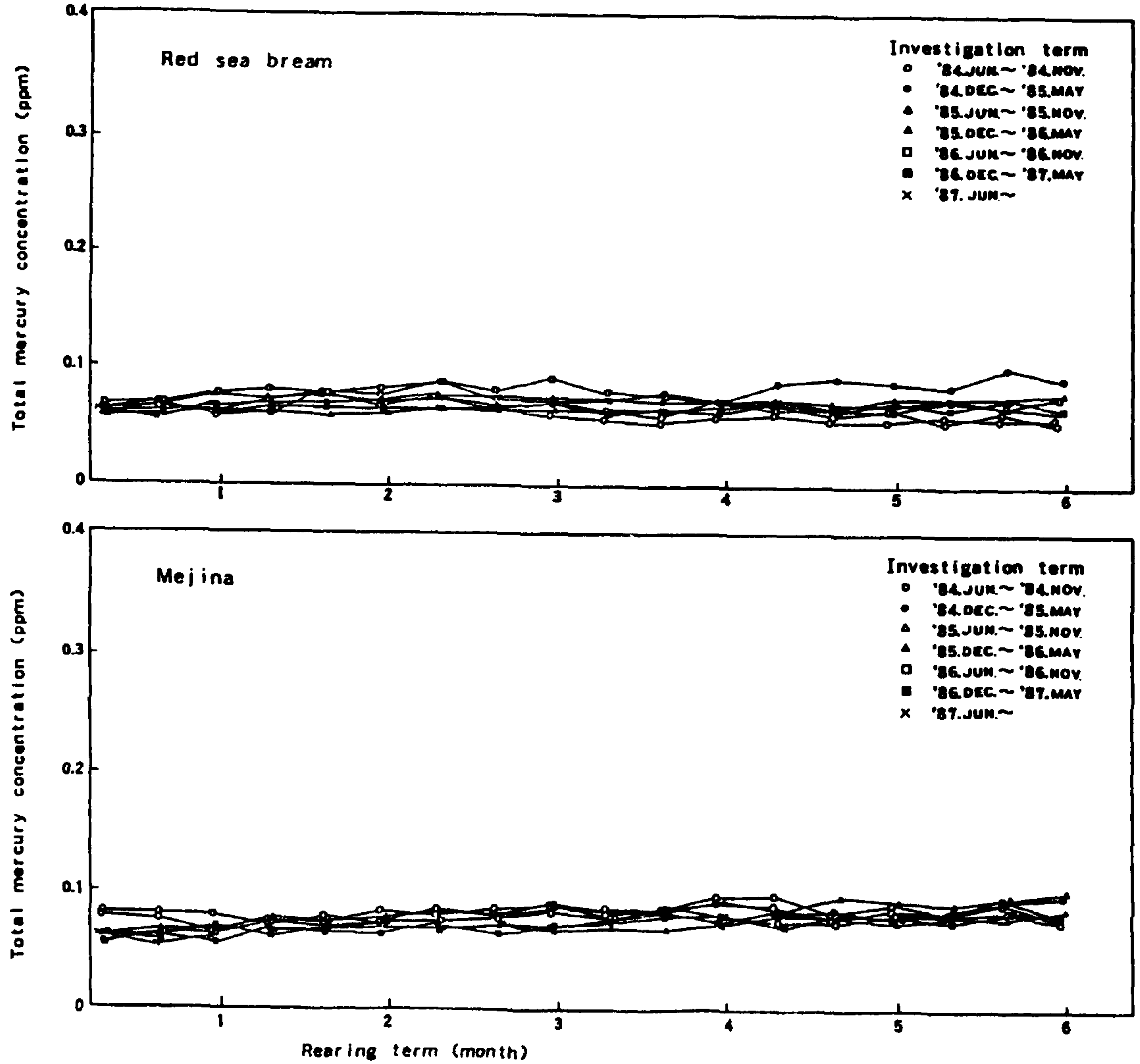


Figure 15. Results of fish rearing test (transition of central value)

concentration in fishes was corrected by the calculation using the linear regression formula of each fish species. This minimized the deviation of mercury concentration among fishes and allowed comparison of the mercury concentration in the larger fishes and smaller fishes.

The mercury concentration in six kinds of fishes from the dredging area showed an upward trend until 1981. Afterward, the mercury concentration decreased until 1984. The mercury concentration in each of the fishes except mebaru demonstrated a transitional increase in 1984. Since 1985, the mercury concentration in each of the fishes has shown a downward trend or equilibrium. From these results, the mercury concentration in six kinds of fishes has indicated a tendency of decrease (with upward and downward variation) since the use of mercury was discontinued in the factory.

CONCLUSIONS

In dredging of bottom sediments containing mercury, it is very important that the work is carried out carefully and that water quality is not allowed to deteriorate, including the prevention of secondary pollution from stirring the bottom sediment. Moreover, it is important to detect any secondary pollution and to monitor successive work to prevent deterioration.

For the dredging work in Minamata Bay, four water quality monitoring methods were used:

a. Measurement of turbidity (as discussed by Nakayama et al., 12th US/Japan Experts Meeting), which obtained rapid results.

b. Corrected value of mercury concentration in fishes to determine accurately the transition of mercury.

c. Fish rearing test, using red sea bream and mejina.

d. Measurement of mercury concentrations in plankton to determine the effect of mercury bioaccumulation.

From the results of the monitoring work, no further deterioration of the water quality and no further pollution of fishes have been found since initiation of the dredging. From the facts described above, it was concluded that method of monitoring fishes as the indicator of the pollution accurately detected the effects induced by the dredging work and led us to obtain successful results.

STRATEGIES AND TECHNIQUES FOR HANDLING CONTAMINATED SEDIMENTS IN THE MARINE ENVIRONMENT

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ABSTRACT

Bottom sediment contamination in the marine environment has its origins in point and nonpoint source pollution, direct dumping, onshore hazardous waste disposal, and in-water and onshore spills. It is significant because of its potential to adversely affect aquatic resources, contaminate the human food chain, degrade water quality, constrain navigational dredging, and complicate hazardous waste site remedial action. The US Environmental Protection Agency's (USEPA) Superfund National Priorities List and the National Oceanic and Atmospheric Administration's (NOAA) Coastal Hazardous Waste Site Review were examined to identify coastal Superfund sites in which bottom sediment contamination appeared to be a significant factor. Of the latter sites, information was reviewed for those that had progressed to at least the Feasibility Study stage and, consequently, had recommended remedial actions. Various combinations of excavation, stabilization, capping, monitoring, and cleanup of onshore contamination, as well as no action, constituted the preferred strategies in 10 sample cases evaluated. Although differing approaches may well be warranted in the widely different fact patterns involved, each cleanup plan appeared to have been developed on a totally ad hoc basis, completely independent of similar Superfund cleanups, or other relevant experience, in other settings. The Marine Board of the National Academy of Sciences/ National Academy of Engineering has constituted a Committee on Contaminated Sediments to provide an improved understanding of contaminated marine sediments, to serve as a basis for management decisions and technical research and development. The approach of this committee effort, aimed at suggesting improved remedial technologies and strategies, is discussed.

INTRODUCTION

Bottom sediment contamination comes from a variety of sources (Figure 1):

a. Runoff from construction and farming activities, and atmospheric fallout (nonpoint source pollution).

b. Discharges from industrial and municipal sources (point-source pollution).

c. Direct dumping (both from shore, by tractor and truck, and at sea via ocean dumping).

d. Onshore waste disposal activities (e.g., coastal hazardous waste landfills).

e. Accidental spills from shore-based and waterborne sources.

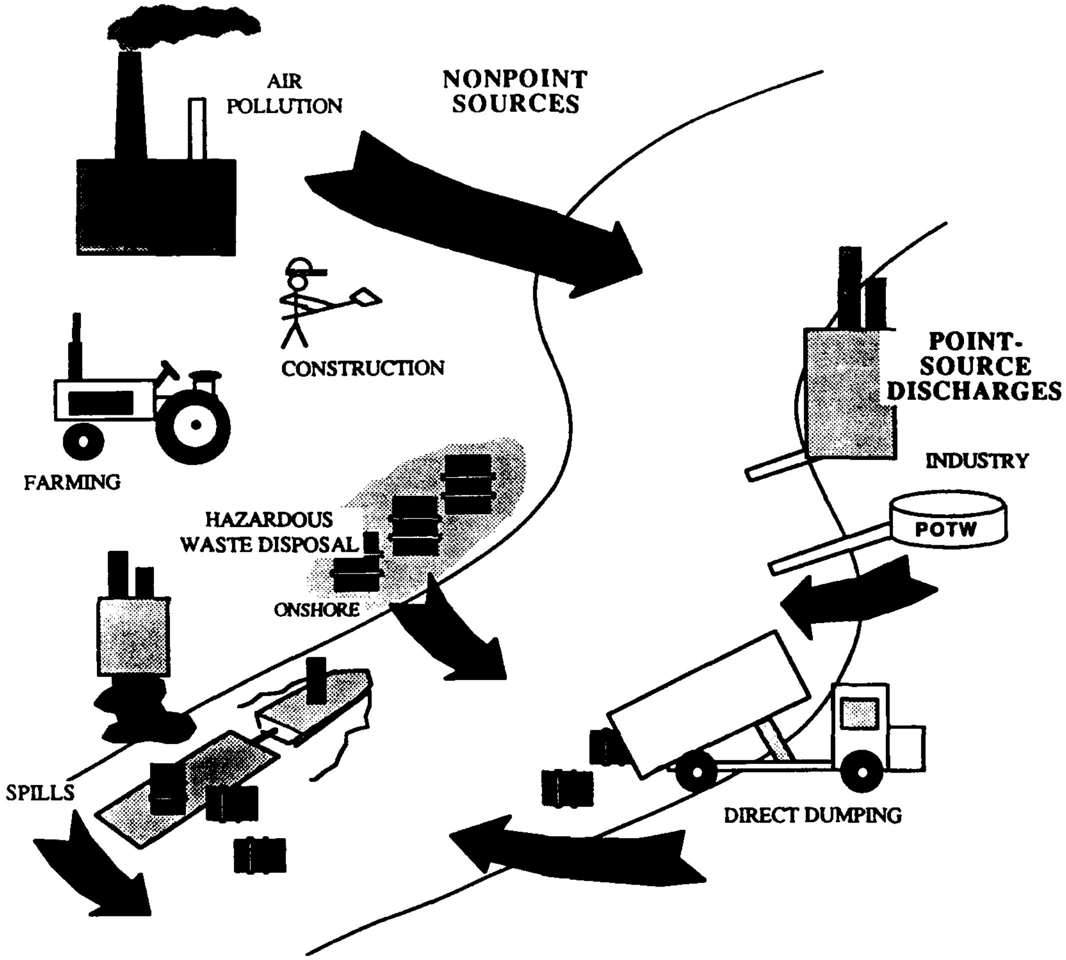

Figure 1. Schematic representation of sources of bottom sediment contamination

These contamination sources fall within the regulatory jurisdiction of several Federal environmental statutes (Figure 2):

a. The Clean Water Act, as most recently amended by the Water Quality Act of 1987 (covers point and nonpoint source pollution and spills of oil and hazardous substances).

b. The Superfund Law (technically referred to as the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended by the Superfund Amendments and Reauthorization Act of 1986) (covers inactive and abandoned hazardous waste sites, areas where hazardous substances have come to be located, releases of environmentally threatening pollutants or contaminants, and injuries to natural resources resulting from such releases).

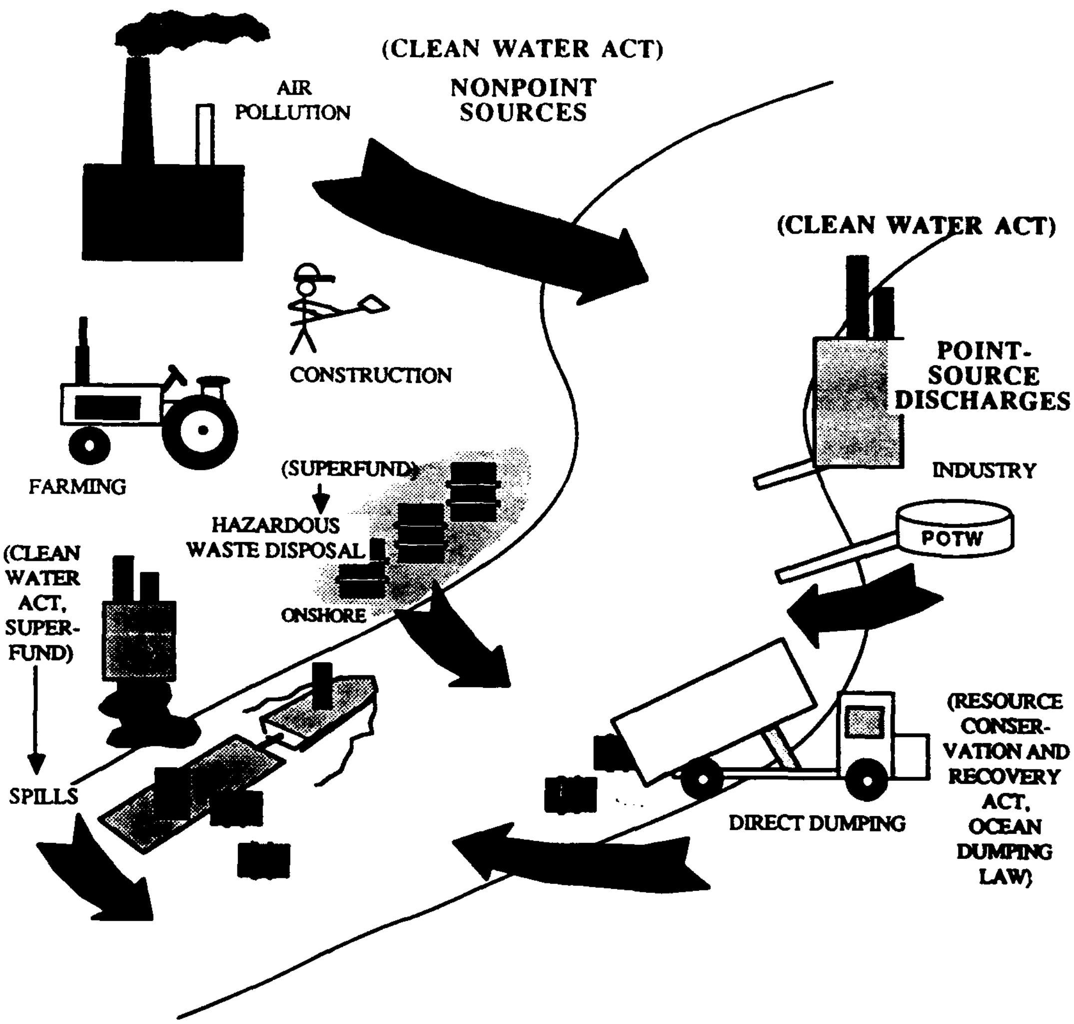

Figure 2. US laws that regulate the sources of bottom sediment contamination

c. The Resource Conservation and Recovery Act, as amended by the Hazardous and Solid Waste Amendments of 1984 (covers the generation, transport, handling, and disposal of hazardous waste at active hazardous waste management facilities).

d. The Marine Protection, Research, and Sanctuaries Act (better known as the Ocean Dumping Law) (covers the transportation of materials from a US port for the purpose of dumping them in ocean waters, and the associated ocean dumping).

The US Regulatory Framework is summarized in greater detail in Table 1.

Special note should be taken of the Superfund Law, most recently amended in 1986. Although it is often regarded as covering only inactive or abandoned hazardous waste sites, it is, in fact, very broad in its coverage. It encompasses:

a. Any area where a hazardous substance has come to be located--whether by intentional dumping or by accidental spillage.

b. Releases or threatened releases into the environment of any hazardous substance or any environmentally threatening pollutant or contaminant.

c. Any injury to, destruction of, or loss of natural resources--defined very broadly--resulting from such pollutant releases.

The applicability of Superfund has been limited in practice by the USEPA, primarily by means of a Hazard Ranking System (HRS) that is used to place Superfund sites on a National Priorities List (NPL). Only NPL sites come within the scope of Superfund's full-scale remedial cleanup program.

The HRS methodology employed by the USEPA to date to give sites a hazard ranking places very heavy weight on the potential for contamination of drinking water sources and resultant health impacts and gives little, if any, weight to the possible contamination of edible fish and shellfish. In other words, the USEPA has emphasized the drinking water pathway of human exposure to the virtual exclusion of the food chain pathway.

Contaminated bottom sediments do not often threaten drinking water supplies--especially in the marine environment. It is, therefore, not surprising that there are few sites on the NPL involving predominantly bottom sediment contamination. This may have to change, however, since the 1986 Superfund amendments directed USEPA to revise the HRS to require consideration of the potential for contamination of "natural resources in the human foodchain."

SIGNIFICANCE OF BOTTOM SEDIMENT CONTAMINATION

Bottom sediment contamination can be of great environmental significance from the following standpoints (Figure 3):

a. It can damage aquatic resources in terms of lethal and sublethal effects, including reproductive impairments and tumor and disease induction.

TABLE 1. US REGULATORY FRAMEWORK

Law	Scope of Coverage
"Superfund" (CERCLA/SARA)	Any area where a hazardous substance has come to be located
	Removal or remediation of any release or threatened release into the environment of any hazardous substance (or of any pollutant or contaminant that may present an imminent and substantial danger to the public health or welfare)
	Hazard Ranking System and National Priorities List to determine priorities for remedial action (and, to the extent practicable, removal action)
	Responsible parties liable for damages for injury to, destruction of, or loss of natural resources
	Liability for releases associated with the application of registered pesticides is excluded
	Liability for "federally permitted releases" is limited to that provided elsewhere (if any)
Clean Water Act	
Dredge and Fill Program (Section 404)	Dredging of navigable waters is covered by Section 10 of the Rivers and Harbors Act
	Covers the discharge of dredged or fill material into the navigable waters at specified disposal sites
Oil and Hazardous Substance Spills (Section 311)	Discharges of oil and hazardous materials into the navigable waters of the United States, adjoining shorelines, the contiguous zone, certain OCS and deepwater port activities, or which may affect natural resources under exclusive US management authority
	Excludes discharges in compliance with a Clean Water Act permit or identified in a permit or permit application
	Authorizes removal whenever there is a covered discharge or substantial threat of discharge
	Provides for abatement of any imminent and substantial threat to the public health or welfare because of an actual or threatened release

(Continued)

TABLE 1 (Concluded)

Law	Scope of Coverage
Clean Water Act (Cont.)	
In-Place Toxic Pollutants (Section 115)	In-place pollutants, with emphasis on toxic pollutants in harbors and navigable waterways
	Removal and appropriate disposal, in coordination with the US Army Corps of Engineers, from critical port and harbor areas
Great Lakes Program (Section 118(c)(3))	Removal of toxic pollutants from Great Lakes sediments
Toxic "Hot Spots" (Section 304(1))	Control strategies to reduce toxic pollutant inputs into contaminated waterway segments
National Estuary Program (Section 320)	Identification and protection of nationally significant estuaries
Nonpoint Sources (Section 319)	Best management practices and measures to reduce pollution from nonpoint sources and improve water quality of navigable waters
Marine Protection, Research, and Sanctuaries Act (Ocean Dumping)	Transportation for the purpose of dumping, and dumping in ocean waters
	Prohibited without a permit and except in accordance with ocean dumping criteria
Resource Conservation and Recovery Act	
Hazardous Wastes (Subtitle C)	Listed or characteristic wastes (or mixtures or derivatives thereof), including those displaying toxic properties when subjected to prescribed extraction and leaching procedures
	Subject to manifesting requirements; disposal limited to interim status or permitted hazardous waste facilities. Facilities subject to permitting, monitoring, and post-closure care requirements
Solid Wastes (Subtitle D)	Prohibition against "open dumps"; encouragement of resource recovery and "sanitary landfills"
	State (and local) lead, subject to Federally approved criteria that must protect human health and the environment

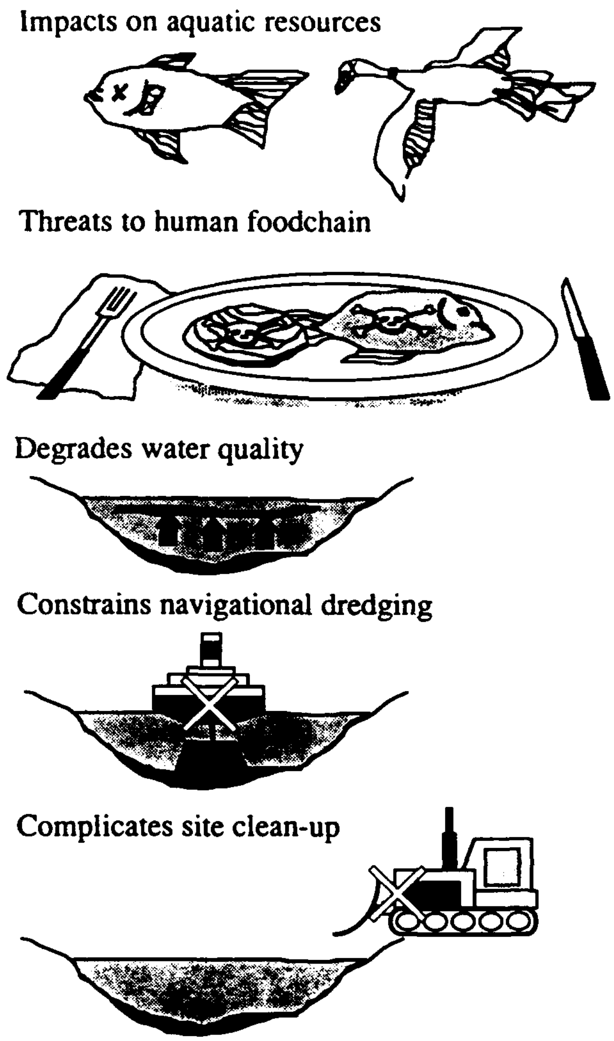

Figure 3. Significance of bottom sediment contamination

b. It can harm the health of human seafood-eaters (via benthic bioaccumulation and trophic transfer).

c. It can degrade water quality (by acting as a reservoir of ongoing contamination of the overlying water column).

d. It can constrain navigational dredging (by limiting options for the disposal and management of the resulting dredged material, and thereby the ability to dredge in the first place).

e. It can complicate the cleanup of hazardous waste sites because of the difficulty of working under water and the greater risk in an aquatic setting of stirring things up and creating new problems.

NEW CLEAN WATER LEGISLATION

It is worth noting several provisions of the Water Quality Act of 1987. This amendment of the Clean Water Act established or gave new momentum to several relevant and important programs:

a. A program geared to removing toxic pollutants from Great Lakes sediments.

b. A program designed to reduce toxic pollutant inputs into contaminated waterway segments.

c. A program to identify and protect nationally significant estuaries.

d. A program to reduce pollution from nonpoint sources.

Since remedial cleanups of sites with contaminated sediments can have lasting effectiveness only to the extent that the ultimate land-based sources of the original contamination are curtailed, the existence of regulatory mechanisms (and funding sources) to deal with these sources is essential. The Water Quality Act of 1987 provides important additions to the preexisting framework of such mechanisms.

REVIEW OF COASTAL SUPERFUND SITES

The following tables (Tables 2-6) of (predominantly) coastal Superfund sites with an apparent sediment contamination problem were compiled using the following sources of information: USEPA computer printouts (from the computerized CERCLIS inventory of Superfund sites) of final NPL sites in coastal states; USEPA site descriptions of final and proposed NPL sites (through about Update 3); NOAA Coastal Hazardous Waste Site Review: Site Reports for 1984, 1985, and 1987 (covering proposed NPL sites through Update 6); Superfund Records of Decision (RODs) available through USEPA Headquarters; and telephone interviews with USEPA Regional Superfund Coordinators.

This review should not be treated as definitive or exhaustive. There were numerous gaps in the information readily available to us. (In some cases, we may have included in our tables sites that are located far from any coastline or where no accumulations of contaminants on bottom sediments have been noted.) This effort was intended to be no more than what it is--an attempt to approximate the size of the universe of Superfund NPL sites with known or potential sediment contamination problems. We also hoped to get a feel for the number and identify of those sites for which specific remedial actions have been proposed, and an indication of the combinations of remedial options selected in each case.

Table 2 catalogs the coastal Superfund sites reviewed by NOAA (and regarded by NOAA as posing a high hazard potential to coastal natural resources) for which RODs were available at USEPA Headquarters. RODs almost invariably specify the remedial technology or technologies chosen by USEPA to be employed in the site cleanup. Not uncommonly, however, site cleanup work may be divided into phases, or may deal with different operable units or areas of the site separately. In such cases, separate RODs may be prepared for each separate element or phase. Of the 14 sites listed in Table 2, only three clearly meet the criteria of being (a) definitely coastal, (b) clearly involving contaminated sediments, and (c) clearly having had remedial technologies considered for their contaminated sediments. These site names are underlined in the far left column of the table.

TABLE 2. HIGH COASTAL HAZARD NPL SITES WITH RODs ON NOAA LIST

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected	Type of Remedial Technology for Bottom Sediment
Beacon Heights Landfill	CT (I)	46.77	Naugatuck River is 2 miles away	Oil, rubber, plastic waste, resins, solvents, pesticides, acids and caustics	Streams adjacent to site are contaminated. Naugatuck River is receiving contamination from the site	None (ROD)
McKin Co.	ME (I)	60.97	Adjacent to Royal River which flows into Atlantic Ocean (22 miles away)	Hazardous waste dump	TCE (trichloroethane)	None (ROD) (currently monitoring)
Bog Creek Farm	NJ (II)	42.43	Adjacent to a bog area and north branch of Squankum Brook which feeds into the Manasquan River	Oily and chemical waste	Carcinogens in sediment from the north branch of Squankum Brook	None (monitoring)
Chemical Control Site	NJ (II)	47.13	In a peninsula between Elizabeth River and Arthur Kill	Acids, arsenic bases, cyanides, PCBs, flammable solvents, pesticides, compressed bases, biological agents		None
Price Landfill	NJ (II)	71.60	Leachate flows to Jarrets Creek which flows to Absecon Creek, then to Absecon Bay and finally to Atlantic Ocean	4.8 million gallons of bulk liquids and solid hazardous waste including benzene, TCE, chloroform, sludge, grease and oil	Soil organic vapor >1,000 ppm	None
Syncon Resins	NJ (II)	43.43	Site lies along the Passaic River which empties into Newark Bay	Resins, solvents	Three plumes: • PCBs • Toluene, xylene, and ethylbenzene • Naphthalene	None (collect and treat contaminated waters from shallow aquifer with discharge to Passaic River)
Marathon Battery	NY (II)	30.27	Located in a marshy area near Cold Springs on Hudson River	930 gal of waste contaminated with Cd, Ni, other metals	Cd, Ni, Co	Hydraulic dredging of contaminated sediments from East Foundry Cove Marsh with Cd concentrations greater than 100 mg/kg

(Continued)

(Sheet 1 of 3)

TABLE 2 (Continued)

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected	Type of Remedial Technology for Bottom Sediment
Marathon Battery (Continued)						Thickening of dredged sediments
						Treatment of thickener supernatant and discharge to the dredged cell
						Chemical fixation of dredged sediment
						Truck transport of the fixated sediments
						Restoration of East Foundry Cove Marsh by addition of clean fill, clay with high affinity for Cd, and revegetation
						Long-term monitoring of marsh sediments and biota
Tybouts Corner Landfill	DE (III)	73.67	Near the confluence of Pigeon Run Creek and Red Lion Creek	Municipal waste, refuse and industrial waste (TCE, vinyl chloride, 1-2-dichloroethane, benzene)	Organics	None (not at remedy stage)
Enterprise Avenue Site	PA (III)	40.80	Along Delaware River	10,000 drums of hazardous waste		None
Wade	PA (III)	36.63	On the banks of Delaware River	Several thousand drums of toxic chemicals		None

(Continued)

(Sheet 2 of 3)

TABLE 2 (Concluded)

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected	Type of Remedial Technology for Bottom Sediment
Chisman Creek	VA (III)	47.19	Chisman Creek watershed is on 4,200-acre coastal basin located on the Virginia Peninsula bounded by York and James Rivers east and west, respectively, and Chesapeake Bay south	Fly ash	Vanadium	None
American Creosote	FL (IV)	58.41	Pensacola Bay and Bayou Chico are 600 yd south of the plant	Wastewater and sludges from wood preserving plant (phenols and chlorinated phenols, benzene, toluene, polynuclear aromatic hydrocarbons)		None
Motco	TX (VI)	62.66	Site is on a marsh about 0.75 mile from Galveston Bay		Vinyl chloride, styrene tars, chlorinated hydrocarbons, polynuclear aromatic compounds, acids, metal catalysts, lead, Hg	None
Western Processing, Inc.	WA (X)	58.63	5 miles south of Puget Sound. Mill Creek is western boundary	Solvents, heavy materials, caustics and acids	87 priority pollutants	Intensive monitoring of Mill Creek, excavation of contaminated sediments from Mill Creek

(Sheet 3 of 3)

TABLE 3. HIGH COASTAL HAZARD NPL SITES WITH RODs ON NOAA LIST

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected	Type of Remedial Technology for Bottom Sediment
Charles George Land Reclamation	MA (I)	48.36-45.92	1.5 km east of Merrimack River. Flint Pond and surrounding wetland and Flint Marsh lie between site and river	Bulk disposal of volatile organics and toxic chemical compounds, 453 kg of Hg	Organic and inorganic contamination in wetland sediments (As, Zn, Cr, Cu, Pb, Ag, Tl, Ni)	Divided site into three operable units. RI/FS for bottom sediment and ground-water contamination only 10% complete. Most probably will recommend fixation technologies for sediment (excavation, fixation, and redisposal)
Industri Plex 128	MA (I)	75.60-58.41	West bank of Aberjona River	Wastes containing As, Cr, Pb, Zn, and Cu were disposed	High levels of toxic metals and volatile organic compounds in soils, surface water, and ground water	Wetland areas--on edges excavate and dredge out (only on ponded wetland area). No remediation of Aberjona River
Nyanza Chemical	MA (I)	75.60-58.41	250 m of Sudbury River	Waste sludge and drums containing waste solids (mercury is a major concern) and Cr, As, and Pb. Organic compounds include TCE, analine, dichlorobenzene, nitrobenzene, phenol	Metals and volatile organics have been detected onsite	No remediation has been recommended
Picillo Farm, Coventry	RI (I)	58.30-55.71	Whitford and Arnold Ponds are located 1 km west. Moosup River flows to Quinebaug River and Thames River before entering Long Island Sound	Four trenches filled with 20,000 drums containing solvents, oils, pesticides, PCBs, paint sludges, and explosives	PCBs, phenols, and volatile organics detected in ground water and soil	No cleanup of bottom sediments proposed in ROD
Western Sand and Gravel	RI (I)	51.62-47.71	Tarkiln Brook runs along the western boundary and enters the upper Slatersville Reservoir approximately 270 miles downstream	Chemical waste and sewage	Contaminants found in the soil, ground water, and surface water onsite	

(Continued)

TABLE 3 (Concluded)

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected	Type of Remedial Technology for Bottom Sediment
Krysowaty Farm	NJ (II)	55.10	450 m from the South Branch of the Raritan River	Various chemicals including paint and dye waste, oils and sludges	Both ground water beneath the site and surface water are heavily contaminated with toluene, naphthalene, trans 1,2-dichloroethylene	
Delaware City PVC	DE (III)	30.55	Site adjacent to stream tributaries of both Dragon Run Creek and Red Lion Creek	Sludge from wastewater treatment system	1,2-dichloroethane, TCE, ethylbenzene, toluene	Will not be recommending remedial technology for another year
Sand, Gravel, and Stone	MD (III)	41.08	Springs, seeps, and intermittent streams flow from the site to the west tributary of Mill Creek and eventually into Chesapeake Bay	Solvents and reprocessing plant sludges	Surface-water contamination	Will not be recommending remedial technology for another year
Geiger	SC (IV)	32.25	0.7 mile from Wallace River	Waste oil	Downgradient monitoring wells indicated the organic compounds 1,1-dichloroethylene, TCE, 1,2-dichloroethane, and 1,2-transdichloroethylene. Sediment onsite indicated aluminum, magnesium, lead, and chromium contamination	Onsite cleanup. No cleanup of bottom sediments proposed to date
Taputimu Farm	American Samoa (IX)	28.62	0.5 mile upstream from public beach	Pesticides and PCBs, contaminated oils		
Commencement Bay South Tacoma Channel	WA	54.63	Confluence of the Payallup River and Commencement Bay		150 organic compounds and trace metals	US Army Corps of Engineers has coordinated dredging as a remedial technology

TABLE 4. NOAA SITES WITH HRS SCORE <28.5

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected
O'Sullivans Island	CT (I)	--	Confluence of the Housatonic and Naugatuck Rivers, 14 miles from Long Island Sound	300 to 800 drums of hazardous waste contain significant concentrations of wastes containing dimethylcyclopentane, ethylcyclopentane, toluene, methylisobutyl ketone, methylcyclohexane, trichloroethane, and trimethylpentene	
F. O. Connor	ME (I)	--	Two miles from Kennebec River	PCB-contaminated oil	10,000 to 20,000 ppm of PCBs in holding ponds, 1 to 10 ppb of PCBs in sediments of Kennebec River
Albert Steel	NJ (II)	8.53	Runoff from site would wash into nearby Pearsen's Creek, which is 0.5 mile of Passaic River	Abandoned drums	Volatile organics, heavy metal and pesticide contamination
Fiore Demolition	NJ (II)	4.85	One mile from Newark Bay and borders an unnamed tributary stream that flows into Newark Bay	20,000 gal of "oily" wastes and and other wastes characterized as unknowns	
Ideal Cooperage	NJ (II)	25.05	Leachate spills from site flow into a ditch that empties into a stream connected to Hudson River	Spillage from drums stored at site includes the following chemicals: PCBs, fluoranthene, pyrene, isophorone, and heavy metals	29 different organics detected in in ditch that empties into a stream connected to Hudson River
Kooper Co., Inc.	NJ (II)	13.10	Hackensack River borders the site on the north and east sides	Plastic wastes, oil, tars, and coal by-products	Oil has been seen seeping into Hackensack River
PJP Landfill	NJ (II)	28.33	Site borders the Hackensack River		Monitoring wells and soil analyses from the site indicate high levels of benzene, chlorobenzene, lead, phenols, arsenic. High levels of Cr and S in the streams
Roosevelt Drive	NJ (II)	6.65	Wetlands of Hackensack River. Two streams on each side directly lead into Hackensack River		High levels of Cr and S in the streams

(Continued)

TABLE 4 (Continued)

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected
White Chemical Co.	NJ (II)	24.77	Site borders Platti Kill, which empties into Kill Van Kull (a commercial shipping lane)	Acid chlorides, PBBs, alkyl bromides, brominated flame retardants	PBBs, carbon, and other chemical wastes were found in the surface water adjoining the site
Horseshoe Round Dump	NJ (II)	16.70	Located on the Raritan River	50 to 70 drums of waste	Hazardous levels of cadmium, lead, and N-nitroso-diphenylamine were detected in runoff from the site
Mobile Chemical Co.	NJ (II)	4.98	Located close to Arthur Kill	Small amount of phosphorous sludge, sulfuric acid (three drums), phosphorous residue, phosphoric acid, and sulfuric acid	
Perth Amboy's PCB	NJ (II)	12.13	Located close to Crane's Creek, Spa Spring Creek, and Arthur Kill	PCB-contaminated sewage	PCBs
Sayreville Pesticide	NJ (II)	17.64	Raritan River is 0.75 mile from site	200 drums of unknown	Hazardous materials detected in the drums
Clear Ambient Service	PR (II)	11.20	500 ft from a canal that drains through a large marshland called Clenagade las Cucharillas. Canal empties into the Bay of San Juan 1.3 miles away	Waste oil	
Joy Reclamation Co.	MD (III)	25.53	Adjacent to a drainage ditch that empties into a stream which empties into Curtis Creek approximately 1 mile from the site	Scrap metal, construction rubble, 100 drums of paint sludge, 1,000-cu-ft pile of slag containing high levels of hexovalent chromium (a known carcinogen)	Slag pile shows elevated chromium levels. Surface water in the ditch contained less than 100 ppm chromium, and sediment samples in Curtis Creek show high background levels of chromium and sulfide
Bridesburg Dump	PA (III)	5.35	Located on the floodplain of the west bank of Delaware River. 100 yd from the Franklin Creek, which drains into the Delaware River 800 yd away	Construction and road rubble, waste and slag from aluminum processing, waste mortar, and drummed waste	High concentrations of metals (Pb, Cr, Cu, Sb) and organic compounds (phthalate, di-n-butyl phthalate) onsite. High concentrations of Al, Cr, Ba, Cu, Fe, Mn, Zn, B, Ca, Mg, Na, and Sb downstream in Franklin Creek and upstream in Delaware River

(Continued)

(Sheet 2 of 3)

TABLE 4 (Concluded)

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected
Wam Chem, Inc.	SC (IV)	--	West bank of the McCalleys Creek, which is a tidal estuary of the Coosaw River	Chromium, toluene, dichloronitroethane, benzene	Pb and Cr were detected in all soils sampled at the site
Pearly City Landfill	HI (IX)	25.45	Adjacent to Waiawa Stream and Middle Loch	Domestic waste, digested sewage sludge, hazardous wastes, security classified wastes	
Stauffer Chemical	OR (X)	19.44	Borders Columbia River	Direct liquid aluminum discharge (combination of bauxite and sulfuric acid)	DDT, DDE, DDD, and chlordane have been found in the ground water and soil

(Sheet 3 of 3)

TABLE 5. NOAA SITES WITH RI/FS

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected	Type of Remedial Technology for Bottom Sediment
Davis Liquid Waste Site	RI (I)	40.70-38.33	1.7 km northwest of Stillwater Reservoir, an impoundment on the Woonasquatucket River	Paint pigments, oils (halogenated and non-halogenated), caustics, pesticides, phenols, and laboratory waste	Pb, Cr, Tl, Cd, Ni, and Zn were found in ground water, and Pb, Ni, and Zn were found in surface water. Also, some off-site contamination	Sediment may be contaminated; however, no remedy has been proposed because, if river is dredged, sediment may be resuspended
New Bedford Harbor Site	MA (I)	58.30-55.71	Located in Bedford Harbor	PCBs	PCBs and other contaminants in harbor sediments	USEPA, Mass. Dept. of Env. Quality Engineering, and US Army Corps of Engineers plan to conduct a pilot study to evaluate feasibility of dredging and disposal of contaminated sediment
Peterson/Puritan Site	RI (I)	40.70-38.33	Located in the Blackstone River Valley	Wastewater from manufacturing of insecticides and cleaning agents	Onsite ground water consists of high levels of volatile organics and inorganic compounds	
Kin-Buc Landfill	NJ (II)	50.64	Bordered on the west and south by a curve of the Raritan River	70,000 gal of spent industrial chemicals and municipal liquid wastes were disposed of at the site	PCBs, TCE, dichlorobenzene, toluene, benzene	
Ventron	NJ (II)	51.38	Leachate enters Barry's Creek, a tributary of Hackensack River	Was a chemical processing plant	Hg, Zn, Pb, Ni, and As are in soil, ground water, and surface water on and around the site	
Fontera Creek	PR (II)	41.23	Site is shallow, small creek that drains into the Caribbean Sea	Wastewater discharges from the nearby industrial park	Mercury and lindane (pesticide)	

(Continued)

TABLE 5 (Concluded)

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected	Type of Remedial Technology for Bottom Sediment
Hudson River PCBs*	NY (II)	55.58-51.94	Hudson River	PCB	40 PCB-contaminated "hot spots" in river sediments	NY State DEC has studied in detail the physical removal of PCB-contaminated sediments by dredging and is considering partial (hot spot) dredging
Alviso Dumping Areas (South Asbestos)	CA (IX)	44.65	Surface runoff from site flows to Alvisco Slough and Guadalupe Slough, which flow to Coyote Creek which forms the southernmost part of San Francisco Bay	Asbestos-contaminated waste	Surface water, ground water and soil in the vicinity of the site is contaminated with asbestos as well as trace metals	
MGM Brakes	CA (IX)	34.70	Adjacent to Icaria Creek, which flows for approximately 1,000 ft into the Russian River	PCB-laden hydraulic fluids	PCBs	At the RI stage for Icaria Creek
Commencement Bay Nearshore/Tidalflats	WA (X)	42.20	Adjacent to the Puyallup River	Metals (As, Pb, Zn, Cu, and Hg) and organic compounds (PCBs, phthalates, PAHs, dibenzofurans, and chlorinated pesticides)	PCBs, trace metals, PAHs, chlorinated butadienes	Remedial action at the site is expected to include dredging and disposal of contaminated sediments from the bay's industrialized waterways

* Not on NOAA List.

TABLE 6. SITES WITH BOTTOM SEDIMENT CONTAMINATION THAT HAVE NOT YET REACHED RI/FS STAGE

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected	Type of Remedial Technology for Bottom Sediment
Yaworski Waste	CT (I)	36.72	Site lies within a meander loop of the Quinebaug River	Drummed materials and bulk wastes including dyes, solvents, resins, acids, and caustics	MEK, ethyl benzene, toluene, and xylene detected in lagoon	
Diamond Alkali	NJ (II)	35.40	South bank of the Passaic River	Agent orange	River is contaminated with dioxin, herbicides; site contaminated with agent orange	
Brick Township Landfill	NJ (II)	58.13	Near Saw Mill Creek, which runs into the Manasquan River	1.5 million gallons of bulk liquids or 1,900 55-gal drums of waste	Monitoring wells indicate high concentrations of organic solvents, heavy metals, volatile organics, and pesticides	
Liberty Industry Finishing	NY (II)	50.65	Adjacent to the Massapequa Creek, which leads into the Great South Bay		Ground water and soil on the site are contaminated with heavy metals. Contaminants have been found in the Massapequa Creek	
Sayreville Landfill	NJ (II)	34.05	Bordered on three sides by the South River (a tributary of Raritan River)	Para-ethyl toluene and pentachlorophenol		
NL Industries	NJ (II)	52.96	Onsite is a marsh area, Oldams Creek, a tributary to the Delaware River	Rubber	Ground water, surface water soils onsite contaminated with heavy metals. Marsh area contaminated with lead	
Mercury Refining Inc.	NY (II)	45.91-43.23	Adjacent to Petroon Creek, a tributary to the Hudson River	Silver, mercury batteries	Stream sediments have high concentrations of heavy metals, mercury, PCBs	
Combe Fill South Landfill	NJ (II)	45.91-43.23	Area near landfill is drained by the north branch of the Raritan River and by Lamington River. Trout Brook runs through the site		Chlorinated hydrocarbons detected in ground water and surface water	

(Continued)

(Sheet 1 of 3)

TABLE 6 (Continued)

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected	Type of Remedial Technology for Bottom Sediment
North Sea Municipal Landfill	NY (II)	34.69-33.73	Near the southern shore by Little Peconic Bay	Refuse, construction debris, septic system wastes	Heavy metals in ground water	
Halby Chemical Co.	DE (III)	32-30.76	Drains into the Lobdell Canal and the Christiana River		TCE, tetrachloroethylene, As, cyanide, and Pb present in water and sediment from lagoon. Thiocyanate in the ground water	
Metal Banks	PA (III)	33.67-32.02	Adjacent to the Delaware River		20,000 gal of PCB-contaminated oil in ground water	
Saltville Waste Disposal Ponds	VA (III)	29.52	Adjacent to the North Fork of the Holston River		Pond - 11 million tons of Hg-contaminated waste. 50 miles of North Fork contaminated with Hg	
U.S. Titanium	VA (III)	35.64-34.69	Adjacent to Piney River	Acidic wastes from one refining process		
Wildcat Landfill	DE (III)	30.61	Adjacent to the St. Jones River	Municipal and hazardous industrial wastes	Ground water is contaminated with Pb, Cd, Be, As, benzene, phthalates, and low levels of PCBs	
Old Brine Sludge	DE (III)	40.32	Adjacent to Red Lion Creek and Delaware River	Mercury contaminated wastewater, stormwater drainage, caustic tank car and truck washings, PVC solids, barium sulfate, calcium sulfate, various carbonates, and chlorides	Red Lion Creek sediment and water sample had elevated levels of chlorinated benzenes, acetone, benzene, mercury, trace levels of suspected carcinogen 1,2-dichloroethane, the human carcinogen bis (2-chloromethyl) ether, and the plasticizer (2-diethylhexyl) phthalate	No RI/FS
Schlyukill Metals Corporation	FL (IV)	75.60-58.41	Pemberton Creek	Heavy metals and sulfuric acid	Ground water and surface water had elevated levels of Pb, Cr, and Ni. Sediment in ditch adjacent to the site had high levels of Pb	

(Continued)

(Sheet 2 of 3)

TABLE 6 (Concluded)

Site Name	Location (USEPA Region)	HRS Score	Proximity to Marine Resources	Potential Waste	Contaminants Detected	Type of Remedial Technology for Bottom Sediment
Sapp Battery Salvage	FL (IV)	48.36-45.92	Little Dry Creek and Steel City Bay		Elevated levels of Pb, Zn, and sulfuric acid detected in Little Dry Creek and Steel City Bay	
Kassauf-Kimerling Battery Disposal	FL (IV)	53.42	Surface drainage runs to Palm River	Battery casings	High levels of Pb were detected in surface water near site	
Bayou Bontonca	LA (IV)	29.78		Creosote spill	Contaminated sediments in Bayou Bontonca	
Old Inger Oil Refinery	LA (IV)	58.30-55.30	Close to a swamp	Oil	Ground water and soils contaminated by organic chemicals	
Mowbray Engineering Co.	AL (IV)	53.67	Nearby swamp that discharges into Persimmon Creek	Waste oil containing PCBs	PCB soil contamination onsite	
PCB Warehouse	North Mariana Islands (IX)	32.60	Adjacent to Philippine Sea	Transformer fluid containing PCBs		
United Chrome Products, Inc.	OR (X)	32-30.76	Adjacent to Booneville Slough	Chrome plating wastewater	Sediments and water in surface drainages including Booneville Slough are contaminated with Cr	
Harbor Island Lead	WA (X)	34.60	Confluence of the Duwamish River and Elliott Bay in Puget Sound	Lead dust	Lead-soil at site Duwamish River sediment contaminated with Cu, Cr, Zn, PCBs, PAHs, and lead	

(Sheet 3 of 3)

Table 3 lists similar sites on NOAA's high-hazard list for which RODs were not readily available from USEPA Headquarters, but for which we were able to obtain information on selected remedies through telephone interviews with USEPA Regional Superfund Coordinators. Of the 11 sites listed in this table, four appeared to meet the criteria applied in Table 2. These site names are, again, underlined.

Table 4 lists 19 sites that, although viewed by NOAA as posing a significant potential hazard to coastal natural resources, scored less than the 28.5 cutoff (under USEPA's Hazard Ranking System) required to list the site on the NPL. As unlisted sites, these sites are not eligible for full-fledged cleanup under Superfund. (Only more limited emergency removals are possible, where an imminent hazard is believed to exist.) Only two of these sites (site names underlined) appear to clearly implicate bottom sediment contamination.

Table 5 lists nine NPL sites on NOAA's high-hazard list (and one site inexplicably not on NOAA's list) for which Remedial Investigations and Feasibility Studies (RI/FS) have been completed under Superfund. Although a final ROD does not yet exist for these sites, the available RI/FS report contains expert recommendations on the preferred remedial technology or technologies for site cleanup. Three of these sites (site names underlined) seem to clearly involve bottom sediment contamination and apparently have explored specific remedial technologies for addressing this contamination.

Table 6 lists NPL sites with potential bottom sediment contamination and an apparent coastal location (whether or not on the NOAA high-hazard list) which have not yet reached the RI/FS stage. Consequently, no preferred remedial technology has yet been recommended for any of these sites. Of the 25 sites on this list, four seem clearly to involve bottom sediment problems in a coastal marine setting (site names underlined).

Comparison of the 17 sites whose names were underlined in Tables 2-6 (i.e., coastal marine Superfund sites that clearly involve contaminated bottom sediments) shows that site locations ranged from Maine to Louisiana to Washington State and that the sites' HRS scores ranged from 25.53 to as high as 58.3.

It may be observed that this list of 17 sites is not very long--especially when one considers that there are now more than 1,500 sites (present or proposed) on USEPA's Superfund National Priorities List. However, this list is also clearly not complete.

Figure 4 summarizes, for 10 of these sites (those for which remediation of contaminated sediments had been considered and on which we had information) the elements of a remedial strategy employed (or proposed to be employed) at each site. The elements considered include: excavation, onsite or off-site stabilization (including fixation and thickening), capping, monitoring, cleanup of onshore contamination as a means of curbing a sediment contamination source, and no action.

Although it can be seen that excavation or dredging was a frequently adopted approach, appearing in at least half the sites in this figure, there was wide variation from site to site in the combination of techniques

Site	Excavation	(on or off-site) Fixation, Thickening, Stabilization	Capping	Monitoring	Cleanup of Onshore Contamination	No Action
Charles George Land Reclamation	✓	✓				
Picillo Farm						✓
Davis Liquid Waste Site						✓
New Bedford Harbor	?					
Bog Creek Farm				✓		
Marathon Battery	✓	✓	✓	✓		
Hudson River PCBs	✓ (?)					
Geiger					✓	
Commencement Bay (Nearshore/ Tide Flats)	✓					
Western Processing, Inc.	✓			✓		

Figure 4. Elements of remedial strategies

proposed. Even where excavation was selected as the primary technology, in three of five cases it was to be used together with other techniques (which differed in all three cases).

One evident conclusion from this table is that there is little consistency in the approach taken from one site to the next. This in itself is not an indictment. Different contaminants and widely differing site conditions make it entirely appropriate that different strategies and mixes of technologies be employed from one situation to another. The more serious criticism (which, at this stage, is no more than a strong impression) is that a systematic thought process is not followed in deciding whether to excavate or treat contaminated sediments, on the one hand, or to leave them entirely alone, on the other.

It was precisely for this reason that the National Academy of Sciences/National Academy of Engineering Marine Board (under the National Research Council and the Commission on Engineering and Technical Systems) has initiated the study that is outlined below.

MARINE BOARD STUDY

The Marine Board has formed a nine-member Contaminated Sediments Committee to conduct an assessment aimed at providing an improved understanding of contaminated marine sediments. This assessment is intended to aid managers and decisionmakers in developing a more cohesive and systematic framework for making remedial action decisions involving contaminated sediments. It will also, hopefully, help to define technical research and development needs and priorities.

To accomplish these objectives, the Committee will be holding a workshop (probably in the late winter of 1987-88). This workshop will:

a. Examine the extent of bottom sediment contamination in coastal areas of the United States and its significance.

b. Review the state of practice of technology for cleanup and remediation.

c. Identify and appraise alternative management strategies.

d. Identify research and development needs and issues for subsequent assessment (both by the Marine Board and by others). These issues may well include sediment classification and waterway management strategies.

The Committee will then prepare a report which includes:

a. Proceedings of the workshop.

b. A summary appraisal describing relevant technical and programmatic issues.

c. Recommendations to the US Army Corps of Engineers, the USEPA, and others for further study and technical development.

CONCLUSIONS

Much remains to be learned about optimal strategies for cleaning up inactive hazardous waste sites. This is especially the case where the contamination that must be cleaned up is underwater. The very attempt to remove contaminated bottom sediments could result in the resuspension and mobilization of contaminants (with resultant impacts on aquatic resources, including food chain species), such that the "cure" could easily turn out to be worse than the "disease." Clearly, such decisions must be made with great care and justifiably may differ from location to location.

On the other hand, the fact that sites such as the James River Kepone site and the Hudson River PCB site could entail diametrically contrasting remedial action decisions (leave the sediment alone, to be covered over by natural deposition, in the Kepone case; excavate contamination hotspots, in the PCB case) raises understandable questions about the thought process used in making such a decision. This is especially so for sites like these two, which appear to be so similar: both involved bottom sediment contamination with a bioaccumulative organohalogen, and are located within a few hundred miles of one another.

It is hoped that the Marine Board's study will provide new insights into the nature and extent of bottom sediment contamination in coastal environments. Hopefully, too, the results of this study will aid decisionmakers in deciding when the best course of action is active remediation, as opposed to benign neglect.

RESTORATION OF URBAN RIVER WATER QUALITY--INTRODUCTION OF SECONDARY TREATED DOMESTIC WASTEWATER INTO THE NOBIDOME CHANNEL

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ABSTRACT

Comprehensive surveys for water quality and benthic invertebrates were carried out in the Nobidome Channel in which filtered secondary wastewater was introduced to restore the waterfront. The suspended solids concentration increased downstream as a result of erosion of the bank and the bottom. Self-purification was not significant for biological oxygen demand (BOD). The dominant species of periphyton and benthic invertebrates were typical of polluted streams and coincide with the poor water quality. Standing crops, however, were less than expected based on nutrient concentrations, with the major controlling factors being the lighting conditions affected by the fall of leaves from the deciduous broad-leaved trees around the channel and the stability of sediments. Distribution of Chironomidae was strictly controlled by the repeated dosage of growth-inhibition chemicals.

INTRODUCTION

Sewage works and sediment dredging improved the water quality of polluted rivers running through or near large cities. However, all the wastewater and stormwater that used to flow into the rivers is collected into sewer pipes and transferred directly to a wastewater treatment plant generally located downstream of the river basin. Thus, in spite of the improved quality of water, the quantity of running water has decreased and, in some small streams, no running water can be observed except for stormwater runoff after construction of the sewer system. There are many small streams in the vicinity of Tokyo in which the rate of flow has decreased remarkably in recent years.

Rivers or streams are important to the quality of life in urban areas and attract many people to the waterfront. Therefore, the decrease or disappearance of flow is a serious problem, and in some cases, may be more serious than water pollution. There is now an urgent need to maintain the river environment not only for water quality but also for quantity of running water (Ooe 1986).

Many municipalities are now planning or have begun to introduce clean water to keep the necessary amount of running water for restoration or improvement of the waterfront (Japan Environment Agency 1984). However, many large cities are now facing a shortage of water for this purpose. They are now looking at treated wastewater as one of the most promising sources of water for maintaining riverflow.

The first full-scale project was the restoration of a clear stream in the Nobidome Channel in Tokyo (Tokyo Metropolitan Government 1984). Secondary wastewater treated by the activated sludge process and rapid sand filtration has been introduced into the channel where no natural water was running, i.e., running water is kept only by the secondary effluent. It has been pointed out, however, that secondary effluent from the activated sludge process has a high potential to stimulate algal growth in shallow rivers and to deteriorate water quality (Ohtake, Aiba, and Sudo 1978).

The purpose of this study was to evaluate the use of secondary effluent for maintaining riverflow under a full-scale project for the first time in Japan. Water chemistry and benthic invertebrates were surveyed for 2.5 years following introduction of the effluent.

THE NOBIDOME CHANNEL PROJECT

A map of the Nobidome Channel is shown as Figure 1. It was constructed in the 17th century by orders of Nobutsuna Izunokami Matsudaira, governor of the Nobidome area and civil engineer for the construction of Tamagawa Jousui to provide a tap water supply to downtown Edo (Tokyo) and to develop new agricultural fields in the Musashino Plateau, the western part of Tokyo. Water in the Tamagawa River was diverted into the channel and distributed over the plateau for irrigation. It is recorded that agricultural production in the plateau increased up to 10 times as a result. In addition to the irrigation, the channel was used for drinking water and for hydrant and miscellaneous usage until recently (Tokyo Metropolitan Government 1984).

With the spread of metropolitan Tokyo during the rapid economic growth after World War II, the channel area was developed for housing, without construction of a public sewer system. The channel became a waterway for the discharge of polluted water and sewage from septic tanks, and the demand for irrigation decreased. In 1973, the Tokyo Metropolitan Government stopped the diversion from the Tamagawa River to cope with the shortage of water to downtown Tokyo. Construction of a sewer system resulted in diversion of the wastewater flow from the channel.

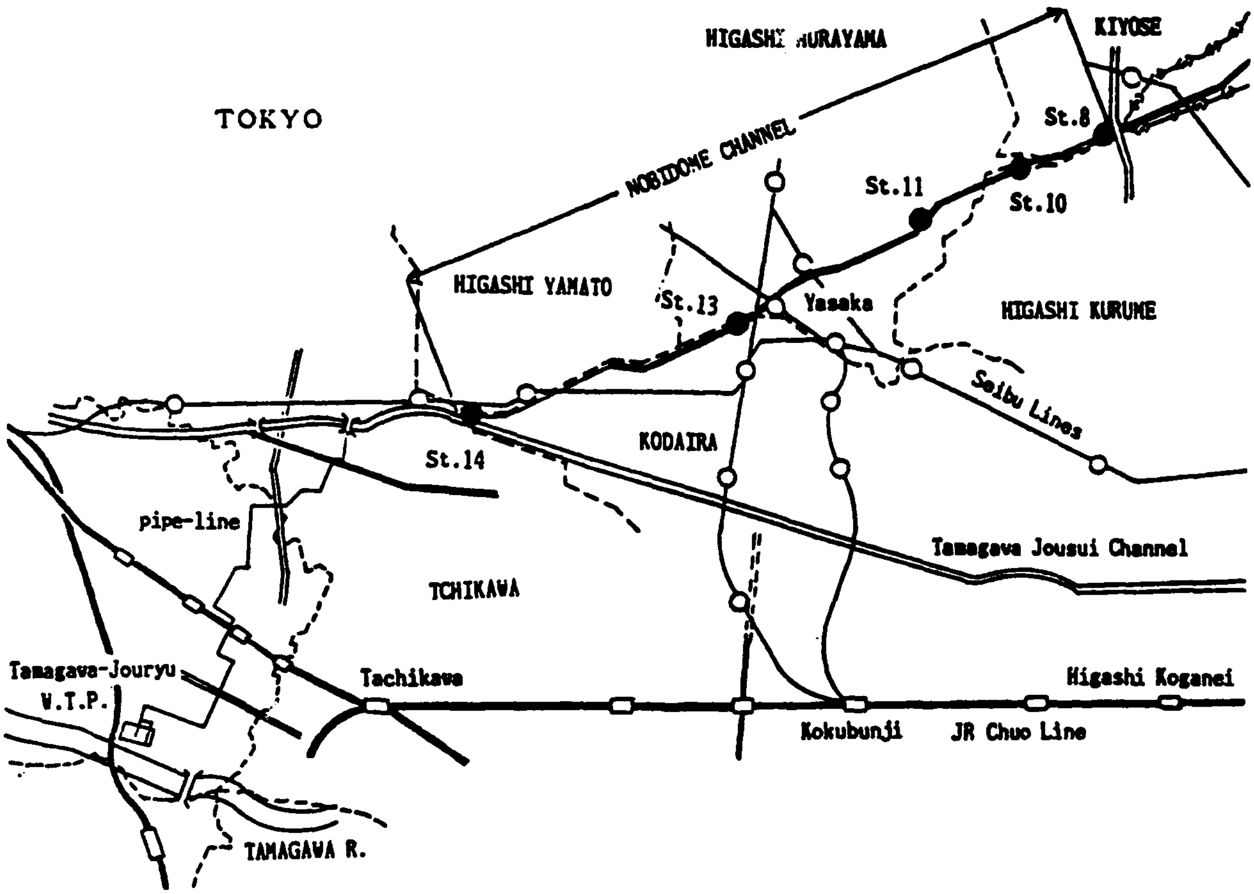

Figure 1. Aerial map of the Nobidome Channel and sampling stations

In 1974 the government of Tokyo prepared a plan to restore the former waterfront of the Nobidome Channel as one of the projects to create a better urban environment in Tokyo. Secondary effluent from Tamagawa Jouryu Wastewater Treatment Plant was filtered through a continuous upflow, moving sandbed filter and transferred through a pipeline for 8.7 km to the channel. The objectives were to obtain water with an average BOD of 8 mg/ℓ, at a flow rate of 20,000 cu m/day. The construction began in 1981, and the discharge of secondary effluent started in August 1984.

FIELD SURVEYS AND CHEMICAL/BIOLOGICAL ANALYSES

Sampling of water and benthic invertebrates was carried out at five sampling stations (St. 14, 13, 11, 10, and 8) distributed between the point of discharge (St. 14) and the points where the channel crosses the border between the Tokyo Metropolitan District and Saitama Prefecture (St. 8). The distance between St. 14 and St. 8 is 8,700 m. All of the areas channel surveyed were open channel except for a short closed channel near St. 13.

Hydraulic and chemical parameters of running water, periphyton, and benthic invertebrates of the bottom sediment were analyzed 13 times during the 2.5 years following discharge. All samples were taken in the morning. The hydraulic parameters were width and depth of the channel and flow rate. Water temperature and light intensity at the water surface were also monitored. The chemical parameters determined were pH, suspended solids (SS), BOD, chemical oxygen demand/manganese (COD_{Mn}), total organic carbon (TOC), dissolved organic carbon (DOC), and various forms of nitrogen and phosphorus. The numbers of coliform groups and fecal colis were also determined. All determinations were conducted according to the Methods for Chemical Analysis of Water and Wastes (USEPA 1976).

Periphyton were collected from a 5- by 5-cm quadrat on the surface of a relatively flat stone on the bottom or from the surface of bottom sediments, using a nylon toothbrush. Benthic invertebrates were collected from a 30- by 30-cm quadrat by using a D frame net with a mesh of GG40. Species were identified by microscopic examination.

RESULTS AND DISCUSSION

Hydraulic Parameters

In other small streams in the Tokyo area, the banks and bottom were covered with concrete before discharge; however, no protection was executed in this channel. The surface of the banks and bottom was clay, as before (Table 1). The maximum rate of flow observed at the center of the channel ranged from 40 to 70 cm, except for St. 13 where the bottom has the largest slope and the rate was more than 100 cm. Gravels have been exposed at this station by erosion.

TABLE 1. CHARACTERISTICS OF NOBIDOME CHANNEL (JUNE 22, 1985, FLOW RATE = 20,000 cu m/day)

Parameter	Station 14	Station 13	Station 11	Station 10	Station 8
Width, m	1.6	1.6	1.8	1.6	1.6
Maximum depth, cm	20	20	26	25	25
Maximum flow rate, cm/sec	43	105	55	64	55
Bottom material	Clay	Gravel + clay	Clay	Clay	Clay
Time of flow between stations, min	51 (14–13)	42 (13–11)	52 (11–10)	40 (10–8)	

The width ranged from 1.6 to 1.8 m, and maximum depth was between 20 and 26 cm. Although the values shown in Table 1 were determined at the specified date, little difference in values was noted throughout the sampling period because the amount of discharge is controlled at a constant level at the pumping station.

The intensities of light at the surface of the channel compared with open (unshaded) areas nearby are shown in Table 2. Large relative intensities were noted at St. 8, where only a small number of trees cover the channel. In the other stations, many deciduous broad-leaved trees, such as zelkova, grow on the banks and cover the channel. In summer, when their leaves shade direct sunlight from the surface of the water, small values of relative intensity were recorded. After leaf fall in autumn, high values of relative intensity were noted.

TABLE 2. RELATIVE INTENSITY OF LIGHT (PERCENT) AT THE SURFACE OF THE CHANNEL

	Station				
Date	14	13	11	10	8
Nov 1985	2-90	5-50	1-5	8	100
Feb 1986	100	90	100	80	70
Apr 1986	42-67	61-69	20-33	43-58	92
May 1986	7-10	9-11	1-5	1-4	93
Jun 1986	3-4	6	1-2	2-4	74
Jul 1986	1-3	4-5	1-2	2-3	81
Sep 1986	3	12-13	Under 1	1-2	92
Oct 1986	1-2	71	Under 1	1	92
Dec 1986	10-38	83	89	43	92

It must be noted that the typical odor of sewage was detected occasionally. Also, foaming by surfactants was seen a few times. Although these phenomena were not common, dosage with antifoaming agents has been implemented. No action has been taken to correct the odor.

Chemical Parameters

Results of the chemical analyses are summarized in Table 3. The secondary effluent discharged into the channel at St. 14 was clear, with small values of SS. The values increased with distance downstream. The maximum value observed was more than 100 mg/ℓ, and the average was 47.3 mg/ℓ in St. 8.

Contrary to SS, no significant increase or decrease was noted for organic parameters such as BOD, COD_{Mn}, and TOC. The BOD ranged from 10 to 15 mg/ℓ, and TOC was ca. 10 mg/ℓ throughout the channel studied. The increase in SS, therefore, could be attributed to the increase in inorganic substances along the flow of water downstream. It is most likely that erosion or resuspension

TABLE 3. SUMMARY OF CHEMICAL ANALYSIS (CONCENTRATIONS IN MILLIGRAMS/LITRE)*

Parameter	Station 14	13	11	10	8
pH	6.8	7.1	7.2	7.2	7.2
DO	5.4	6.5	7.1	6.6	6.3
SS	4.7	24.4	37.9	38.2	47.3
COD_{Mn}	10.3	10.2	11.8	11.9	12.6
BOD	12.0	12.6	15.8	15.8	14.5
TOC	9.0	8.7	9.3	9.6	9.8
DOC	7.8	7.9	8.4	8.2	7.9
T-P	1.88	1.76	1.89	1.80	1.89
PO_4-P	1.36	1.25	1.17	1.14	1.12
T-N	12.3	12.8	12.4	14.1	12.4
NH_4-N	5.1	4.4	3.9	3.7	3.5
NO_2 + NO_3-N	7.4	8.1	8.5	9.2	9.3

* Averaged values for 13 samplings from November 11, 1984, to December 2, 1986.

of clay materials from the bank and bottom of the channel increased the SS concentration. The current condition of the bank and bottom is not conducive to maintaining clear water.

Slight increase in pH was noted, whereas the water was neutral. Dissolved oxygen (DO) concentration was low at the point of discharge and increased gradually downstream. However, low DO values were observed throughout the channel, and percent of saturation ranged from 50 to 80.

Although no remarkable changes in nitrogen and phosphorus concentrations were noted, ammonium nitrogen decreased and nitrite plus nitrate nitrogen increased gradually downstream by nitrification. It must be noted that the relatively high rate of nitrification was noted even in winter because water temperature in the channel was high, i.e. 10° C or more even in the morning, under a low atmospheric temperature of 3.2° C.

Hygienic Parameters

Numbers of coliform groups and fecal colis in the water are listed in Table 4. The number of coliform groups at the point of discharge, St. 14, met the water quality standard of class A for the living environment in Japan, i.e, less than 1,000 per 100 ml. Although the numbers increased in stations downstream, they could satisfy the standard for class B.

TABLE 4. NUMBER OF COLIFORM GROUPS AND FECAL COLIS IN THE WATER (COUNTS PER 100 ML)

Parameter	Station 14	13	11	10	8
Coliform groups					
Feb. 17, 1986	5.9×10^1	4.0×10^2	2.0×10^3	1.4×10^3	1.4×10^3
Apr. 25, 1986	9.3×10^1	5.0×10^2	1.5×10^3	3.2×10^3	4.2×10^3
Sep. 5, 1986	1.2×10^2	5.7×10^3	7.0×10^3	9.4×10^3	9.7×10^3
Fecal colis					
Nov. 11, 1984	3.4×10^1	2.9×10^2	1.4×10^2	2.3×10^2	2.0×10^2
Feb. 17, 1986	4.3×10^1	3.1×10^2	1.3×10^3	1.2×10^3	7.2×10^2
Apr. 25, 1986	1.0×10^1	1.0×10^2	2.6×10^2	4.9×10^2	8.6×10^2
Sep. 5, 1986	9.3×10^1	1.7×10^3	4.6×10^3	5.8×10^3	6.7×10^3

The number of fecal colis is regarded to be a more reliable indicator of bacterial contamination and is now used to check the safety of coastal and lakeside beach resorts for bathing. The guideline number is now less than 100 per 100 ml but will accept 400 per 100 ml. Based on these criteria, discharged water at St. 14 is acceptable. Although figures for some stations downstream were above the allowable level, the water in this channel does not have to meet the requirements of a bathing resort. It may be concluded that the water is safe for regular activities around the channel from the standpoint of hygiene.

Periphyton

The periphytic species that appeared in 65 samples collected during the 2.5-year period (13 samplings) are listed in Table 5. The value in parentheses after the name of the species is the number of samples in which the cell number of corresponding species was more than $10^4/mm^2$. The total numbers of species identified were 5 for Cyanophyceae, 1 for Rhodophyceae, 41 for Bacillariophyceae, and 9 for Chlorophyceae.

TABLE 5. PERIPHYTON COLLECTED FROM THE NOBIDOME CHANNEL

Family	Species
Cyanophyceae	*Chroococcus* sp. (5)*
	Fisherella sp.
	Oscillatoria sp.
	Phormidium sp. A
	Phormidium sp. B
Rhodophyceae	*Audouinella chalydea* (1)
Bacillariophyceae	*Achnanthes hungarica*
	A. lanceolata
	A. microcephala
	A. minutissima
	A. sp.
	Amphora sp.
	Ceratoneis arcus var. *vaucheriae*
	Cocconeis placentula var. *lineata*
	Cymbella minuta
	Fragilaria capucina (1)
	F. producta
	F. sp.
	Frustlia vulgaris
	Gomphonema angustatum
	G. intricatum var. *pumila*
	G. parvulum (6)
	G. pseudoaugur (2)
	G. sp.
	Hantzschia amphioxys
	Melosira varians
	Navicula cryptocephala
	N. frugalis
	N. goeppertiana (3)
	N. gregaria (1)
	N. seminulum (31)
	N. symmetrica
	N. yuraensis
	N. veneta (5)
	N. sp.
	Nitzschia amphibia
	N. frustulum var. *perpusilla*
	N. gandersheimiensis
	N. linearis
	N. palea (5)
	N. romana
	N. sp.
	Pinnularia braunii
	P. gibba var. *parva*
	Surirella angustata
	Synedra ulna
	S. ulna var. *oxyrhynchus*
Chlorophyceae	*Ankistrodesmus* sp.
	Chlamydomonas spp.
	Chlorococcum sp.
	Cladophora glomerata
	Coleochaete sp.
	Oedogonium sp.
	Scenedesmus sp.
	Stigeoclonium sp. (11)
	Ulothrix sp.

* Number of samples in which cell number was more than $10^4/mm^2$.

The dominant species was *Navicula seminulum*. In 31 of the 65 samples, their cell numbers were more than $10^4/mm^2$. The other dominant species and numbers of samples with more than $10^4/mm^2$ were *Stigeoclonium* sp. (11 samples); *Gomphonema parvulum* (6); and *Chroococcus* sp., *Navicula veneta*, and *Nitzschia palea* (5). However, the population densities observed were far smaller than those observed in experimental artificial channels where secondary effluent was discharged (Ohtake, Aiba, and Sudo 1978).

These species are regarded to be the typical and most common species in polluted rivers where BOD values are more than 10 mg/ℓ (Fukushima 1987). They are tolerant species for organic pollution and are frequently used as biological indicators of pollution (Lange-Bertalot 1979). It is also known that more than 100 algal species can be identified from nonpolluted streams (O'Quinn and Sullivan 1983, Wehr 1981). The fact that only 56 species were identified seems to be due, in part, to the environmental condition, the water temperature and flow rate, and the channel stability. However, it must be admitted that the channel is not in a state that could be called "clear stream" but is a typical polluted stream, based on the periphytic indicator.

Temporal and aerial distributions of the two dominant species, *Navicula seminulum* and *Stigeoclonium* sp., are shown in Table 6. *Navicula seminulum*, which is known to grow both under high and low light intensities, appeared in all stations studied irrespective of lighting condition (Hynes 1972). *Stigeoclonium* sp., which favors high light intensity, appeared mainly in stations with relative light intensity of 50 percent or more.

TABLE 6. TEMPORAL AND AERIAL DISTRIBUTIONS OF *NAVICULA SEMINULUM* AND *STIGEOCLONIUM* SP.

		Date											
		1984	1985				1986						
Species	Station	Dec	Apr	Jun	Aug	Nov	Feb	Apr	May	Jun	Jul	Sep	Oct
Navicula seminulum	14	***	***	***	***	**	***	***	***	***	***	***	**
	13	***	***	*	*	*	***	***	**	**	**	***	*
	11	*	***		*	*	**	***	**	***	**	*	*
	10	*	***	**	*		**	***	***	**	*	**	*
	8	*	***	***	***	**	***	***	***	***	***	**	**
Stigeoclonium sp.	14	*	***		*	*	***	***	*	*	*	**	*
	13	*	***	***	*			**	**	*	*	*	*
	11		***		*			**	*	**	*		*
	10		***	**		*	**	**	**	*		*	*
	8	**	***	***	***	**	**	**	***	**	**	**	*

Note: The number of cells per square millimetre is represented by the following symbols: * ($<10^3$), ** (between 10^3 and 10^4), *** ($>10^4$).

Figure 2 shows seasonal variations of total cell numbers of periphyton in St. 14, 11, and 8. Both in St. 14 and 11, algal population density increased from winter to spring and decreased in summer, whereas higher population density was observed even in summer in St. 8. The variation in St. 14 and 11 corresponds well with the variation of relative intensity of light shown in Table 2, i.e., high intensity after leaf fall increased the population density, and low intensity in summer decreased the population density (Summer and Fisher 1979).

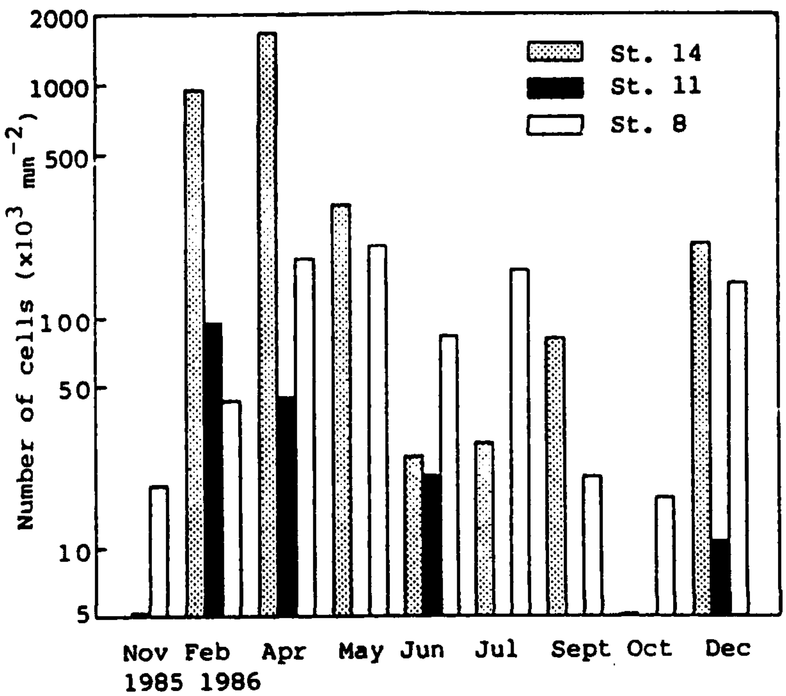

Figure 2. Seasonal variations of periphyton in the Nobidome Channel

The effect on light intensity of deciduous trees along the channel seems to be one of the major factors controlling population density and species composition of periphyton. It is likely that periphyton pollution potential would be worse without the light-shielding effect of trees.

Numbers of periphyton on the surface of clay and gravel in the same stations are shown in Figure 3. Although total population varied among stations, population density on the clay surface was 50 percent or less compared with the surface of gravels. As shown in the increase in SS downstream, the surface of clay in the bottom is always eroded; thus, the clay is not a stable substrate for algal growth. The natural surface of the clay bottom may be another factor controlling population density.

Benthic Invertebrates

Benthic invertebrate species collected from the channel are listed in Table 7. There were nine insects and seven other small invertebrates. Chironomidae were the most common insects. It must be noted that the population density decreased from spring to autumn, after an insect growth regulator

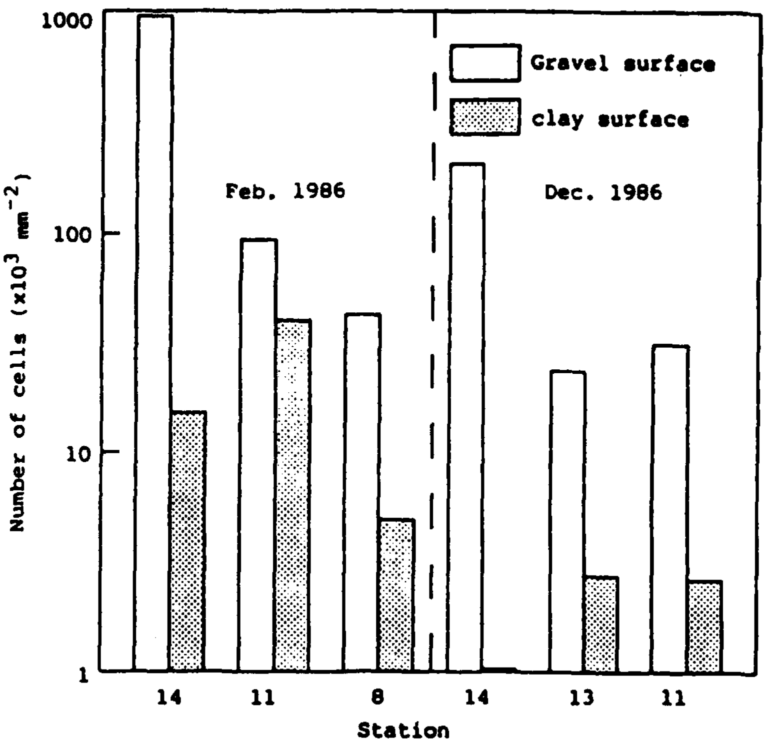

Figure 3. Number of periphyton on gravel and clay

TABLE 7. BENTHIC INVERTEBRATES COLLECTED FROM THE NOBIDOME CHANNEL

Type	Species
Insects	*Chironomus yoshimatui*
	Glyptotendipes sp.
	Chironomidae Gen. sp. 1-8
	Sumilium uchidai
	Psychoda alternata
	Cheumatopsyche brevilineata
	Antogaster siebordii
	Odonata sp.
	Baetis sahoensis
Others	*Asellus hilgendorfii*
	Gammarus nipponensis
	Physa acuta
	Erpobdellidae Gen. sp.
	Branchiura sowerbyi
	Tubifex sp.
	Nais sp.

was applied to satisfy the complaints of residents about flies. Representative species, such as *Chironomus yoshimatui*, are well known as pollution-tolerant species. They can live even under high BOD values, as much as 70 mg/ℓ (Kaneda and Kobayashi 1986). This biological indicator also demonstrates that the channel must be regarded as polluted.

CONCLUSIONS

Comprehensive surveys of water quality and benthic invertebrates were conducted in the Nobidome Channel, into which filtered secondary wastewater was introduced to restore the waterfront. Specific conclusions were as follows:

a. Suspended solid concentration increased downstream along the flow by the erosion of the bank and clay bottom, and the channel could not be maintained as clear running water. Self-purification was not noted for organic substances.

b. Dominant species of periphyton and benthic invertebrates were typical of polluted streams and coincided with poor water quality in the stream. Standing crops, however, were less than those observed in experimental channels receiving secondary effluent. Major controlling factors were the light conditions controlled by the growth and fall of leaves from the deciduous broad-leaved trees along the channel and the stability of the bottom sediments. Distribution of Chironomidae was strictly controlled by the repeated dosage of growth-inhibition chemicals.

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LONG-TERM MANAGEMENT STRATEGY FOR DREDGED MATERIAL RELOCATION OR DISPOSAL

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ABSTRACT

The Corps of Engineers (CE) has taken a major step in developing a technically sound strategy for management of dredged material. This strategy is intended to be applicable to the wide range of materials that are dredged in Federal navigation projects and other waterways throughout the Nation. This paper presents an overview of the technical management strategy with emphasis on the steps required to develop appropriate alternatives for the placement, relocation, or disposal of dredged material. The guidance and appropriate testing and evaluation procedures incorporate the state of knowledge acquired by the CE and others worldwide in the dredging and long-term management of clean, contaminated, and toxic sediments. The CE is refining the technical management strategy and has performed selected field evaluations to demonstrate the appropriateness of the strategy. Interim results of the field verification studies are also discussed in this paper.

INTRODUCTION

The National Dredging Program includes the maintenance and development of approximately 25,000 miles (40,000 km) of Federal waterways that flow through 42 states and serve 130 of the Nation's largest cities. Most of the navigation channels in the waterways require periodic dredging to maintain safe and efficient operating conditions for maritime traffic. Only one estuary, Puget Sound in the State of Washington, has sufficient natural depth to accommodate large ships engaged in commercial international maritime activities. Thus, due to the significant economic and defense importance of this extensive navigation system, it is usually not a question of whether to dredge, but rather, how to effectively dredge and relocate or dispose of the dredged material in an environmentally acceptable yet economic and efficient way.

Because terminology is important to convey the proper connotation, the XXVI International Congresses on Navigation (1985) passed a resolution that addressed the negative impact of terminology such as the use of the term "spoil" instead of the more positive term "dredged material." Recognizing the importance of this matter, interchangeable words such as "placement" and "relocation" are introduced in the text of this paper to supplement the traditionally used word "disposal."

Obviously, there is a critical need to develop a logical, technically valid, and systematic approach to evaluate relocation or disposal alternatives for dredged material. Since the nature and level of contamination in sediment vary greatly on a project-to-project basis, the appropriate method of disposal or placement may involve any of several options. Control measures to manage specific problems associated with the presence or mobility of contaminants may be required as a part of any given alternative. Further, many states, in an effort to fully manage their natural resources, expect CE assistance via a long-term approach to operating and managing dredged material relocation areas and providing additional storage capacity.

An overall long-term management strategy for dredged material, therefore, is required. Such a framework for decisionmaking must include a technical management strategy with appropriate testing protocols and design procedures to aid in selecting the best possible relocation or disposal options and to identify appropriate control measures to offset any problems associated with the presence of contaminants (Francingues and Palermo 1984).

The diversity of relocation alternatives and techniques for managing dredged material requires a comprehensive yet flexible strategy for selecting environmentally and cost-effective placement or disposal options (Palermo et al. 1986). The selection of an appropriate strategy will depend on a variety of factors including:

a. Project size.

b. Available dredging equipment and placement techniques.

c. Physical characteristics of dredged material.

d. Nature and level of contaminants present.

e. Site-specific placement conditions.

f. Technical feasibility of relocation alternatives.

g. Potential environmental impacts of relocation operations.

h. Economics.

i. Social, political, and regulatory considerations.

TECHNICAL MANAGEMENT STRATEGY

The two major features of the technical management strategy are consideration of placement or disposal options and steps required for selection and implementation of appropriate dredged material management practices (see Figure 1) (Francingues et al. 1985). The required steps are as follows:

a. Conduct an initial evaluation to assess contamination potential.

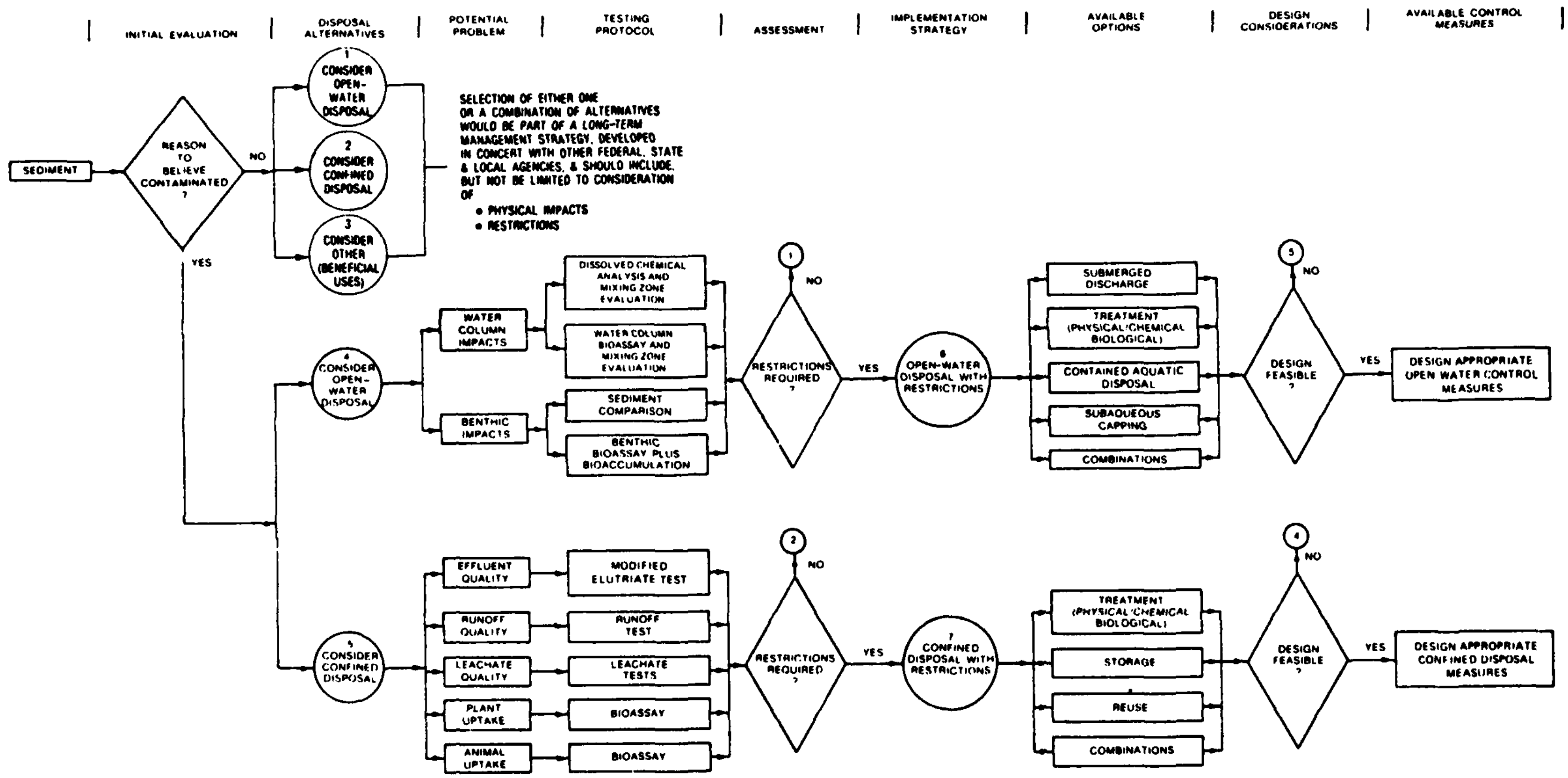

Figure 1. Management strategy flowchart

b. Select a potential placement or disposal option.

c. Identify potential problems associated with that option.

d. Apply appropriate testing protocols.

e. Assess the need for placement or disposal restrictions.

f. Select an implementation strategy.

g. Identify available control alternatives.

h. Evaluate design considerations for technical and economic feasibility.

i. Select appropriate control measures.

Each step of the strategy will be discussed in the following paragraphs.

Conduct an Initial Evaluation

The initial screening for contamination is designed to determine if there is reason to believe the sediment contains any contaminants in forms and concentrations that are likely to cause degradation of the environment, including potential availability to organisms in toxic amounts. This screening procedure also identifies specific contaminants of concern in a site-specific sediment, so that subsequent testing and analyses are focused on the most pertinent contaminants.

Initial considerations may include but are not limited to:

a. Potential routes by which contaminants could reasonably have been introduced to the sediments.

b. Data from previous bulk sediment analysis and other tests of the material or other similar material in the vicinity, provided the comparisons are still appropriate.

c. Probability of contamination from agricultural and urban surface runoff.

d. Spills of contaminants in the area to be dredged.

e. Industrial and municipal waste discharges.

f. Source and prior use of dredged material.

g. Substantial natural deposits of minerals and other natural substances.

Select a Potential Placement Option

The two major placement or disposal options identified in Figure 1 are aquatic (subaqueous) and upland. A number of variations exist for each of the major options, each having some influence on the fate of contaminants at disposal sites. Environmentally sound placement or disposal of dredged material can be achieved using any of the major options if appropriate management practices are used. The selection of a relocation option should be based on evaluation of specific contaminant problems using accepted testing methodology and procedures designed specifically for dredged material evaluations. Research and experience have shown that, in most cases, procedures developed to evaluate disposal practices for industrial waste, domestic sewage, etc., are not applicable to the assessment of dredged material.

Identify Potential Problems

Each placement option may pose potential problems for managing contaminated dredged material. Potential contaminant problems can be identified after the initial evaluation and consideration of site-specific conditions, dredging methods, and anticipated site use. For aquatic sites, contaminant problems may be either water quality related (water column) or sediment related (benthic environment). For upland sites, potential contaminant problems may be either water quality related (effluent, surface runoff, or leachate), contaminant uptake related (plants or animals), or air related (gaseous emissions).

Apply Appropriate Testing Protocols

The magnitude and potential impacts of specific contaminant problems must be evaluated using appropriate testing protocols. Such protocols, designed for evaluation of dredged material, consider the unique nature of dredged material and the physicochemical conditions of each relocation or placement option under consideration. The type of testing of the contaminated sediment to be dredged depends on which of the questions in Figure 2 is being addressed.

Testing intended to answer the question "Where should sediment be placed to minimize contaminant mobility?" is site selection testing and addresses the situation in which aquatic sites as well as upland or nearshore confined sites are available. The emphasis is on selecting the most appropriate environment for the placement of dredged material.

Testing intended to answer the question "Is the available site acceptable for dredged material?" is acceptability testing and addresses the situation where there are limitations on available sites. Therefore, the sediment is tested to determine the acceptability of a given site for the placement or disposal of the sediment. For example, if the only sites available are confined inland sites, then testing should focus on upland environments and not on aquatic environments. Ultimately, the testing should be tailored to the available relocation or disposal site.

Assess Need for Placement or Disposal Restrictions

The results of all testing are compiled and evaluated to determine the potential for environmental harm from contamination, to examine the interrelationships of the problems and potential solutions, and to determine what restrictions or controls on aquatic placement or upland placement are appropriate. If impacts as evaluated by the testing protocols are acceptable, traditional aquatic or upland placement may again be considered.

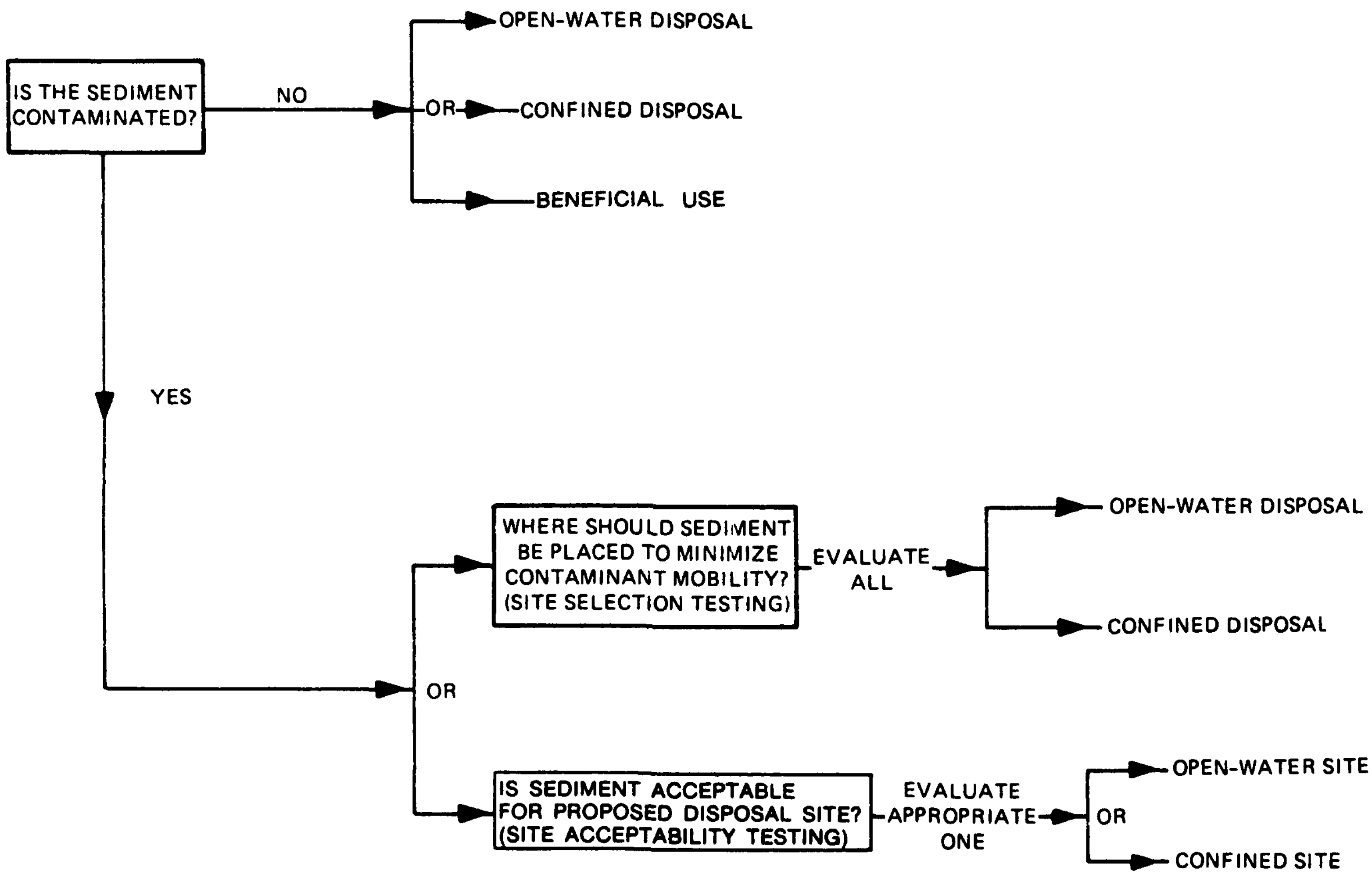

Figure 2. Initial questions to be addressed for testing of contaminated sediments

Select an Implementation Strategy

Specific environmental problems identified by the testing protocols must be considered in the development of an implementation plan appropriate for dredged material and appropriate for the level of potential contamination. Certain strategies may be eliminated from consideration due to restrictions and local authority decisions or agreements.

Identify Available Control Alternatives

Several alternatives may be available for the selected implementation strategy. Alternatives for controlling water column and benthic impacts include bottom discharge via submerged diffusers, treatment, confined aquatic disposal, and subaqueous capping using cleaner sediment. Alternatives for controlling confined disposal impacts include treatment, long-term relocation, and dredged material reuse.

FIELD VERIFICATION AND APPLICATION

Several examples can be cited where the CE has applied the technical management strategy to assist in the evaluation of dredged material disposal or relocation. For example, applications for Puget Sound, in the State of Washington, include the Commencement Bay Superfund project, the Puget Sound Dredged Disposal Analysis (PSDDA) study, and the US Navy Homeport facility at Everett, Wash.

To provide assistance in interpreting test data on dredged material and in making decisions associated with the high cost of remedial action, a decisionmaking framework was developed for proposed dredging in Commencement Bay (Lee et al. 1985). The framework focuses on procedures for answering the questions of how dredged material should be tested and how the results should be interpreted to determine the degree of potential contaminant mobility and the placement option that would have the least adverse impact on the overall environment.

Also, as part of the PSDDA study, the second component of the technical management strategy was developed to assist in evaluating various dredging, transportation, and disposal alternatives for contaminated dredged material (Cullinane et al. 1986). These guidelines provided a strategy for selecting control and treatment options for contaminated dredged material that requires restrictions. This "dredged material alternative selection strategy" is intended to provide a general approach to selection while allowing as much detail as possible to guide decisionmakers through the process of formulating and choosing an appropriate dredging/transportation/disposal alternative.

The initial field application of the technical management strategy in Puget Sound was to dredging for the Navy Homeport facility at Everett, Wash. In June 1984, the Navy contracted with the CE to provide technical assistance for dredging and disposal of the dredged material. The CE applied the suite of tests specified in the strategy to assess the requirements for dredged material placement or disposal. Results of the tests have been critical to decisionmaking and final design of the Navy's dredging plans.

In addition to the Puget Sound application, the CE has applied appropriate portions of the technical management strategy to several key projects. These projects include the Indiana Harbor Canal in the Chicago District, the Corps/US Environmental Protection Agency Field Verification Program at Bridgeport, Conn., and the New Bedford Superfund site at New Bedford, Mass. Results of these efforts are being used to further refine the technical aspects of the overall management approach.

SUMMARY

A technically feasible and environmentally sound management approach to the relocation or disposal of dredged material has been developed and presented. This strategy is based on results from many years of research and on dredging experience worldwide. The evaluative procedures allow specific potential problem areas to be defined and addressed. A number of variations are presented for each of the major options of aquatic, intertidal, nearshore, and upland placement, each having a significant influence on the fate of contaminants at relocation sites. The strategy provides a framework for choosing an appropriate alternative for placement or disposal based on specific problem areas. It is applicable to materials ranging from clean sand to highly contaminated sediments.

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REMOVAL OF NITROGEN AND REFRACTORY ORGANIC COMPOUNDS IN MUNICIPAL LANDFILL LEACHATE BY SEQUENCING BATCH REACTOR ACTIVATED SLUDGE PROCESSES

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ABSTRACT

Laboratory-scale experiments on aerobic/anaerobic operations of the sequencing batch reactor (SBR) activated sludge processes, in which methanol was added as a hydrogen donor, were conducted to remove nitrogen and refractory organic compounds in municipal landfill leachate. The NH_4-N concentrations in leachate from landfill ranged from 100 to 200 mg/ℓ. A high concentration of nonbiodegradable organic compounds (100 to 150 mg/ℓ as chemical oxygen demand (COD)) was observed in the leachate. Ninety-five percent or more nitrogen removal was achieved in the operation with an optimum length of aerobic and anoxic/anaerobic period for the nitrification-denitrification process. Fifty percent or more removal of refractory organic compounds was achieved by the SBR activated sludge process with the addition of ozonation pretreatment.

INTRODUCTION

An increasing amount of municipal and industrial solid waste is being disposed. This waste is incinerated, shredded or baled, and then landfilled. The landfill sites discharge large amounts of leachate that contains nitrogen and refractory organic compounds, resulting in the pollution of ground water (subsurface formations and aquifers) at the landfill sites (Robertson, Toussaint, and Jorque 1974; US Environmental Protection Agency 1978). It is urgent, therefore, that this situation be remedied by establishing an effective method of treating leachate that contains high concentrations of nitrogen and refractory organic compounds.

There are two types of methods to reduce the nitrogen in leachate: (a) biological treatment consisting of nitrification-denitrification processes and (b) physical and chemical treatment. The first type is considered preferable because it costs less, produces N_2 gas as the final product, and can effectively treat nitrogen in various forms. Existing leachate treatment facilities at land disposal sites have been making use of rotating biological contactors, a biological filter method, because of the ease of maintenance and the nitrification efficiency. The most significant problem with this method is that salt in the leachate accumulates on the surface of disks and the rotary shaft as scales of gypsum and calcite, deteriorating the efficiency of treatment and power consumption and damaging the rotary shaft (personal communications, S. Matsui, 1984, and Y. Matsufiji, 1985). The second type is expensive, may result in another kind of pollution (i.e., the production of chemical sludges and increased NH_4-N gas concentration in air by ammonia stripping), and is capable of treating nitrogen in only limited forms (i.e., the breakpoint method can treat only NH_4-N in water).

The SBR activated sludge process with biological nitrification-denitrification has the following advantages: the device is less likely to be damaged by scales; maintenance is easy; sludge bulking is not likely; a wide range of pollutant load can be treated by selecting operations suitable for the pollution load (such as the time in a cycle and the length of aerobic and anaerobic period); and nitrogen and phosphorus can be removed at the same time (Goronszy 1979; Irvine and Busch 1979; Irvine, Miller, and Bhamrh 1979; Dazai, Fuutai, and Takahara 1982; Silverstein and Schroeder 1983; Okada and Sudo 1985). Also, it is said that even some nonbiodegradable halogenated organic compounds can be degraded by a biological treatment through the denitrification process under anoxic conditions (Bouwer and McCarty 1983). These are some of the reasons why the SBR activated sludge process is attracting so much attention for leachate treatment at landfill sites.

On the other hand, ozonation treatment, known to be effective for disinfection and the oxidation of organic compounds, has been found satisfactory for transforming high molecular weight compounds to low molecular weight compounds and also for increasing the biodegradability of organic substances (Glaze et al. 1982; Peyton et al. 1982; Sakumoto et al. 1984; Jones, Sakaji, and Daughton 1985). It is expected, therefore, that the SBR activated sludge processes will work more effectively for refractory organic compounds when used with pretreatment by ozonation.

Laboratory-scale experiments were conducted on aerobic and anoxic/anaerobic operations of the SBR activated sludge processes for leachate from a land disposal site to examine the effectiveness of this method in reducing the high concentration of nitrogen and refractory organic compounds contained in the leachate. The following points are discussed:

a. Seasonal changes in the chemical composition of the leachate from landfill sites.

b. The effectiveness of the SBR activated sludge processes combined with the Bringmann method (Sudo 1977), in which methanol is added to the leachate as a hydrogen donor, for removing the nitrogen in the leachate from the landfill site.

c. Comparative analysis of the effectiveness of two different methods (the SBR activated sludge processes with and without pretreatment by ozonation) in degrading refractory organic compounds.

EXPERIMENTAL PROCEDURES

Sampling and Chemical Analysis of the Leachate

The chemical composition of the leachate was examined every 10 days at a municipal landfill site, where noninflammable waste (plastics, glass, large-volume rubbish, etc.), sludge, and ash of food waste are disposed.

Table 1 shows the chemical properties measured and the methods used in analysis of the leachate (Japan Sewage Works Association 1985, Hosomi and Sudo 1986).

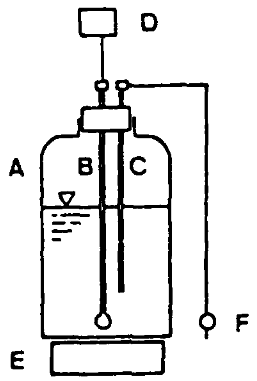
TABLE 1. METHODS FOR CHEMICAL ANALYSIS OF WASTEWATER

Property	Methods
Biological oxygen demand (BOD)	5-day BOD using the azide modification of the iodometric method
Chemical oxygen demand (COD)	Acid-potassium-permanganate method at 100° C
Total organic carbon (TOC)	TOC analyzer
Dissolved oxygen (DO)	Azide modification of the iodometric method
pH	pH meter
Alkalinity	Potentiometric titration to end-point pH
NH_4-N	Automated phenate method
$(NO_2 + NO_3)$-N	Automated cadmium reduction method
PO_4-P	Automated ascorbic acid method
Total nitrogen (T-N), total phosphorus (T-P)	Simultaneous determination of T-N and T-P using persulfate digestion
Suspended solids (SS)	Glass-fiber filter method
Mixed-liquor suspended solids (MLSS)	Nonfilterable residue of a well-mixed sample of the suspension
Na, K, Mg, Ca	Inductively coupled argon plasma atomic emission spectrometry

Nitrogen Removal by the SBR Activated Sludge Processes

Experimental Apparatus

Figure 1 shows the apparatus used in the study. The reactor is a 10-ℓ glass bottle with a diffuser pipe and drain valve. An air pump is attached for aeration, and a magnetic stirrer for mixing. The reactor was kept in a thermostatic chamber at 20° ± 2° C.



A	Sequencing batch reactor
B	Diffuser pipe
C	Discharge and waste sludge
D	Air pump
E	Magnetic stirrer
F	Drain valve

Figure 1. Experimental apparatus for SBR activated sludge processes

Chemical Analysis of Treated Water

The same sample that was used for chemical analysis of the leachate was used as the influent of the SBR activated sludge processes. The sample was kept at 10° C until start-up of the SBR. Figure 2 shows the operational schedules. Runs 1-5 comprised preliminary study, for the purpose of determining appropriate operational conditions for removing nitrogen in the leachate. The result of Runs 1-5 was applied to Run 6 to affirm the efficiency of nitrogen removal from the leachate by the SBR. In Run 7, the NH_4-N loading was increased to further analyze the nitrogen removal efficiency of the SBR.

The chemical composition of the effluent and the water phase of mixed liquor of activated sludge in each run was measured by the analytical methods listed in Table 1.

Removal of Refractory Organic Compounds with Ozone Pretreatment

Figure 3 shows the experimental apparatus for ozonation (Labo70, Communitor Service). The ozonation reactor is a 10-ℓ cylindrical Plexiglas container with a height of 120 cm and a diameter of 12 cm. The air inflow was 170 ℓ/hr; the ozonizer power was 120 W; the reaction period was 30 min; and the reaction temperature was 10° C.

The same sample as described above for the nitrogen removal analysis was used. The sample leachate was first ozonated and then treated in the SBR. The operational schedules were the same as for Runs 6 and 7 described above.

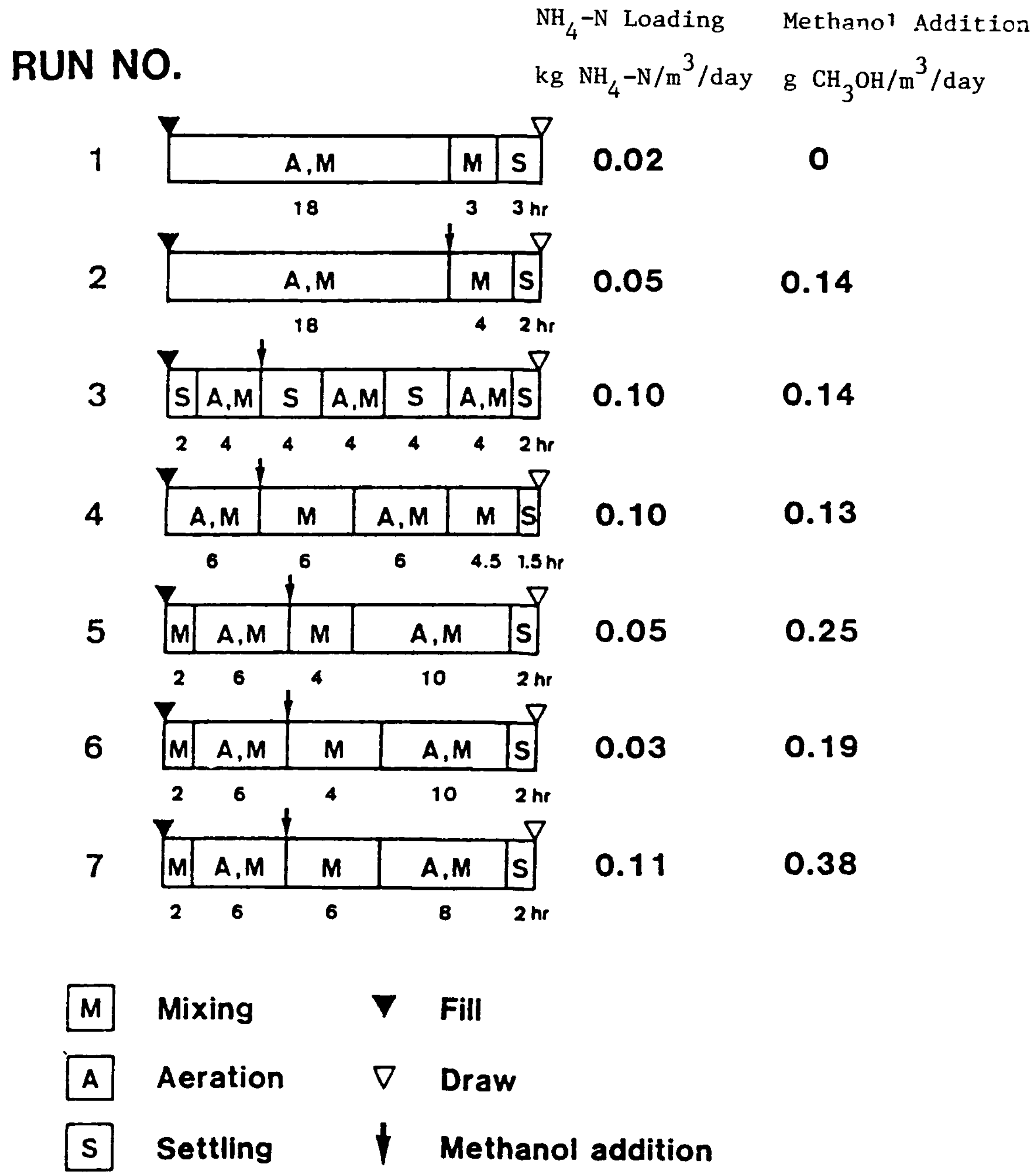


Figure 2. Operational schedules for the SBR activated sludge processes

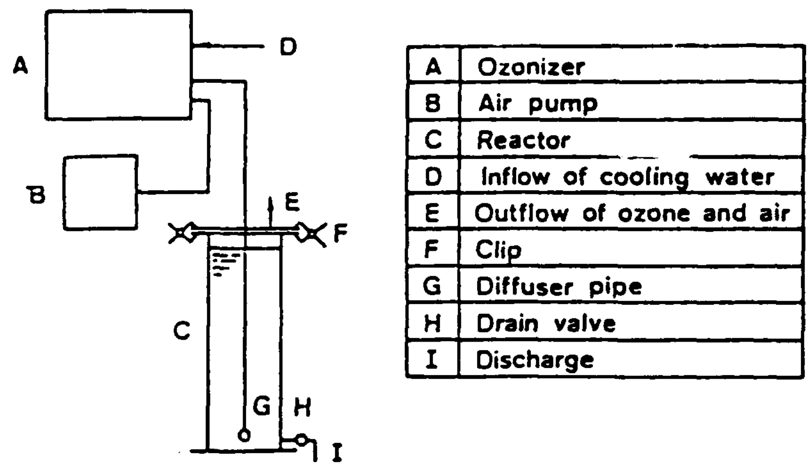


Figure 3. Experimental apparatus for ozonation

RESULTS AND DISCUSSION

Seasonal Changes in Chemical Composition of the Leachate

Figure 4 shows the seasonal variations in the concentrations of BOD, COD, TOC, and SS of the leachate. Figure 5 shows those of NH_4-N, NO_2-N + NO_3-N (NO_x-N), and T-N. Table 2 presents statistical data on each of the chemical compositions.

All compositions commonly showed larger values in the summer (July-August) than in autumn (September-November). One possible reason for this is

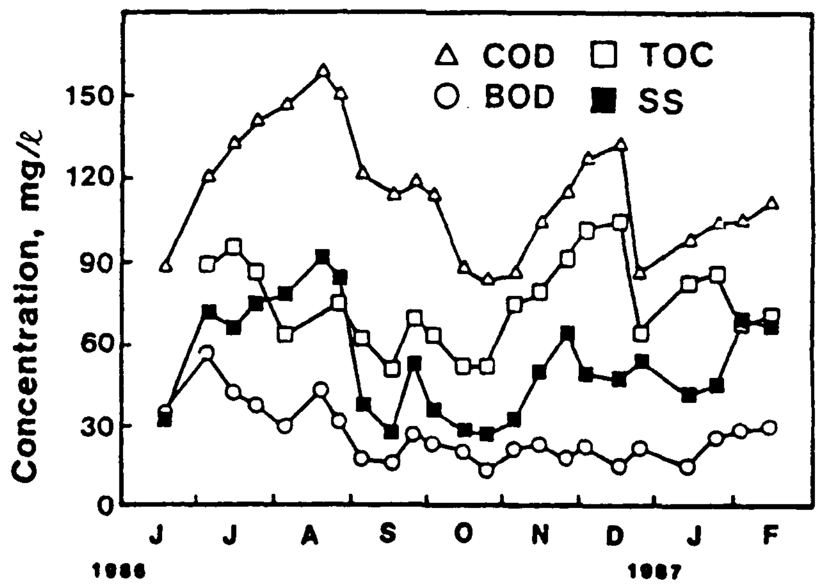


Figure 4. Seasonal variations in the concentration of BOD, COD, TOC, and SS of the leachate

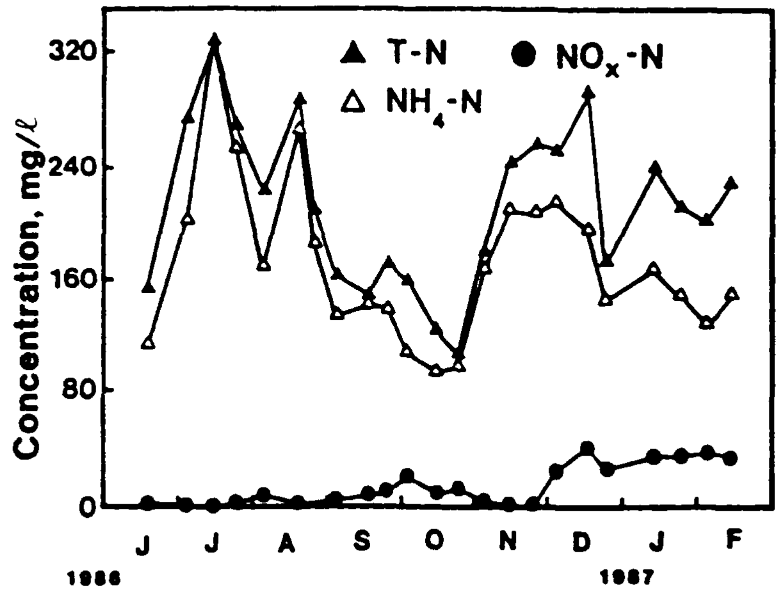


Figure 5. Seasonal variations in the concentrations of NH_4-N, NO_x-N, and T-N of the leachate

that the concentrations increased in the summer through the evaporative loss of water caused by higher temperatures and less precipitation. Another reason may be that the high temperatures accelerated anaerobic decomposition in the landfill site. The concentrations of COD and NH_4-N also increased in the winter. This is probably because of the lower precipitation in the winter.

The concentration of BOD varied from 13 to 57 mg/ℓ, with an average of 27 mg/ℓ, lower than that obtained at landfill sites where the main waste is ash (Matsufuji, Hamajima, and Yanase 1982). This indicates that the landfill site chosen for the experiment had a very small amount of biodegradable organic compounds. The concentration of COD was about 100 mg/ℓ, much higher than that of BOD. The ratio of BOD to COD was therefore 0.2:0.3, much smaller than that in domestic wastewater. From these facts, we can assume that the sampled leachate contained many nonbiodegradable organic compounds, i.e., refractory organic compounds. Thus, considering the extremely small BOD value, the refractory organic compounds in the sample leachate can be represented by COD and TOC values.

Total nitrogen varied around 200 mg/ℓ, with a coefficient of variation of 26 percent, greater than the variations in COD and BOD concentrations. The NH_4-N accounted for 90 percent of the total nitrogen. Actually, the seasonal change in total nitrogen concentration was consistent with that of NH_4-N concentration, which was high in the summer and winter and low in the autumn, similar to that of COD concentration, which varied around 170 mg/ℓ. Also, the NH_4-N concentration showed a high correlation with alkalinity, with a coefficient of correlation of 0.85.

Total phosphorus was between 0.33 and 5.8 mg/ℓ. The PO_4-P concentration was about 0.03 mg/ℓ, which shows that most of the phosphorus contained in the leachate was particulate phosphorus. The ratio of nitrogen to phosphorus was over 100, much greater than that of domestic wastewater, which indicates that phosphorus is the limiting nutrient in biological treatment.

The pH showed only a small seasonal variation around 7.8. Alkalinity showed a large seasonal variation, from 524 to 1,730 mg/ℓ, similar to the NH_4-N concentrations.

The concentrations of major cations such as Na and Ca were very high, as shown in Table 2, indicating that scales of gypsum and calcite could easily be formed.

TABLE 2. WATER QUALITY DATA FOR MUNICIPAL LANDFILL LEACHATE, MAY 1986-FEBRUARY 1987

Parameter	Maximum mg/ℓ	Minimum mg/ℓ	Average mg/ℓ	Median mg/ℓ	S.D. mg/ℓ	No. of Samples
COD	158	83.5	114	114	21.5	24
BOD	57	14	26.5	23	10.4	24
TOC	105	51	74.1	71	15.4	24
SS	93	27	52.8	50	19.4	24
NH_4-N	327	93	172	167	57.2	23
NO_x-N	41	0.36	13.6	8.4	13.6	23
T-N	330	107	211	211	55.9	23
PO_4-P	0.13	0.004	0.03	0.020	0.03	23
T-P	5.8	0.33	1.53	0.73	1.79	23
Alkalinity	1,750	524	1,026	922	345	22
pH	8.77	7.35	7.84	7.78	0.33	24
Na	1,683	1,201	1,524	1,638	191	7
K	1,067	786	972	1,010	103	7
Mg	115	86.9	103	101	10.0	7
Ca	133	95.3	114	108	15.0	7

Nitrogen Removal

Runs 1-5

In the preliminary study (Runs 1-5), the time in a cycle, the amount of methanol addition, and the length of each aerobic and anoxic period, i.e., the length of the mixing periods with and without aeration, were changed from run to run. The results showed that:

a. The nitrogen was removed little by the Wuhrmann method, which makes use of the endogenous respiration of activated sludge as a hydrogen donor to denitrify the contained NO_x-N.

b. Enough methanol should be added so that the ratio of methanol to NH_4-N is greater than 2.5.

c. More than 90 percent of the T-N can be removed, if NH_4-N loading is less than 0.05 kg NH_4-N/m^3/day and both the anoxic and aerobic periods are longer than 4 hr.

Run 6

Figure 6 shows the concentration of T-N in the influent and effluent with the passage of time in Run 6. Run 6a shows the concentration of T-N in the effluent when no preliminary treatment by ozonation has been conducted on the influent. Run 6b shows the concentration of T-N in the effluent when an ozonated sample is used for the influent. In each case, the concentration of T-N leveled off 10 days later. Table 3 shows the nitrogen concentration in the influent and effluent and the percent of T-N removal in the steady state after the passage of this time.

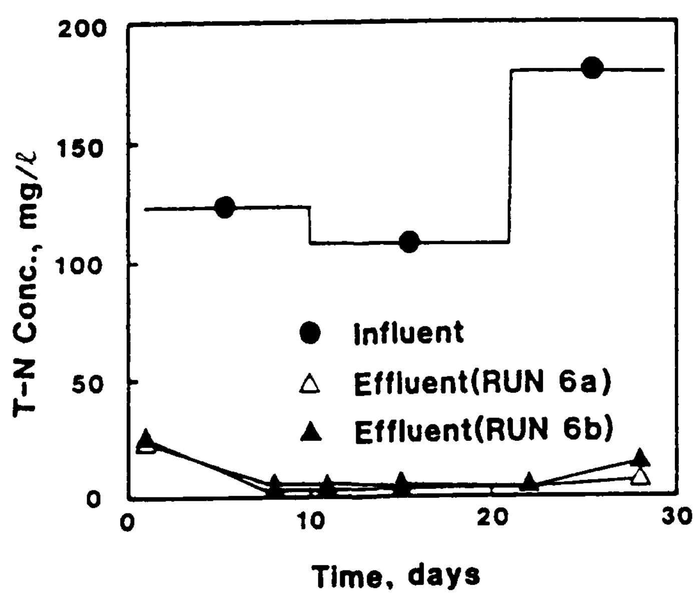


Figure 6. Concentrations of T-N in the influent and effluent in Run 6

TABLE 3. AVERAGE INFLUENT AND EFFLUENT DATA FOR RUN 6 DURING STEADY-STATE PERIOD

Parameter	Influent	Effluent Run 6a	Effluent Run 6b
NH_4-N, mg/ℓ	96.4	0.04	0.05
NO_x-N mg/ℓ	13.8	0.02	0.03
T-N, mg/ℓ	107	4.4	3.4
T-N removal, %	--	95.9	96.8

The concentrations of NH_4-N and NO_x-N in the effluent were less than 1 mg/ℓ for the influent both with and without ozonation pretreatment. The organic nitrogen concentration was 2 to 5 mg/ℓ. The T-N removal was very high, at 96 percent in Run 6a and 97 percent in Run 6b.

Figure 7 shows the track data of NH_4-N, NO_x-N, and PO_4-P concentrations in the water phase of mixed liquor of activated sludge over a cycle of the process. The NH_4-N concentration decreased linearly from 31 to 1 mg/ℓ after the mixing with aeration started. The NO_x-N concentration linearly increased with the decrease in NH_4-N, from 3 to 30 mg/ℓ, and started decreasing just

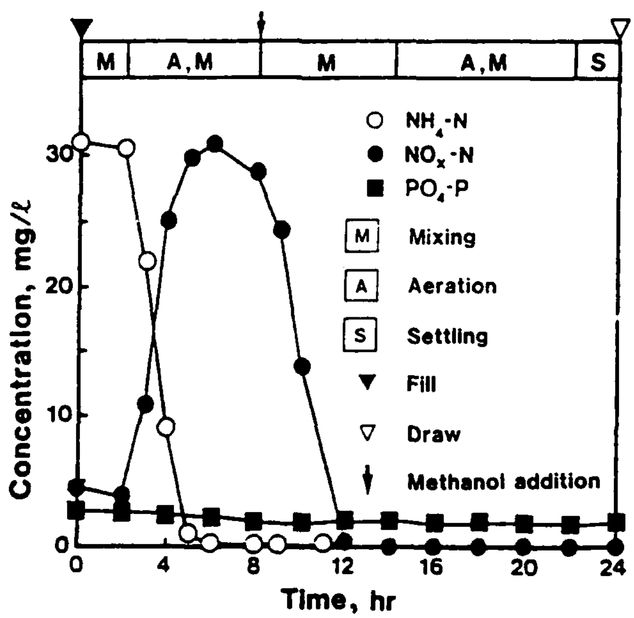


Figure 7. Track data of NH_4-N, NO_x-N, and PO_4-P concentrations in the water phase of mixed liquor of activated sludge over a cycle of operation in Run 6a

after methanol was added until it became 0 mg/ℓ 4 hr later. The PO_4-P concentration remained steady at 2 to 3 mg/ℓ, which indicates that the amount of PO_4-P added can be even less.

Excess sludge was removed only at the time of chemical analysis of water both in Run 6a and Run 6b. The MLSS concentration was maintained at about 3,500 mg/ℓ.

Run 7

The NH_4-N loading was increased approximately three times that in Run 6. Figure 8 shows the track data of the T-N concentration in the influent and effluent water. The influent was not pretreated by ozone in Run 7a, whereas the influent was ozonated in Run 7b. The T-N concentration decreased from the beginning and became almost constant 30 days later.

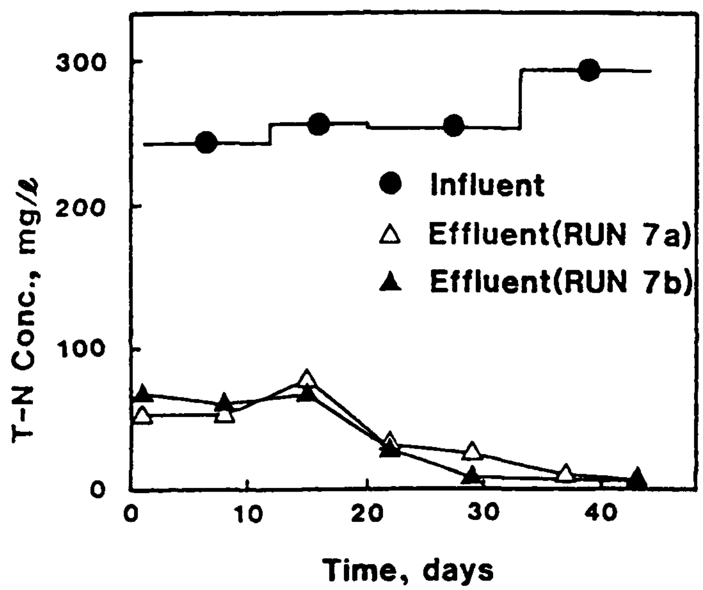


Figure 8. Concentrations of T-N in the influent and effluent in Run 7

Table 4 shows the average influent and effluent nitrogen concentrations and percent of T-N removal during the steady-state period. In Run 7a, the residual NO_x-N concentration was greater than 11 mg/ℓ, and the percent of T-N removal was less than that in Run 6 at 91 percent. However, Run 7b showed the same T-N removal as Run 6, although the NH_4-N loading was approximately three times.

Figure 9 shows the track data of NH_4-N, NO_x-N, and the PO_4-P concentrations for a cycle of the operation in Runs 7a and 7b. In Run 7a, not all of the NH_4-N was nitrified during the aerobic period. This is because nitrification was inhibited by the decrease in pH value down to 5.2. As a result, less

TABLE 4. AVERAGE INFLUENT AND EFFLUENT DATA FOR RUN 7 DURING STEADY-STATE PERIOD

Parameter	Influent	Effluent	
		Run 7a	Run 7b
NH_4-N, mg/ℓ	215	0.02	0.04
NO_x-N, mg/ℓ	23.6	11.1	0.23
T-N, mg/ℓ	253	22.6	7.5
T-N removal, %	--	91.0	97.0

nitrogen was removed during the following anoxic period than otherwise, i.e., in the case of enough nitrification. Because of this, less alkalinity was produced during the process of denitrification than supposed.

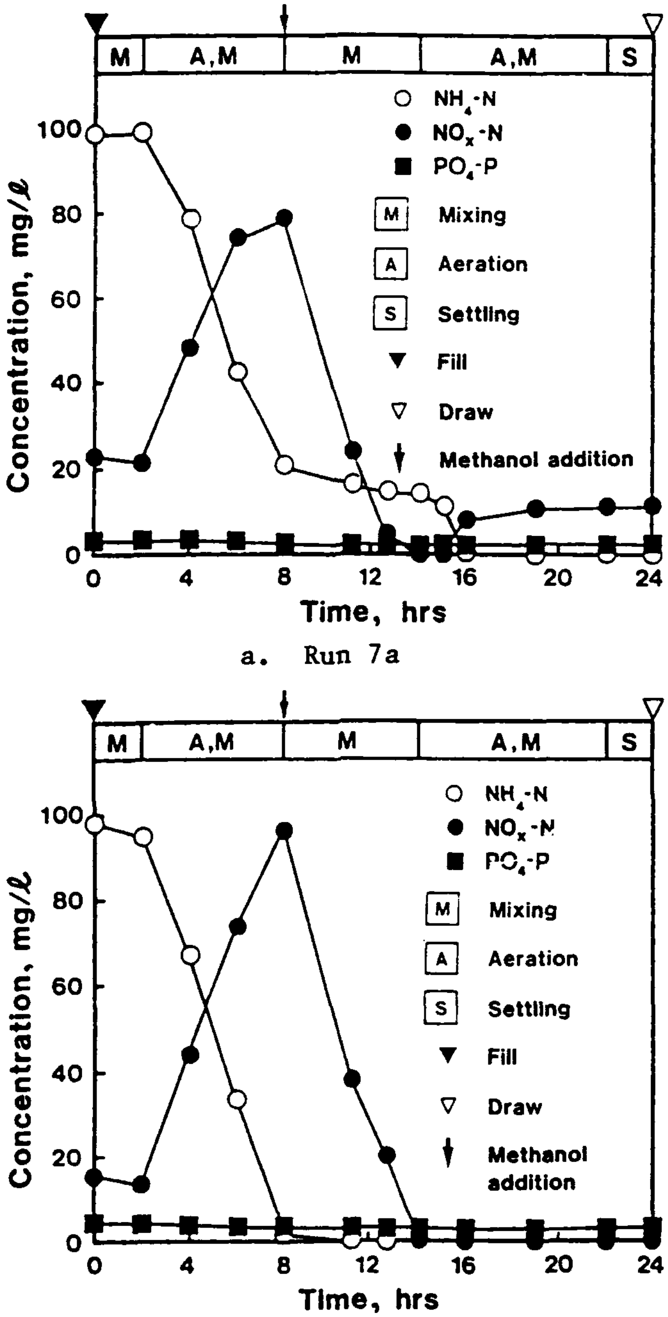
The average alkalinity and NH_4-N concentration during the steady state in Run 7 were 1,400 mg/ℓ and 215 mg/ℓ, respectively. Theoretically, 7.14 g of alkalinity is required to nitrify 1 g of NH_4-N. There was a lack of alkalinity in the water in Run 7. In Run 7b, however, alkalinity slightly increased, and NH_4-N concentration slightly decreased because of ozonation. Also, more alkalinity was produced during the process of denitrification than in Run 7b, which was why the alkalinity was high enough in Run 7b.

In Run 7, the amount of sludge removal was only that necessary for a chemical analysis of the water phase in mixed liquor, as in Run 6. The MLSS concentration remained almost constant at around 3,500 mg/ℓ. Solid retention time ranged from 20 to 50 days, which implies that the sequencing batch treatment of landfill site leachate produces very little excess sludge. Also, protozoa and metazoa such as *Philodina* and *Vorticella*, which are dominant in the flora that appears during this process (Table 5), helped decrease the excess sludge (Sudo and Aiba 1984).

Table 6 shows the rates of nitrification and denitrification calculated from the track data of NH_4-N and NO_x-N concentrations in a cycle of operation in Runs 6 and 7. These values are close to those for anoxic and aerobic sludge from domestic wastewater treatment plants.

Removal of Refractory Organic Compounds

As discussed with regard to seasonal changes in chemical composition, concentrations of organic compounds determined by TOC or COD in the leachate should be considered to be mostly nonbiodegradable substances because BOD concentration is very small. Figure 10 shows the performance of Run 6 in removing refractory organic compounds represented by COD and TOC concentrations in the influent and effluent water. Figure 11 shows the corresponding data for Run 7. Slightly different conclusions regarding the effectiveness of this



a. Run 7a

b. Run 7b

Figure 9. Track data of NH_4-N, NO_x-N, and PO_4-P concentrations in the water phase of mixed liquor of activated sludge over a cycle of operation in Runs 7a and 7b

TABLE 5. MICROFLORA IN SBR ACTIVATED SLUDGE PROCESSES, RUN 7

Species	Population Number/ mg MLSS Run 7a	Population Number/ mg MLSS Run 7b
Small flagellata	139	60
Trachelophyllum pusillum	35	120
Acineta lacustris	17	
Cyclidium sp.	295	15
Vorticella microstoma	555	467
Oxytrica sp.	17	
Euglypha sp.	17	15
Philodina sp.	35	251
Nematoda sp.		5

TABLE 6. RATES OF NITRIFICATION AND DENITRIFICATION IN SBR ACTIVATED SLUDGE PROCESSES

Run No.	Rate of Nitrification mg N/g MLVSS*/hr	Rate of Denitrification mg N/g MLVSS/hr
6a	2.6	2.6
6b	3.0	3.0
7a	4.7	6.0
7b	4.6	4.9

* Mixed-liquor volatile suspended solids.

method in removing refractory organic compounds can be drawn from the COD- and TOC-based analyses. However, it can be said that concentrations of both TOC and BOD in the effluent were in a steady state in each run.

Table 7 shows the performances of Runs 6 and 7 in removing refractory organic compounds. The BOD concentrations of the effluent are 1 to 3 mg/ℓ whether the leachate was ozonated or not. This means that most of the easily biodegradable organic compounds in the leachate and methanol added first in anoxic period were removed. On the other hand, ozonation proved to be

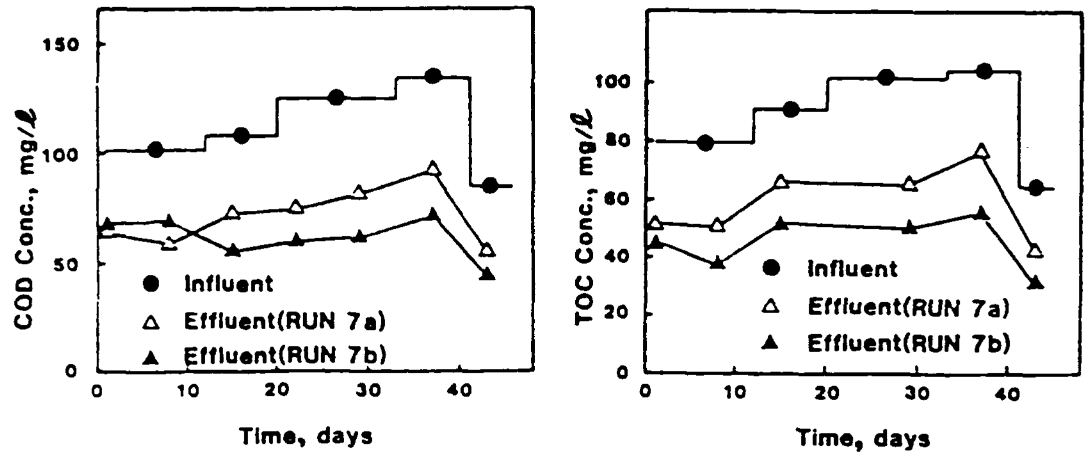


Figure 10. Concentrations of COD and TOC in the influent and effluent, Run 6

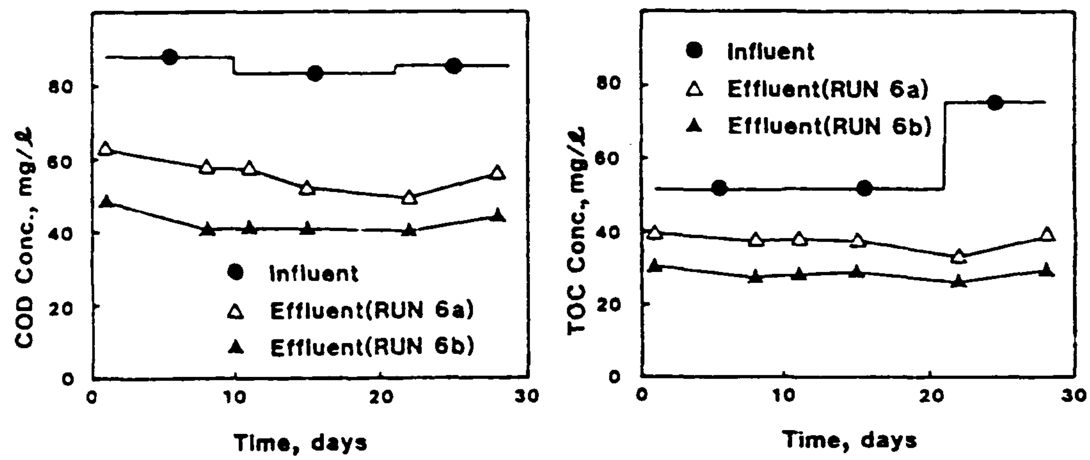


Figure 11. Concentrations of COD and TOC in the influent and effluent, Run 7

TABLE 7. AVERAGE INFLUENT AND EFFLUENT DATA FOR RUNS 6 AND 7 DURING STEADY-STATE PERIOD

Parameter	Influent Run 6	Effluent Run 6a	Effluent Run 6b	Influent Run 7	Effluent Run 7a	Effluent Run 7b
COD, mg/ℓ	83.5	52.1	41.1	127	81.5	60.8
COD removal, %	--	37.6	50.8	--	35.8	52.1
TOC, mg/ℓ	51.7	37.5	29.0	102	65.4	42.6
TOC removal, %	--	27.5	43.9	--	35.8	50.1

effective in removing COD and TOC. The COD and TOC removals were 50.8 and 43.9 percent, respectively, with preliminary ozonation, compared with 37.6 and 27.5 percent, respectively, without ozonation in Run 6.

Figure 12 shows the results of fractionation by molecular weight by Sephadex G-50 gel in three different samples: the influent, the effluent treated by the SBR, and the effluent treated both by ozonation and the SBR. The figure shows that organic compounds were removed after each treatment. It is inferred from three different patterns of fractionation by molecular weight that sequencing batch treatment alone was effective in removing high molecular weight organic compounds that have a peak at approximately fraction number 7, and that the combination of ozonation and sequencing batch treatment was effective in removing low molecular weight organic compounds that have a peak around fraction number 14.

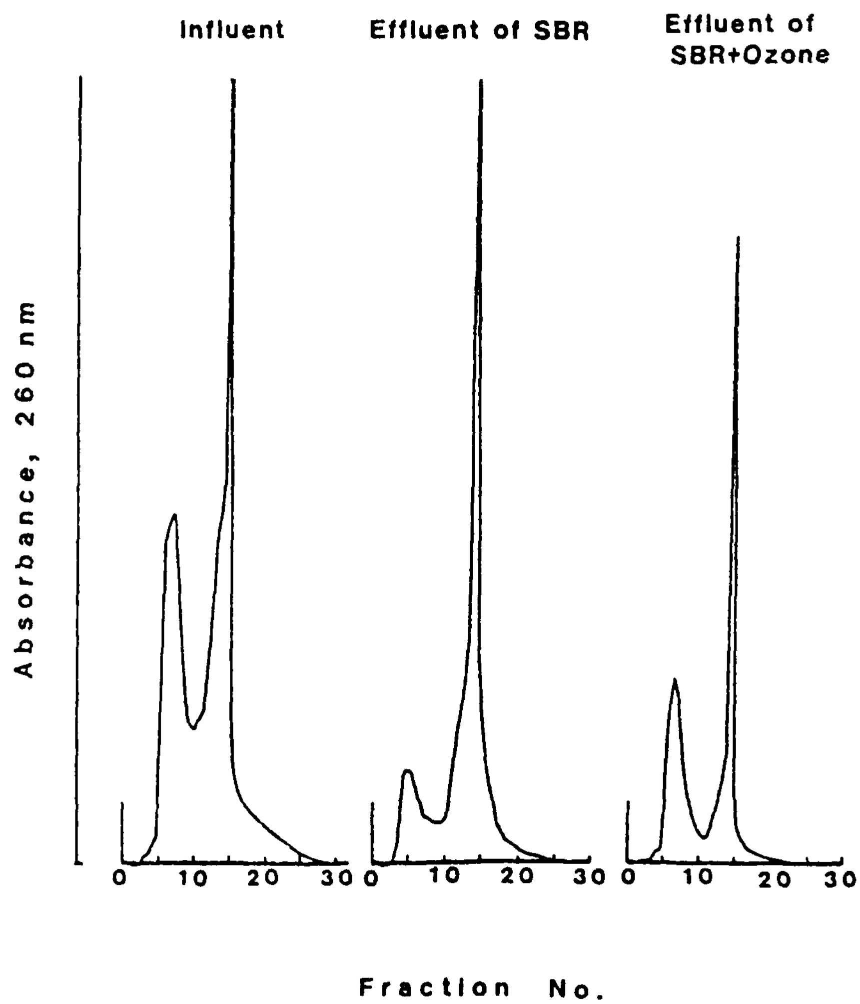


Figure 12. Fractionation by molecular weight by Sephadex G-50 gel

CONCLUSIONS

Laboratory-scale experiments were conducted on aerobic and anoxic/anaerobic operations of the SBR activated sludge processes with the addition of methanol as a hydrogen donor to efficiently remove nitrogen and refractory organic compounds in municipal landfill leachate.

NH_4-N concentrations in leachate from landfill ranged from 100 to 200 mg/ℓ. A high concentration of refractory organic compounds (100 to 150 mg/ℓ as COD) was observed in the leachate. Ninety-five percent or more nitrogen removal was achieved in the operation with an optimum length of aerobic and anoxic/anaerobic period for the nitrification-denitrification process. Fifty percent or more removal of refractory organic compounds was achieved by the SBR activated sludge processes with the addition of ozonation pretreatment.

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REGIONAL EFFORTS THROUGH THE IJC TO ADDRESS CONTAMINATED BOTTOM SEDIMENT PROBLEMS IN THE GREAT LAKES

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ABSTRACT

The International Joint Commission (IJC) is a binational (United States and Canada) organization that was established under the Boundary Waters Treaty of 1909. In 1978, the two countries signed a Great Lakes Water Quality Agreement, pursuant to the Boundary Waters Treaty. Carrying out the provisions of this Agreement, the United States and Canada, through the IJC, are addressing the problem of contaminated bottom sediments both in the traditional context of dredging projects and in the newer context of the potentially harmful environmental impacts of contaminated bottom sediments, even in the absence of dredging activity.

INTRODUCTION

The Great Lakes

The Great Lakes are located in the east-central part of North America, along the border between the United States and Canada (Figure 1). The Great Lakes system represents an enormous resource. The Great Lakes are the largest reservoir of fresh water in the Western Hemisphere. They contain almost 23,000 km^3 of fresh water. Taken together, the Great Lakes occupy over 240,000 km^2 of surface area. Their coastline totals over 15,000 km.

One-fifth of the entire US population and three-fifths of the Canadian population live in the Great Lakes basin (46 million people). The Great Lakes are the source of drinking water for 24 million people.

The commercial and sport fisheries total over \$160 million and \$1 billion per year, respectively, with about 2 million people participating in these activities. The sport fishing and recreation industries combined are estimated to add \$8 to \$12 billion to the Great Lakes economy annually. One-fifth of all US manufacturing and almost half of Canadian manufacturing is located in the States and Provinces along the Great Lakes.

The Great Lakes are interstate waters. Eight of the 50 United States are found along the shores of the Great Lakes--Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York.

Figure 1. Location of the Great Lakes

The Great Lakes are also international waters, forming a portion of the international boundary between the United States and Canada. One-half of the $150 billion annual trade between the United States and Canada starts and ends in the Great Lakes States and Provinces.

The International Joint Commission

Background

The United States and Canada realized the importance of the Great Lakes long ago. In 1909 they signed a treaty, called the Boundary Waters Treaty, to provide a way to resolve disputes between the two countries over the boundary waters, including the Great Lakes. An organization called the International Joint Commission (IJC) was formed to oversee adherence to the terms of the treaty.

In 1972, the United States and Canada signed a Water Quality Agreement specifically for the protection of the water quality of the Great Lakes. The IJC formed a Water Quality Board to oversee the implementation of the Agreement by the two countries. The Board, in turn, formed a number of Committees and Subcommittees charged with overseeing the implementation of specific tasks called for in the Agreement. The Board and its Committees and Subcommittees are staffed primarily by US and Canadian federal, state, and provincial government agency personnel.

Areas of Concern

To assist in tracking the attainment of the goals of the Water Quality Agreement, the IJC has designated a number of locations around the Great Lakes as "Areas of Concern" (Figure 2). These areas are typically harbors and river mouths in highly populated areas, where environmental problems have been identified. These geographical areas are designated as Areas of Concern because one or more beneficial uses of the water (such as for swimming, drinking, and propagation of a healthy fishery) are impaired. Evidence for this impairment is found in violations of water quality standards, criteria, or guidelines. There are 42 Areas of Concern around the Great Lakes.

As a step toward the restoration of beneficial uses in the Areas of Concern, the IJC has requested that the States and Provinces prepare Remedial Action Plans. The Remedial Action Plans are to lay out specific steps that need to be taken to fully identify the environmental problems of an area and to remedy those problems. The Plans are to include a time table for the required actions and are to identify the institutional mechanisms (laws, sources of funds, responsibilities) that will be used to implement the required actions.

Contaminated bottom sediments have been identified as a significant source of the environmental degradation in 38 of the 42 Areas of Concern (Figure 3). Increasingly stringent controls over other sources of pollution, such as direct discharges from wastewater treatment plants and manufacturing plants, will continue to reduce the loadings from these sources. This will serve to increase the visibility and relative significance of contaminated bottom sediments as a source of pollution problems. The need to take some kind of remedial actions on the contaminated sediments will become more urgent.

The various Areas of Concern exhibit the full range of problems caused by contaminated bottom sediments. Some of the more prominent illustrative examples include the following:

Sheboygan River, Wisconsin - Bottom sediments in the river are contaminated with polychlorinated biphenyls (PCBs). The source of the contamination is past discharges from an aluminum die-casting manufacturer. Fish caught in the river have the highest concentration of PCBs in the entire Great Lakes basin.

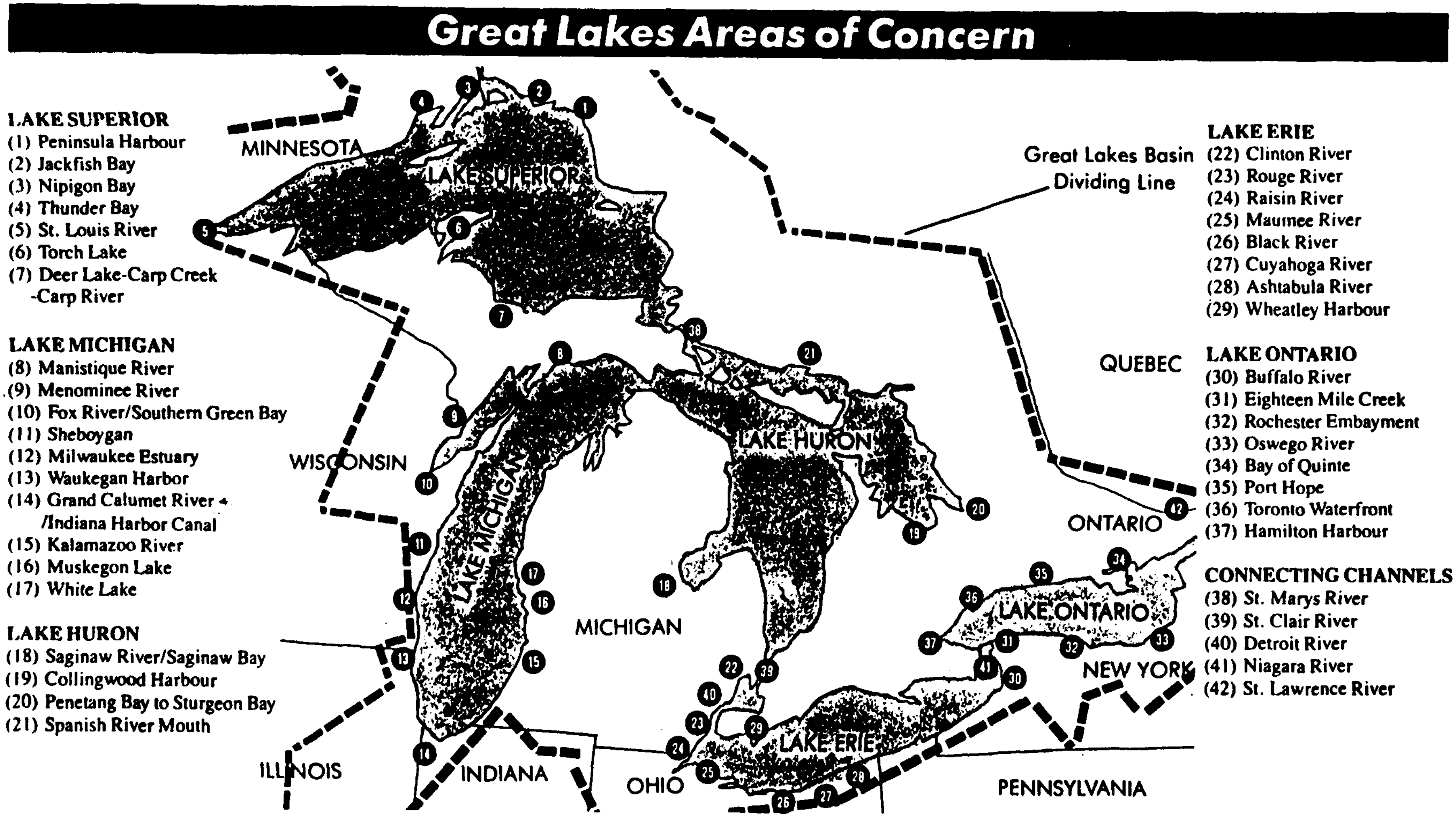
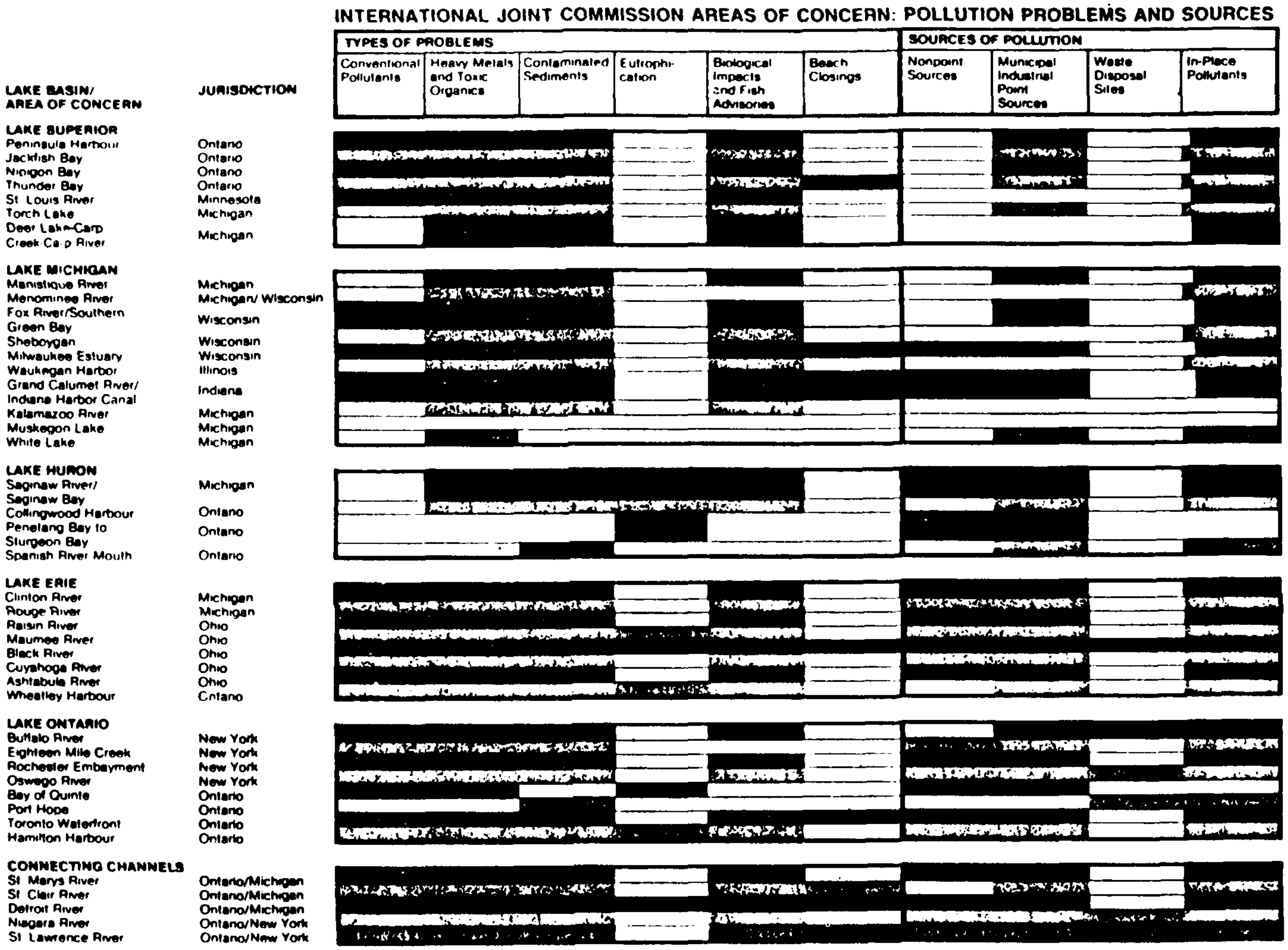


Figure 2. Great Lakes Areas of Concern designated by the IJC



SOURCE: Adapted from IJC 1985 REPORT ON GREAT LAKES WATER QUALITY. Report of the Water Quality Board. Kingston, Ont. 1985

INTERNATIONAL JOINT COMMISSION AREAS OF CONCERN. The IJC has identified 42 areas where the use of water has been impaired by continuous pollution or where the objectives of the Great Lakes Water Quality Agreement and local standards are not being achieved. Studies and remedial action plans are being undertaken for many of the areas.

Figure 3. Pollution problems and causes in the Great Lakes Areas of Concern. ("In-place pollutants" means contaminated bottom sediments)

Waukegan Harbor, Illinois - Bottom sediments in a slip of the harbor are contaminated with PCB concentrations up to 250,000 mg/kg. This is the highest known concentration of PCBs in sediments in the Great Lakes. The source of the contamination is past releases from another aluminum die-casting manufacturer.

Menominee River, Wisconsin and Michigan - Sediments in this river, which forms the border between Wisconsin and Michigan, are contaminated with very high concentrations of arsenic as a result of past releases from a manufacturer of herbicides.

Buffalo River, New York, and Black River, Ohio - Fish caught in these rivers have been found to exhibit a very high incidence of lip and liver tumors. The tumors are believed to be caused by the high concentrations of polycyclic aromatic hydrocarbons (PAHs) found in the river sediments. Discharges from coking operations at local steel manufacturing plants are believed to be the primary source of the PAHs.

Keweenaw Waterway, Wisconsin - Bottom sediments in the waterway are contaminated with very high concentrations of copper from past copper mining activities. The sediment is so toxic to benthic organisms that large parts of the bottom are a biological desert, devoid of any life.

St. Clair River and Lake St. Clair, Michigan and Ontario - The St. Clair River and Lake St. Clair system forms the border between the State of Michigan and the Province of Ontario. Fish caught in this waterway are contaminated with mercury and chlorinated styrenes. Sediments contaminated by discharges from chemical plants in Ontario near the head of the St. Clair River are the most likely cause of the fish contamination.

Port Hope Harbor, Ontario - Bottom sediments in this harbor are contaminated with uranium, radium, thorium, radioactive lead, heavy metals, and PCBs. The contamination is the result of local radium and uranium refining operations prior to 1948.

Toronto Harbor, Ontario - Sediments in parts of the harbor are highly contaminated with a variety of metals and synthetic organics. Benthic biota have bioaccumulated mercury, zinc, copper, chlorinated organic chemicals, including PCBs, and pesticides.

Thunder Bay Harbor, Ontario - A wood preserving operation in the north end of the harbor has contaminated the harbor sediments with a wide variety of toxic substances, including dioxins, furans, creosote, pentachlorophenol, and PAHs.

CONTAMINATED SEDIMENT ACTIVITIES

Past Actions Regarding Contaminated Sediments

The United States and Canada have given increasing recognition to the problems posed by contaminated sediments, and they have taken specific steps through the IJC to deal with them.

In the past, contaminated sediments in the Great Lakes basin have only been addressed in the context of dredging and disposal projects. When the sediments needed to be dredged, decisions had to be made about where to dispose of them. In particular, it was necessary to determine whether the dredged sediments were sufficiently free from contamination so that they could be disposed of in the open waters of the Great Lakes. The United States and Canada developed individual dredging and disposal guidelines for this purpose. The guidelines were empirically derived from a data base of bulk concentrations of chemicals in the harbors.

The Water Quality Agreement recognized the need for compatible guidelines between the two countries for evaluating dredging projects in the Great Lakes. The Agreement called for the establishment of a Dredging Subcommittee to develop these guidelines, in addition to other charges they were given regarding reporting on dredging and disposal activities in the Great Lakes. In 1982, the Dredging Subcommittee published their recommended guidelines for the evaluation of disposal options for dredging projects (IJC 1982). These guidelines were based upon the principle that disposal of the dredged sediments should not degrade the benthic quality of the main bodies of the Lakes. However, they were still only dredging guidelines and did not consider the situations in which the contaminated sediments were creating a problem by their mere presence in the waterway.

A Task Force of the Science Advisory Board of the IJC held an international conference on contaminated sediments in Aberystwyth, Wales, in August 1984. This was the first IJC activity that dealt specifically with the contaminated sediment issue outside the dredging context. A conference proceedings was published (Thomas et al. 1987).

With the subsequent emphasis on Remedial Action Plans for the Areas of Concern, the IJC sponsored a workshop on monitoring that was held in Burlington, Ontario, in October 1985. A report entitled "Guidance on Characterization of Toxic Substances Problems in Areas of Concern in the Great Lakes Basin" was produced based upon the results of that workshop (IJC 1987). This document addressed the entire range of pollution issues, including monitoring of point and nonpoint sources, as well as monitoring of sediment, water, and biological quality.

In 1986, as a result of the growing recognition of contaminated sediments as an issue to be addressed in a broader context, beyond that of navigational dredging, the Water Quality Board restructured the Dredging Subcommittee as the Sediment Subcommittee. The Sediment Subcommittee was given a broad Terms of Reference to address contaminated sediment issues of all kinds.

Guidance on Sediment Assessment and Remedial Option Selection

The IJC felt an urgent need to provide those responsible for preparing the Remedial Action Plans for Areas of Concern with guidance on how to address contaminated sediment problems. Therefore, it charged the Sediment Subcommittee with the preparation of a draft guidance document for presentation at a meeting of Remedial Action Plan Coordinators to be held in Toledo, Ohio, on November 19, 1987. The purpose of the guidance document is to assist the

Remedial Action Plan authors in designing the proper studies to assess contaminated sediment problems, and to provide guidance on how to select from among the possible actions that could be taken to remedy the problem.

The guidance document will recommend a set of tools to be used in problem assessment, including:

a. Physical tests to characterize the distribution, type, and quantities of sediments.

b. Chemical tests to determine the nature and degree of chemical contamination.

c. Laboratory and field test protocols to assess the biological impacts of the contaminated sediments, including tests of:

   (1) The acute and chronic toxicity of the sediments.

   (2) The bioaccumulation of chemicals by benthic and pelagic organisms.

   (3) The impairment of reproductive processes.

   (4) The induction of mutagenic or carcinogenic responses in biota.

The guidance document will also discuss the selection of remedial action alternatives. Among those that will be discussed are the following:

a. Removing the contaminated sediments from the water body.

b. Covering the contaminated sediments to isolate the contaminants from the water column.

c. Solidifying the sediments to reduce the mobility of the contaminants.

d. Decontaminating the sediments using some process to extract or separate the contaminants from the sediments.

e. Relocating navigation so that dredging and navigation do not disturb the contaminated sediments.

f. Taking no action and letting natural cleansing processes reduce the severity of the problem with time.

In conjunction with the remedial action options, the guidance document will discuss a number of disposal alternatives for contaminated sediments, should removal be needed as part of the process. Among the disposal options that will be considered are:

a. In-water unconfined disposal, which is the traditional type of disposal.

b. In-water confined disposal, which is disposal inside a diked area of the lake, often adjacent to the harbor breakwater structures.

c. Upland disposal, which is disposal in a bermed facility (possibly lined with clay or plastic) above the water table.

d. Deep-hole in-water disposal, which consists of disposing in an existing or excavated depression in the lake bottom to prevent the transport of the deposited sediments outside the disposal area.

e. Capping with clean sediment to isolate the contaminants from the overlying water column and to prevent the erosion and transport of the capped contaminated material.

f. Agricultural land application similar to the process used to dispose of sewage sludge.

g. Beach nourishment where lightly contaminated, coarse-grained material is used to rebuild an eroded beach.

This guidance document is only the first step by the Sediment Subcommittee in providing guidance on contaminated sediment issues. Some of the assessment techniques discussed, as well as remedial options identified, will become the focus of future efforts by the Sediment Subcommittee.

The Sediment Subcommittee will be hosting workshops to further refine the assessment criteria. The Subcommittee will conduct technology transfer workshops to identify and clarify the utility of emerging remedial options. Finally, the Subcommittee will promote the field-testing of the recommended assessment methods and candidate technologies.

Through the efforts of the Sediment Subcommittee of the IJC, the United States and Canada are coordinating their attack on the contaminated sediment problem in the Great Lakes.

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92-18905

REMOVAL AND DISPOSAL OF ACCUMULATED ORGANIC SLUDGE IN THE OSAKA PORT AND HARBOR AREA

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ABSTRACT

Since 1974, the Osaka Port and Harbor Bureau has removed organic sludge totaling more than 3 million m^3 and disposed of it at the North Port disposal area.

As this is a sea reclamation disposal area, water quality control and discharged water quality improvement are important in terms of environmental preservation.

The present survey has clarified the following points:

a. Water quality at a disposal area is affected by the seawater contained in the dredged soil, meteorological conditions (water temperature, precipitation, sunlight, etc.), and proliferation of phytoplankton.

b. When a disposal area occupies a wide area, the chemical oxygen demand (COD) value, which is the typical index of pollution, remains low while the water is deep, but will rise rapidly as the water depth becomes shallower, due to shortened residence time of discharged water and proliferation of phytoplankton.

c. Remarkable improvement in discharged water quality can be achieved by installing pollution-prevention membranes directly in front of the water discharge outlets.

INTRODUCTION

Osaka Port, situated at the center of Osaka Bay, enjoys good meteorological and sea weather conditions and has developed as a leading Japanese international trade harbor serving a wide hinterland. At the core of this expansive hinterland is the city of Osaka, which has a population of approximately 1.5 million and is one of the two biggest centers of Japanese industry and economy.

Large quantities of water-polluting substances are discharged from this area and carried via rivers to the port and harbor area, deteriorating the bottom sediment quality. Therefore, since 1974, the Port and Harbor Bureau of Osaka has been dredging sludge from rivers and estuaries in polluted areas of the bay as a part of the port and harbor pollution control project.

This report represents results of studies and analyses of organic sludge removal and disposal, with focus on water quality control at the disposal areas in respect to the bottom sediment quality improvement project of Osaka Port.

PROJECT FOR IMPROVEMENT OF BOTTOM SEDIMENT QUALITY, OSAKA PORT

A number of rivers flow into Osaka Port (Figure 1) and the water of these rivers is becoming more and more contaminated, both organically and artificially, from rapid industrial development and urbanization in the basin areas and from sludge accumulated in the Aji, Shirinashi, and Kizu Rivers and their estuaries, which are particularly contaminated by organic substances.

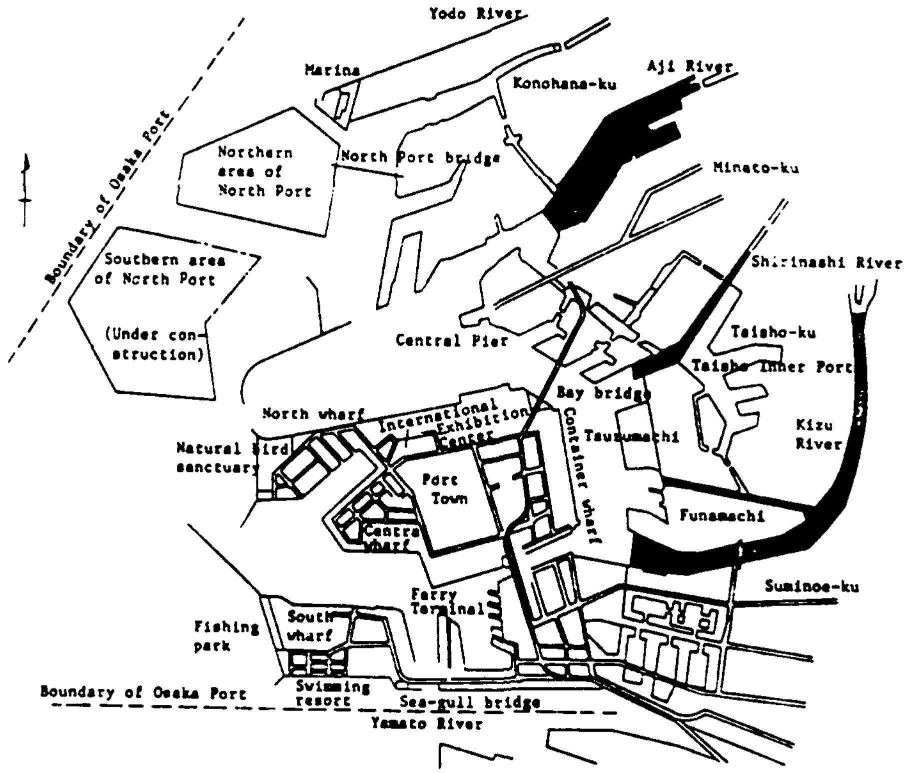


Figure 1. Organic sludge dredging areas (blackened areas)

The objectives of the bottom sediment quality improvement project of Osaka Port, as outlined in Table 1, are based on the Osaka area pollution prevention plan and are as follows:

a. To improve water quality by preventing dissolved oxygen (DO) consumption and the generation of foul odors and noxious gases due to the stirring of deposited organic sludge by navigating ships.

b. To improve water conditions to a life-sustaining level by removing sulfides and oily substances contained in the bottom sediment.

TABLE 1. POLLUTION PREVENTION PROJECT, OSAKA PORT

Project Element	Description
Source of pollution	Drainage from factories and households
Subject sections	Kizu, Shirinashi, and Aji Rivers and their estuaries in Osaka Port
Period	1974-1995
Contamination condition	Organic sludge COD,* 27-54 mg/g Oil substances, 23-38 mg/g Sulfides, 5-11 mg/g Ignition loss, 15-22 percent
Removal standard	Removal of organic sludge of more than 15 percent ignition loss satisfies standard requirements for COD, oily substances, and sulfides, etc.
Volume to be handled	Handled - 1974-1986 3,174,000 m^3 Planned - 1987-1995 1,720,000 m^3
Dredging and disposal	Dredging by the Pneuma pump dredge system, 450 m^3/hr (pure water) Dredging by closed-type grab dredge, 4 m^3/bucket Transport by box barge, 350-450 m^3 Sludge unloading by disposal ship, 160 m^3/hr (pure water) Discharge filling by discharge pipe
Disposal areas	North Port disposal area North region second and third areas 1,622,000 m^2 South region second and third areas 2,148,000 m^2
Measures to be taken for discharge source of polluting substances	Improvement of sewerage in Osaka Prefecture, as well as Osaka: 100% target, to be achieved in 1990
Other projects	Rivers upstream of those flowing into the bay area and running through Osaka City have been cleared of sludge under the river purification project

* COD determined by permanganate oxidation.

DREDGING OF ORGANIC SLUDGE

Organic sludge removal has been accomplished using a Pneuma pump dredge and closed-type grab dredge. Since dredged earth and sand contain a high proportion of mud and since this system causes less pollution and less disturbance of the existing earth bed and resultant muddy water, the dredging work has been carried out mainly by Pneuma pump dredge, with additional dredging by the closed-type grab dredge for areas of shallower water depth and small-scale dredging for areas of harder earth. Figure 2 is a flowchart of organic sludge removal.

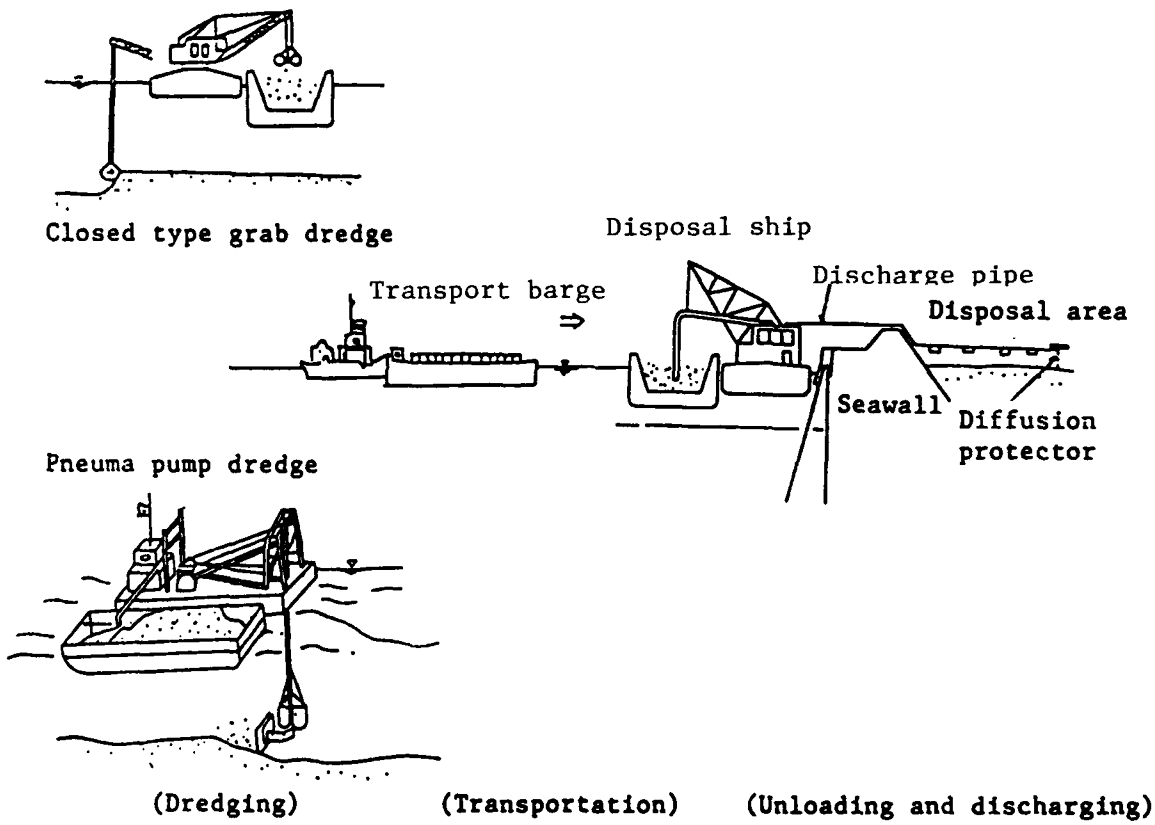


Figure 2. Organic sludge removal flowchart

The yearly volumes of dredged organic sludge are shown in Table 2. Table 3 summarizes the surveys conducted before, during, and after dredging activities.

NORTH PORT DISPOSAL AREA

Disposal Area Description

The North Port disposal area is situated at the western end of Osaka Bay and is composed of two sea reclamation areas (northern and southern), each divided into three zones (Figure 3).

TABLE 2. YEARLY VOLUME OF ORGANIC SLUDGE

	Fiscal Year													
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	Total
Dredged volume, 1,000 m^3	110	244	189	285	290	256	256	251	287	279	252	275	200	3,174

TABLE 3. SURVEY WORK ASSOCIATED WITH DREDGING OF ORGANIC SLUDGE

Activity	Description	Purpose
Before dredging		
Surveying of bottom sediment quality	Mud sampling down to clay layer by thin wall-type bottom sampler	Mainly for use as basic data to determine removal depth
	Sampling of surface mud by Ekman barge-type sampler	To determine disposal method acceptability according to the acceptance standard
During dredging		
Sounding	Depth measurement by echo-sounder	To determine earth volume to be dredged
Soil exploration	Soil sample taken into a barge for measurement of water content, unit volume, and weight	To confirm earth volume deposited in disposal area
Environmental monitoring	Water quality analysis surveys in dredging areas and areas downstream	To monitor environmental parameters (COD, SS, DO, etc.) to determine water pollution in compliance with Article 15 of the Water Pollution Prevention Act
After dredging		
Sounding	Depth measurement by echo-sounder	To confirm dredged depth and calculate dredged earth volume
Bottom soil exploration	Sampling of surface layer soil by Ekman barge-type sampler	To confirm improved bottom soil quality by dredging

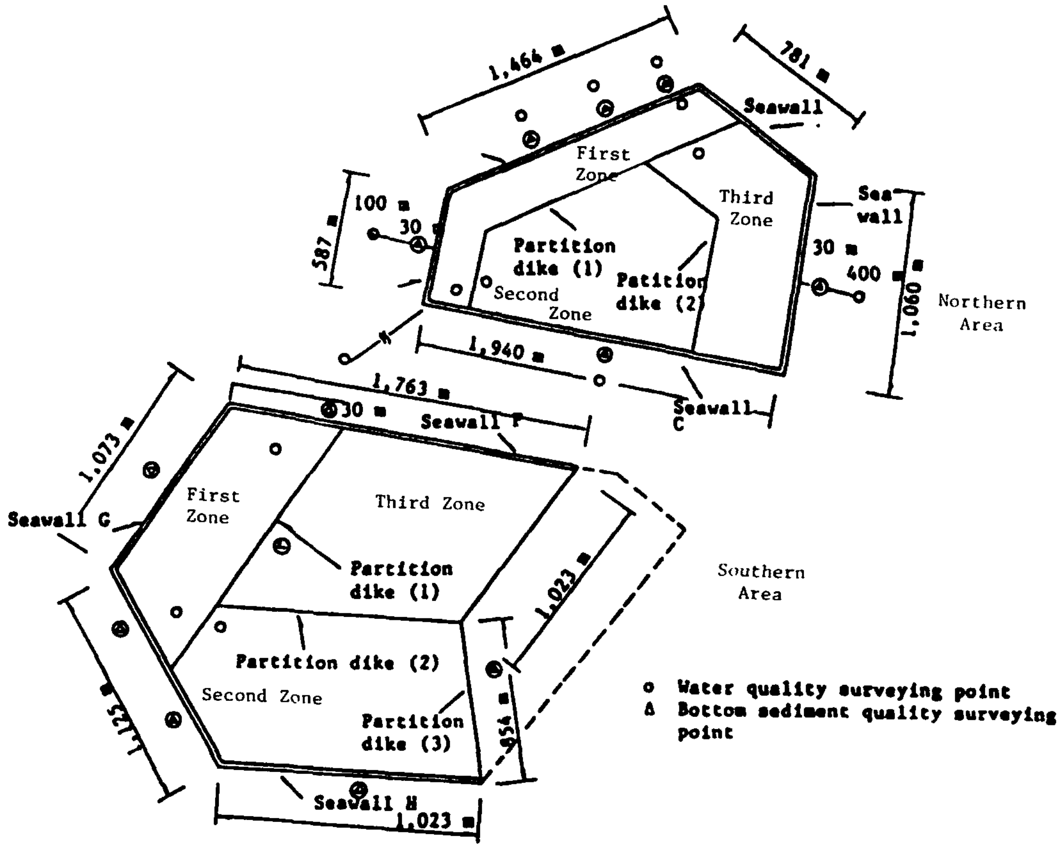


Figure 3. Layout of North Port disposal area

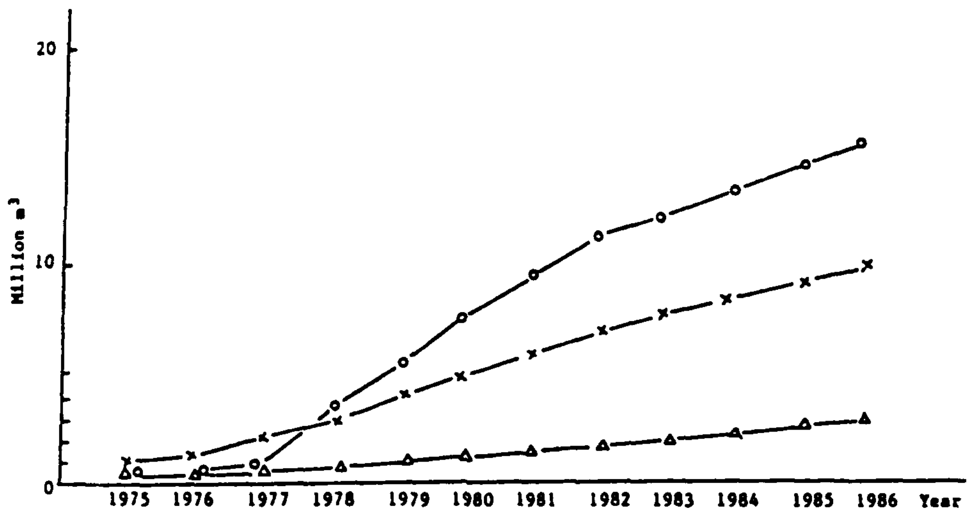
The northern area began accepting waste in 1974, while the southern area is still under construction; however, this area has been partially accepting waste since 1985 and dredged earth and sand since the beginning of 1987. Features of the North Port disposal area are summarized in Table 4.

TABLE 4. NORTH PORT DISPOSAL AREA

Item	Northern Area	Southern Area
Area, ha	209	288
Capacity, m^3	25,000,000	50,000,000
Construction period	1972-1977	1977-1990
Acceptance period	1974-1987	1985-1995
Acceptance conditions, m^3	28,000,000 (112%)	460,000 (First area)

Disposal Records

The first area of the North Port disposal area accepts not only organic sludge, but also ordinary waste such as refuse, sludge from city water and sewerage systems, and industrial waste. Organic sludge, other dredged earth and sand, as well as excavated earth from construction sites are placed in the second and third areas. Acceptance records for 1975-1986 are presented in Figure 4.



Remarks: x First zone - ordinary waste, sludge from city water and sewerage systems, industrial waste

Δ Second and third zones - organic sludge from the bay areas

O Second and third zones - other dredged earth, and sand and earth from construction sites

Figure 4. Acceptance records at the North Port disposal area

Seawalls and Partition Dikes

Figures 5-9 indicate typical seawalls and partition dikes. As shown in Figure 5, seawall A comprises a composite breakwater fronted with wave dissipation blocks; for its foundation, the sand drain method was adopted for subsoil improvement.

As shown in Figure 6, seawall C faces a ship navigation route. To avoid interfering with this route, to shorten the construction period, to decrease the construction cost, and to enhance safety in construction, the driven steel pipe pile system was used. The subsoil was also improved by the sand compaction pile method.

Since seawall G is exposed to rough waves from the open sea in winter, the wave passivation caisson structure was adopted for this seawall; subsoil was improved by the sand compaction pile method.

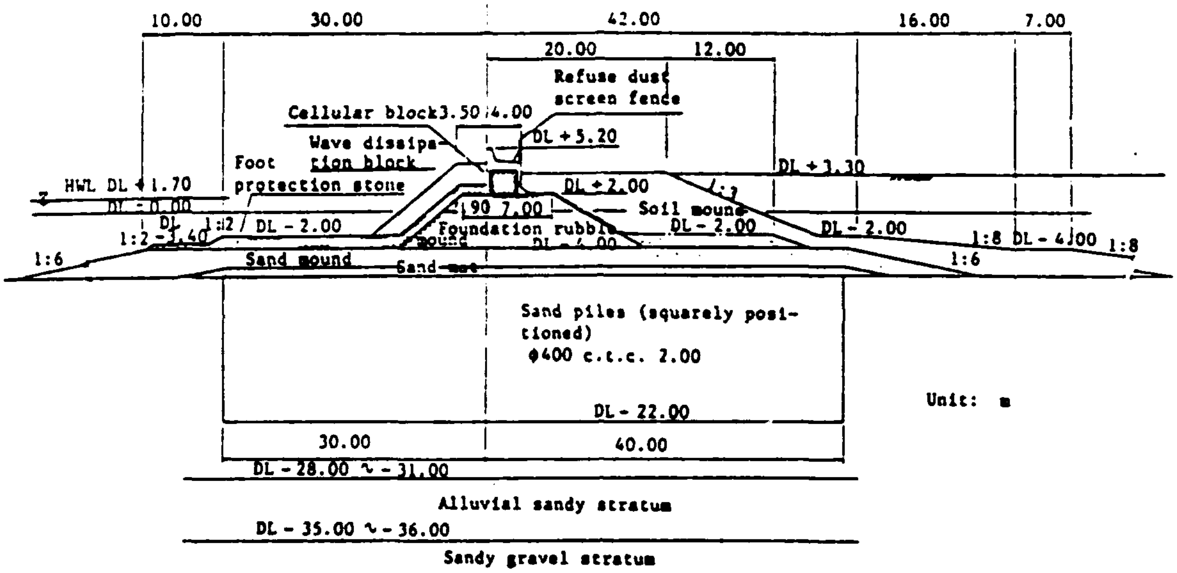


Figure 5. Cross section of seawall A

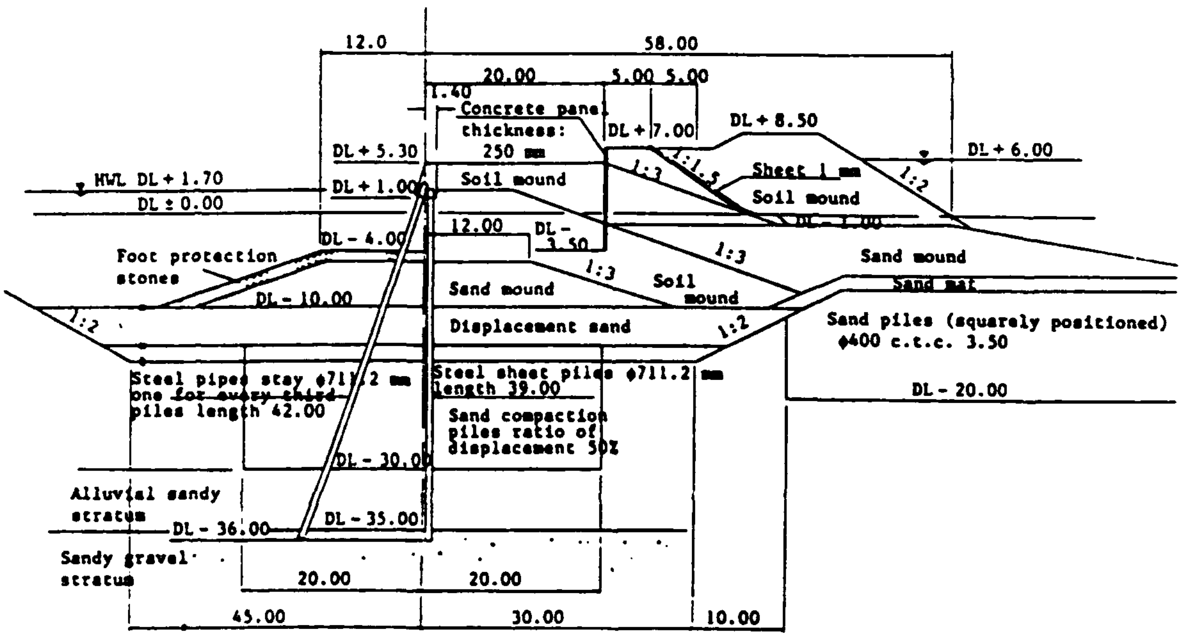


Figure 6. Cross section of seawall C

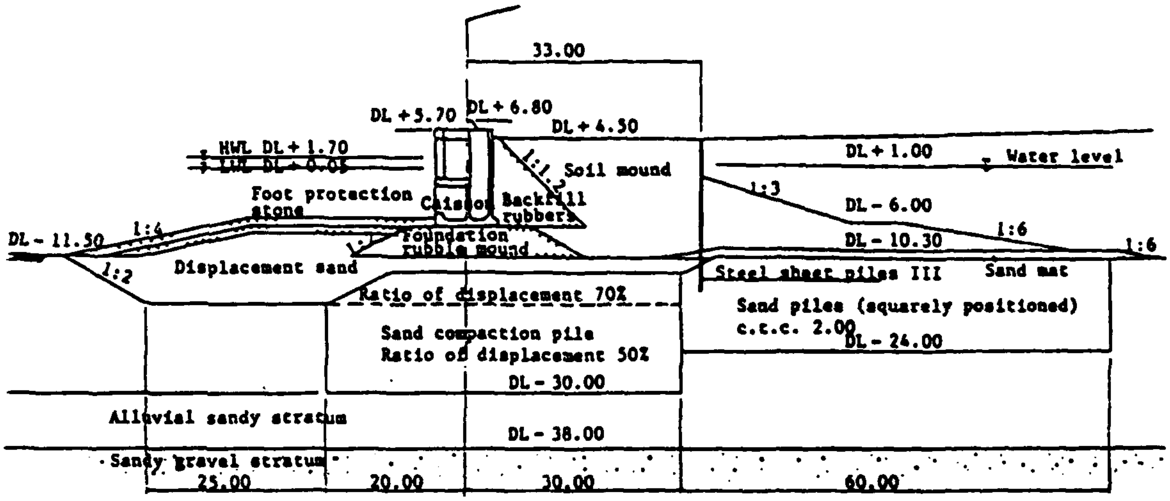


Figure 7. Cross section of seawall G

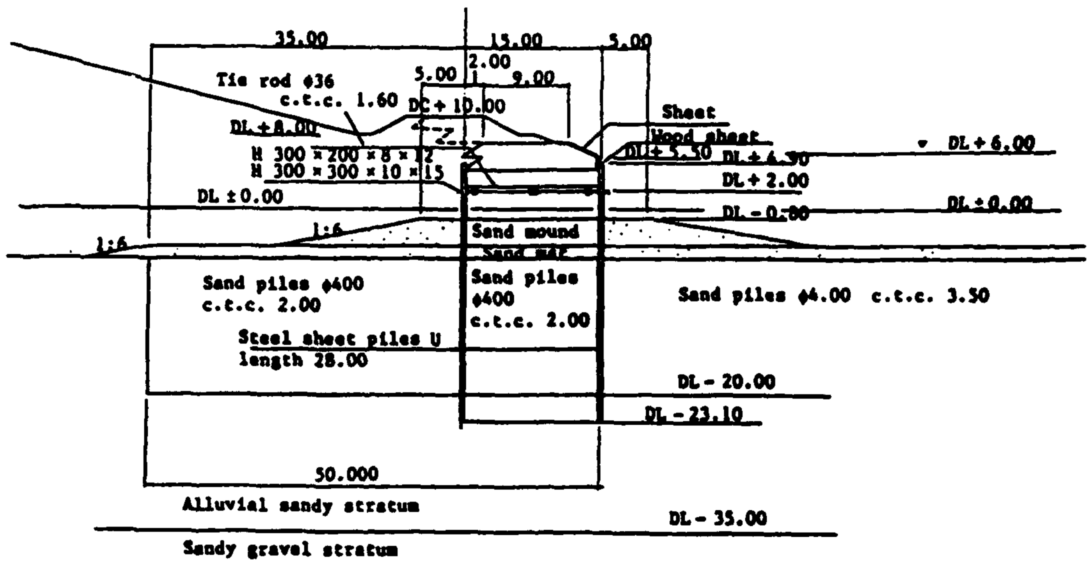


Figure 8. Cross section of partition dike 1

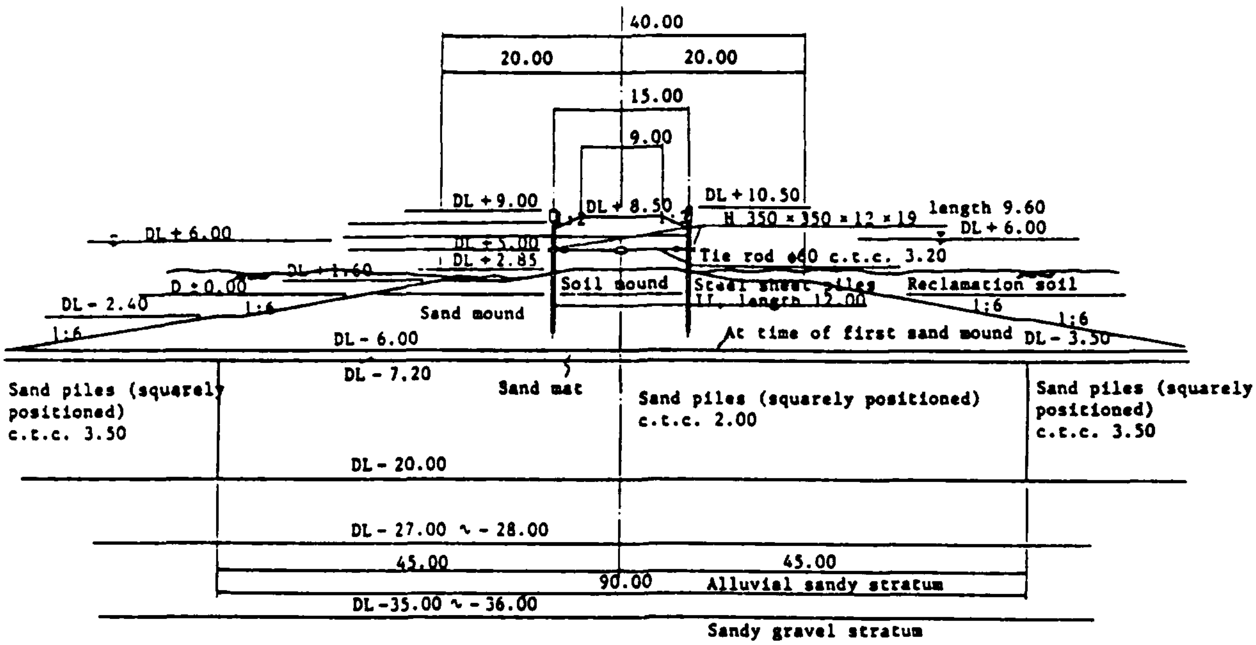


Figure 9. Cross section of partition dike 2

Since the North Port disposal area is used to bury waste of different kinds, such as organic sludge and ordinary waste for disposal, a partition dike of double steel sheet piles was installed to isolate the area. Further, since the partition dike can handle traffic, its installation serves to ease reclamation work, maintenance, and control. In addition, steel sheet piles longer than those used for partition dike 2 are used for partition dikes 1 and 3 to secure watertightness. Partition dike 3 has the same structure as partition dike 2.

ORGANIC SLUDGE DISPOSAL

Organic sludge pumped from barges through the ship is then discharged through the sand discharge pipe into the disposal area. Diffusion protectors are installed near the sand discharge pipe outlet to expedite sedimentation of sludge and prevent the spread of muddy water oil contamination (see Figure 2).

Since the North Port disposal area accepts various other kinds of waste in addition to organic sludge and since overall water quality control is important, acceptance ranges for other kinds of waste have been developed and are discussed below.

Earth and Sand Dredging

These materials are carried by barges to the second and third zones of the disposal area and pumped via the following two methods:

a. Direct pumping. Dredged earth and sand are pumped from the barge through the ship; then, they are pumped to the disposal area via the sand discharge pipe.

b. Pumping after temporary storage at the pocket. Dredged earth and sand are carried by the bottom-hopper barge to a sea bottom pocket to be stored there temporarily, and are then pumped to the disposal area via the sand discharge pipe. However, in recent years, method a has been used primarily for pumping to the discharge area.

In both methods a and b, diffusion protectors are installed in front of the sand discharge pipe outlets to expedite sludge sedimentation and prevent the spread of muddy water and oil contamination.

Ordinary Waste

This type of waste is carried by barges from the shipping base and landed by crane; then, it is carried by dumptrucks to the disposal area, where it is scattered by bulldozers.

Further, over every 3 m of waste fill, an earth covering 0.5 m thick is emplaced to prevent airborne waste, odor, and the generation of noxious insects.

Sludge from city water and sewerage systems, as well as residual earth from construction sites, is also carried by barges from their shipping base and disposed of by reclamation in a manner similar to that for ordinary waste.

Before disposal by reclamation, all wastes are checked for noxious substances, in accordance with the acceptance standards.

Environmental Preservation Measures

Environmental monitoring activities, including surveys of water quality and bottom sediment quality, in addition to the following preservation measures, are carried out in the disposal and peripheral sea areas.

a. Wastewater discharged in the first zone is improved in quality by aeration treatment in the oxidation basin.

b. To remove gas generated by the waste, gas extractor equipment is installed in the first zone.

c. To prevent airborne refuse, preventive fencing is installed around the first zone.

Water quality is surveyed once a week in the disposal area and once a month in the peripheral sea area (at points shown in Figure 3) for pH, DO, COD, etc. Bottom sediment quality is surveyed once a year in the peripheral sea area for pH, DO, ignition loss, etc.

WATER QUALITY CONTROL AT DISPOSAL AREA

The discussion that follows focuses on the northern area, since the southern area is not yet accepting waste regularly.

Wastewater flow in the disposal area is as follows: the wastewater in the first zone is aerated in the oxidation basin and discharged to the second zone; from the second zone, wastewater is discharged to the third zone. Wastewater is released to the open sea from the second discharge outlet (Figure 10). (Use of the first discharge outlet has been suspended since 1983.)

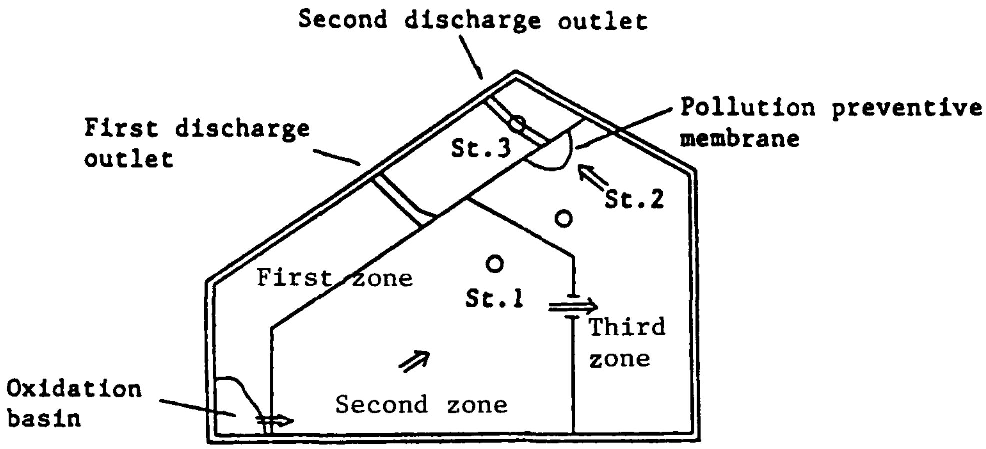


Figure 10. Wastewater flow in northern area

Water quality conditions at the oxidation basin just before discharge from the first zone to the second are pH 7.7 to 8.2 (average 8.0), COD 60 to 110 mg/ℓ (average 84 mg/ℓ), and DO 1.5 to 9.0 mg/ℓ (average 7.3 mg/ℓ). However, since the volume of this discharge is not great and since the organic sludge dealt with in this paper is disposed of in the second and third zones, the discussion herein presents the results of analyses of wastewater from the second and third zones.

Soil and Water Levels
at Second and Third Zones

The second and third zones, which comprise 1.622 million m^2 in reclaimed land area, are used as stabilization ponds for physical and biological purification during a continuous flow time of from 100 to 200 days, to purify sludge pumped into these zones and to repurify water discharged from the first zone.

Presently, reclamation activity in the second and third zones is almost complete. Figure 11 indicates the yearly change in soil and water levels in the reclamation land.

Water Quality Surveys

Water quality surveys (once a month) have been conducted for 4 years (since 1983) to analyze water quality in the disposal area and at the discharge outlet based on survey results taken at three points, Stations (St.) 1, 2, and 3 (shown in Figure 10).

Water Temperature

As indicated in Figure 12, annual seasonal change patterns of individual sampling points do vary greatly, which is also true of them collectively. It

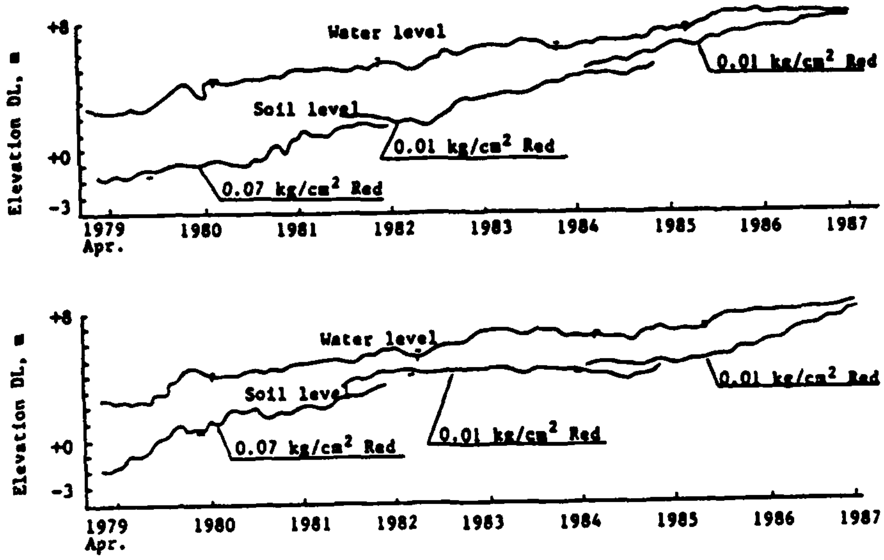


Figure 11. Changes in soil and water levels

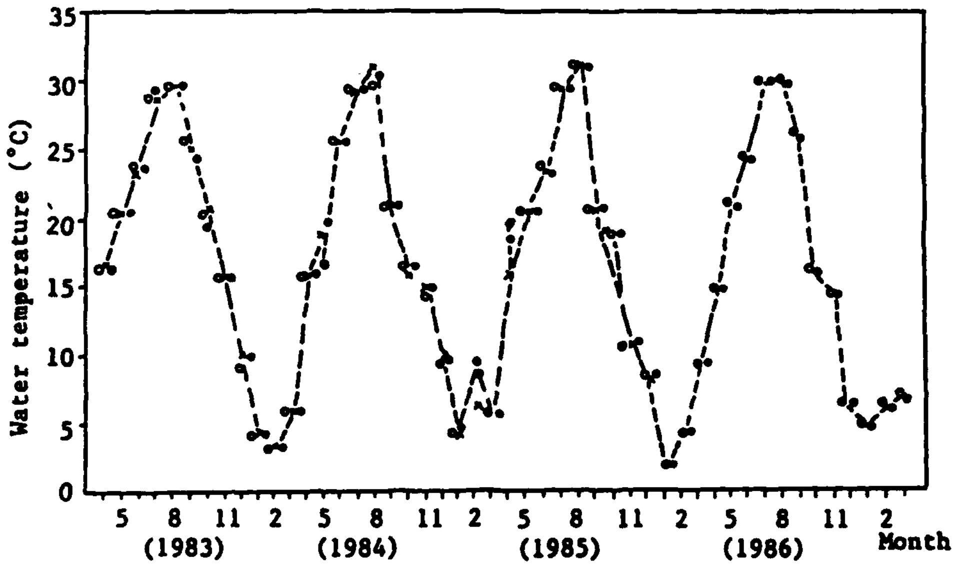


Figure 12. Monthly changes in water temperature

should be noted that no measurements were taken at St. 1 in 1986 because of reclamation work. Also, the reader should note that seasons of the year are defined as follows: spring (March, April, and May), summer (June, July, and August), fall (September, October, and November), and winter (December, January, and February).

pH

As shown in Figure 13, the so-called cyclic changes, i.e., the increases of pH in spring and fall and decreases in summer and winter, are notable.

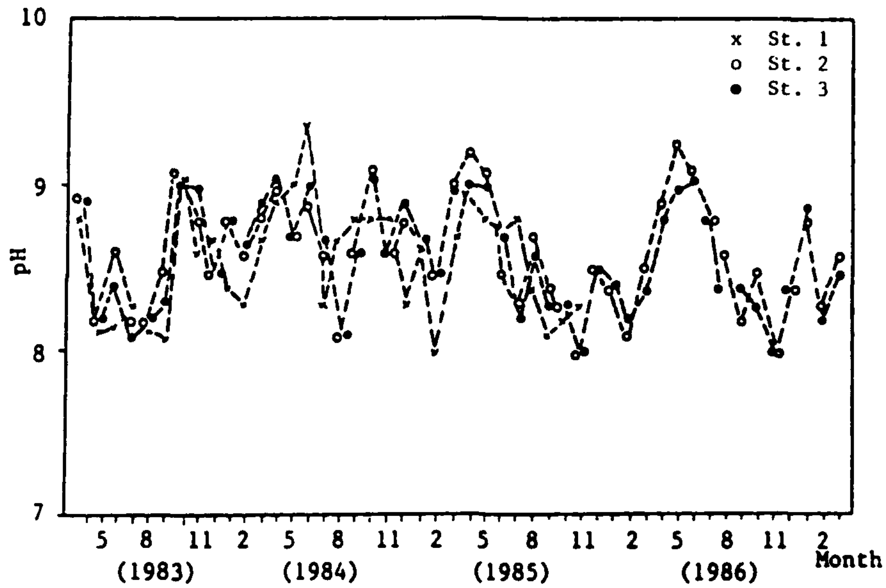


Figure 13. Monthly changes in pH

Possible factors involved in the increase are the photosynthesis of plants and deposited earth and sand; however, since the cyclic changes in pH level coincide with extraordinary proliferations of phytoplankton, this is believed to be the cause.

Suspended Solids (SS)

As indicated in Figure 14, the large fluctuations seen in 1983 and 1984 were not seen in 1986; peaks due to proliferation of phytoplankton were seen in the spring and fall seasons of that year, though at no time did SS exceed 40 mg/ℓ.

Probable factors involved in SS increase are the stirring of the bottom sludge of the deposited soil and phytoplankton proliferation.

The low increase at St. 3, especially in spring and fall, is considered to be due to the pollution-prevention membranes installed in 1985.

Dissolved Oxygen (DO)

As shown in Figure 15, the level of DO followed cyclic changes due to water temperature fluctuation (high in winter, low in summer) and temperature increase, due also to the extraordinary proliferation of phytoplankton in 1986.

Chemical Oxygen Demand (COD)

As indicated in Figure 16, COD tends to increase in spring and fall when phytoplankton proliferate, a tendency that was conspicuous in 1984 and 1986. However, measurements at St. 3 were less than 15 mg/ℓ for most months of the year, being as low as 20 mg/ℓ even in February, when the phytoplankton proliferated. This was considered to be the effect of the pollution-prevention membranes.

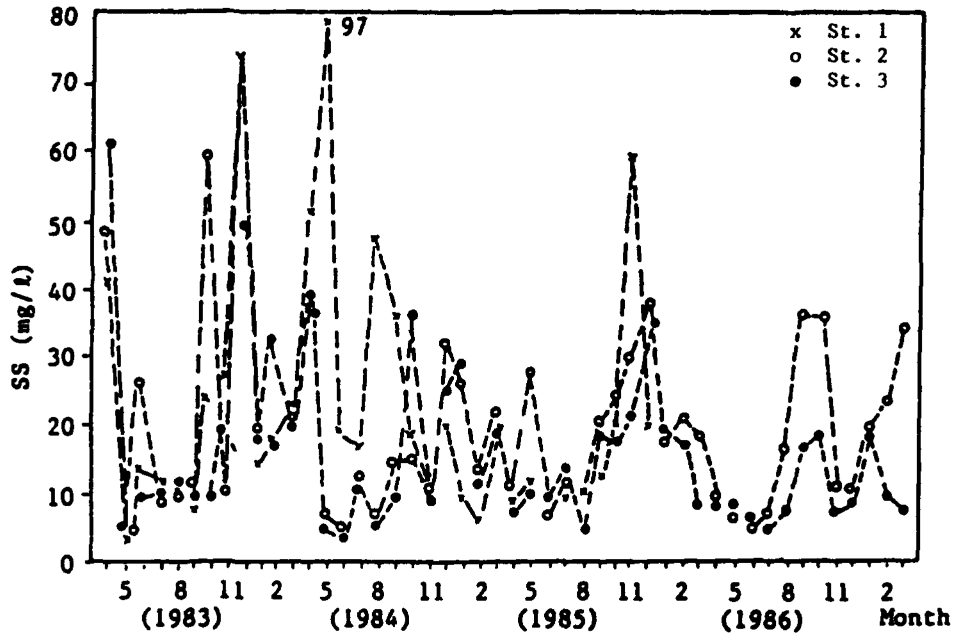


Figure 14. Monthly changes in SS

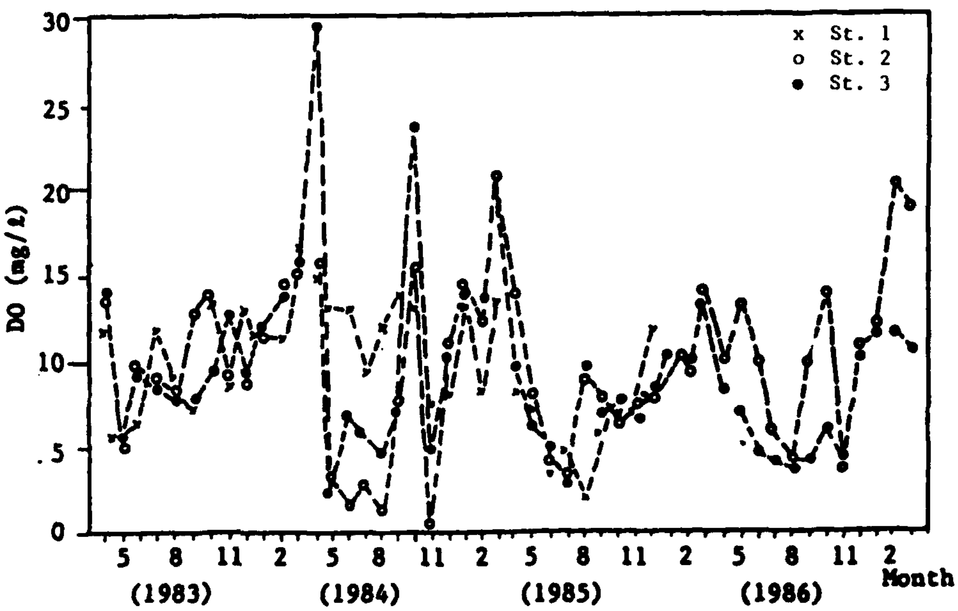


Figure 15. Monthly changes in DO

On the other hand, as shown in Figure 17, the soluble COD level tends to rise every year beginning in spring, when the phytoplankton generally starts to proliferate, and to decrease in the fall. The level of soluble COD has been below 20 mg/ℓ almost continually for the past 4 years, with the fluctuation not so great as that of COD.

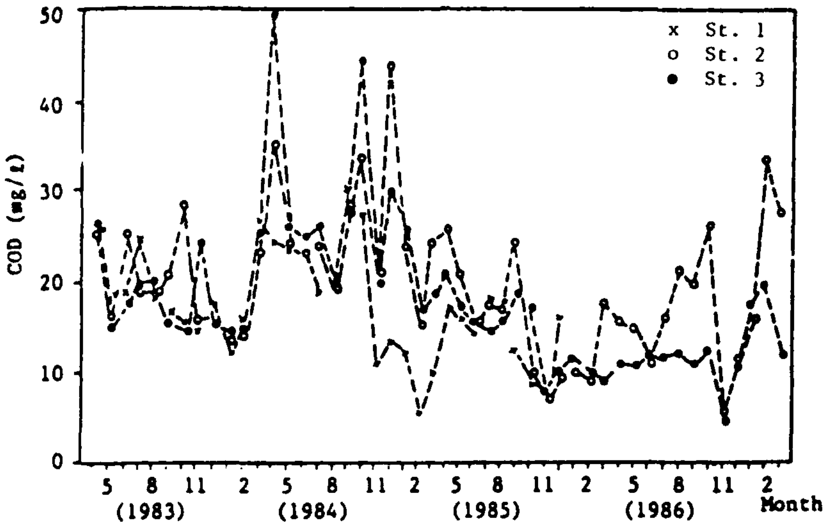


Figure 16. Monthly changes in COD

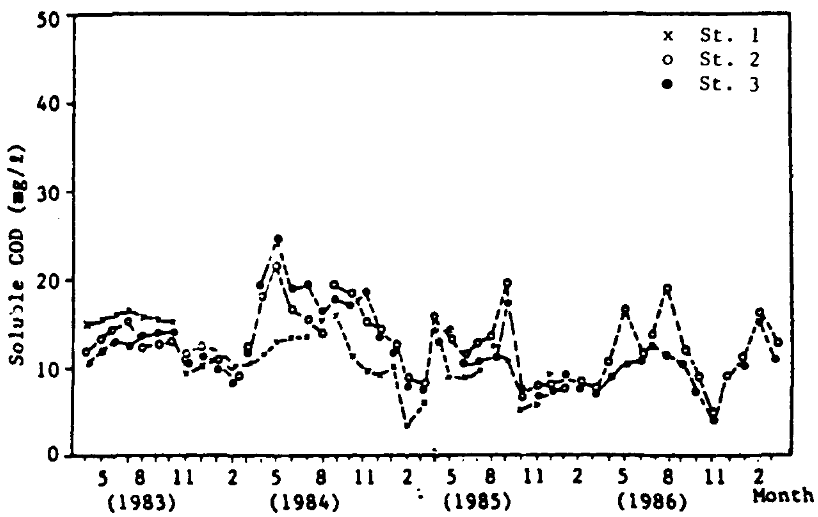


Figure 17. Monthly changes in soluble COD

Kjeldahl Nitrogen

As indicated in Figure 18, this tends to gradually decrease from spring to summer and to increase gradually from fall. However, in 1986 the peak appeared about 2 months earlier than in other years, which is thought to have been due to lessening of water depth and continuous flow time as construction work progressed.

Total Phosphorus (T-P)

As shown in Figure 19, 1986 was also a year in which remarkable cyclic changes occurred in T-P level, gradually increasing from spring to summer and

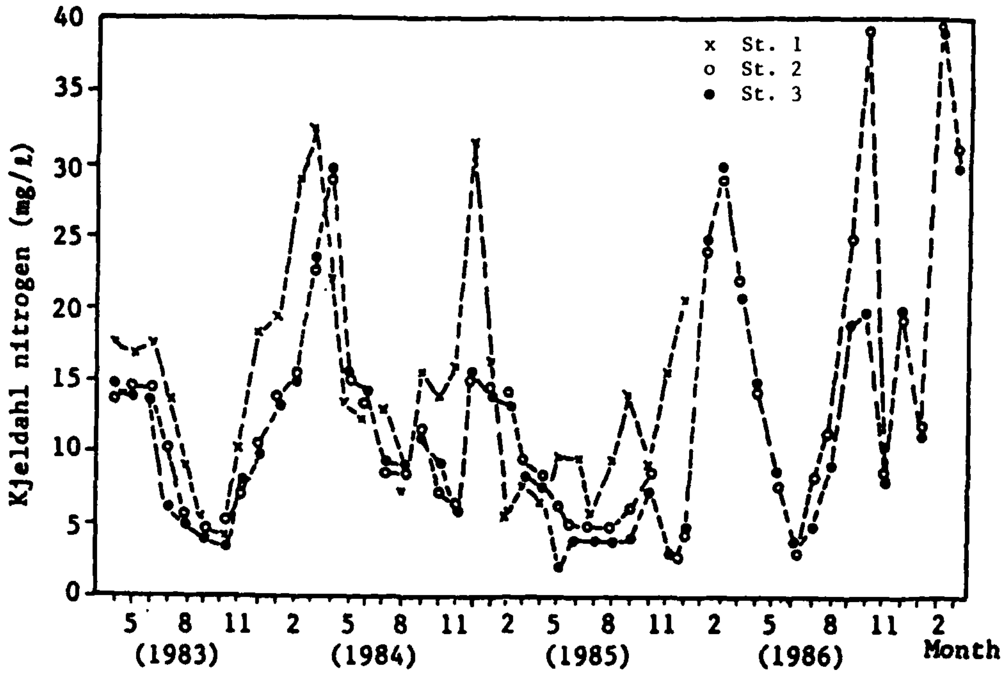


Figure 18. Monthly changes in Kjeldahl nitrogen

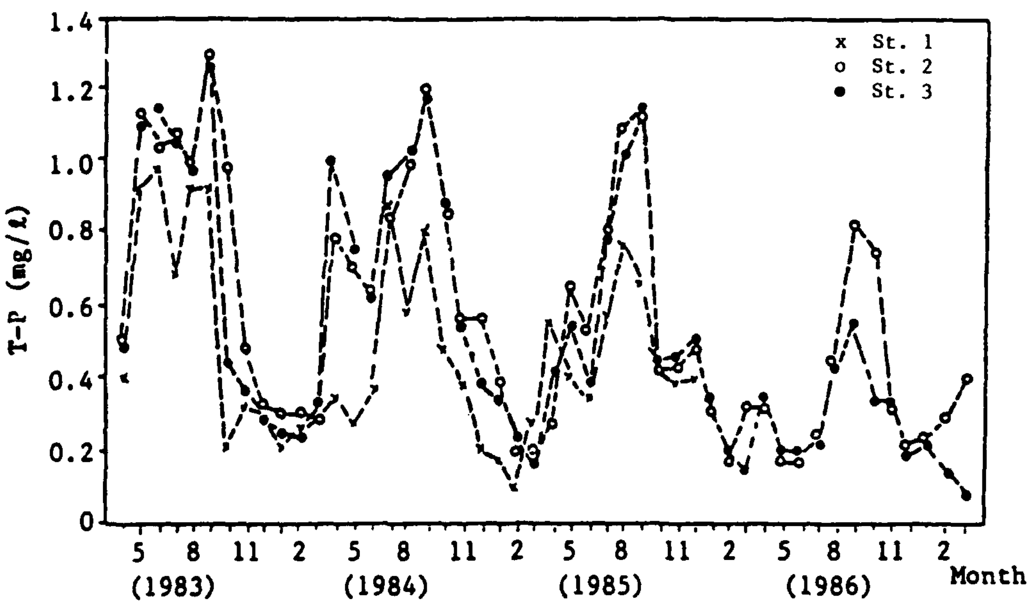


Figure 19. Monthly changes in T-P

again decreasing from fall. Levels of T-P have dwindled year by year such that, even in September, the month of the 1986 peak, the value did not exceed 1 mg/ℓ.

Volume of Pigment

Volume of pigment is an index of phytoplankton proliferation that, as indicated in Figure 20, tends to peak in spring and fall. On the other hand, the pigment volume measured at St. 3 was not very high during the peak seasons of spring and fall. Even in February, when the maximum value was seen, it was 636 mg/m^3, indicating a remarkable difference from St. 2.

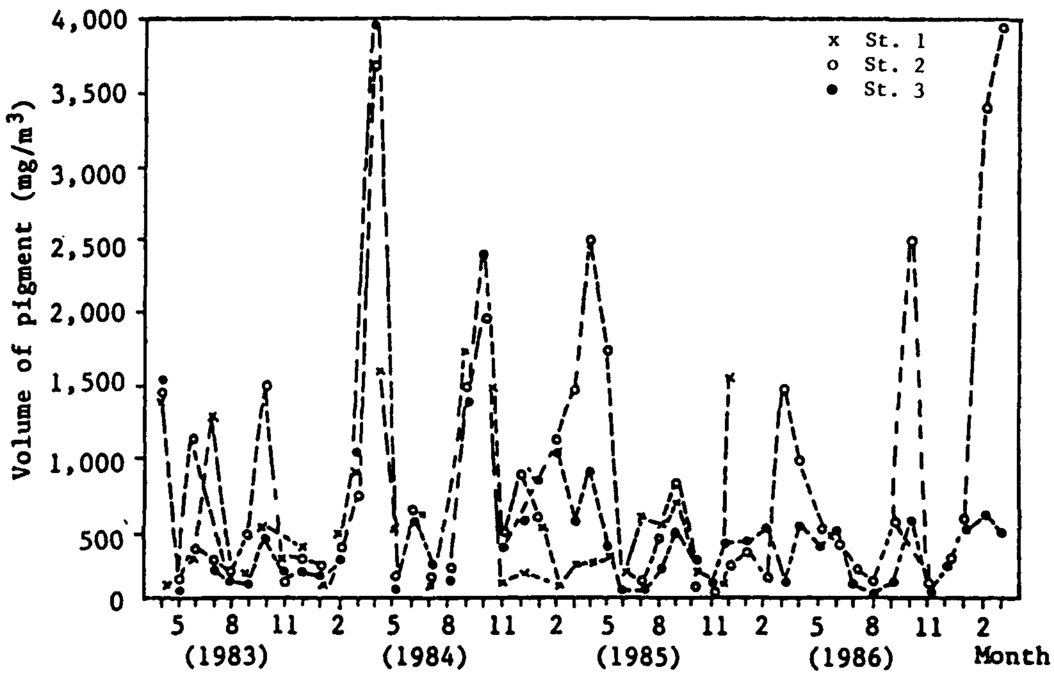


Figure 20. Monthly changes in volume of pigment

Salt Content

As indicated in Figure 21, salt content distinctly increased from fall to winter and decreased from spring to summer.

This cyclic change is considered to be due to the combined effects of seawater contained in dredged soil and meteorological conditions (precipitation volume, sunlight, etc.). The value rise through 1985 and 1986 is considered to be due to diminishing water depth.

Water Discharged to Sea

Target Water Quality

To adhere to the applicable water discharge standards as set forth by the relevant laws and regulations, to observe the purport of the Inland Sea

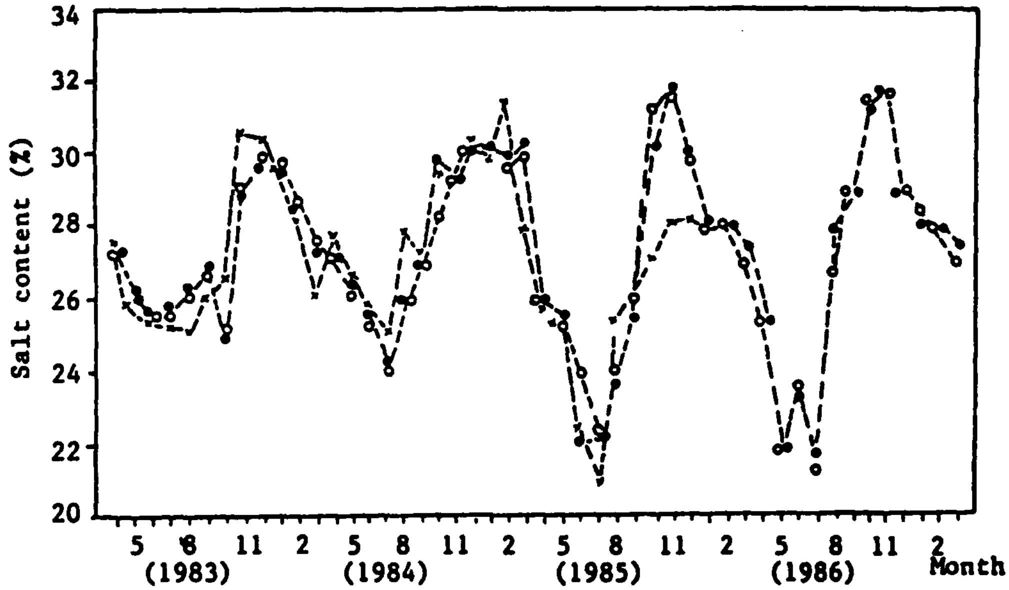


Figure 21. Monthly changes in salt content

Environmental Preservation Special Measure Act, and to decrease the effects on the marine environment, water quality has been controlled by determining control targets for COD and SS (Table 5), which are typical pollution indices.

TABLE 5. TARGET VALUES FOR WATER DISCHARGED FROM NORTH PORT DISPOSAL AREA

Parameter	Standards for Discharge Water Set Forth in Article 1, Order of the Prime Minister's Office	Target Value
COD, mg/ℓ	160, 120*	50
SS, mg/ℓ	200, 150*	70

* Daily average value.

Water Quality Control by COD

Monthly changes in COD since the beginning of reclamation are shown in Figure 22; the value in 1979, when the water at the reclamation site was deep, was less than 20 mg/ℓ, reaching a high point of 50 mg/ℓ in 1984, when the water depth had become shallow.

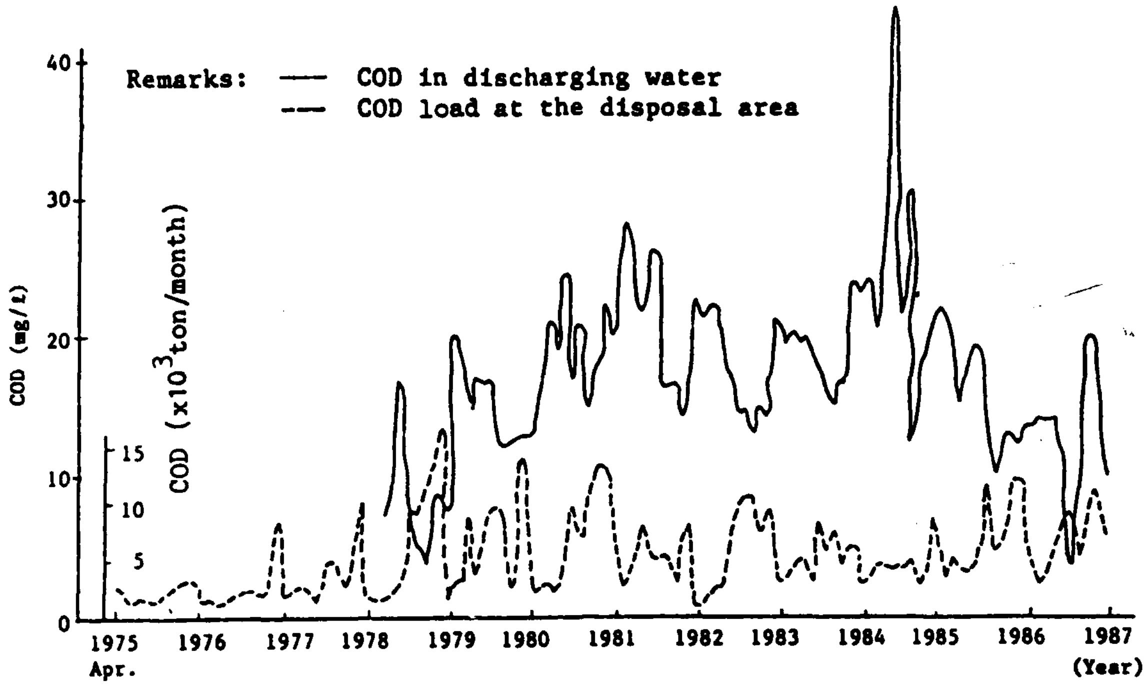


Figure 22. Monthly changes of discharging water in COD

For this reason, as indicated in Figure 10, pollution-prevention membranes were installed immediately in front of the water discharge outlets in 1985; the COD value has thus far been kept to a low level of 20 mg/ℓ on average.

As stated above, controlling the quality of discharged water was somewhat easier when the water at the reclamation site was deeper; however, it was made more difficult due to factors such as continuous flow time as the water became shallower, requiring special water treatments such as the pollution-prevention membrane.

CONCLUSIONS

When a disposal area is a sea reclamation disposal area, water quality control in the disposal area and improvement in discharged water quality are important themes.

The present survey clarified the following points and yielded significant data for future water quality control in the disposal area:

a. Water quality in a disposal area is affected by seawater contained in dredged soil, meteorological conditions (water temperature, precipitation, sunlight, etc.), and proliferation of phytoplankton, of which the latter exerts the greatest effect upon water quality.

b. The water quality indices largely affected by phytoplankton proliferation are pH, SS, and COD, which exhibit remarkable cyclic changes through the year with higher values in spring and fall and lower values in summer and winter.

c. Comparison of the sampling stations in the disposal area showed that water quality in the second (St. 1) and third (St. 2) zones and at the second water discharge outlet (St. 3) exhibited similar changes for each survey item, with no remarkable difference among these points.

d. When a disposal area occupies a wide area, the COD value, a typical index of pollution, is lower while the water is deeper, but deteriorates rapidly as the water becomes shallower, due to the shortened continuous flow time of discharge water and the lessened phytoplankton proliferation.

e. Although various kinds of water treatment are conceivable in coping with water quality deterioration in a disposal area, in the case of the city of Osaka, remarkable improvement in discharged water quality was achieved by installing pollution-prevention membranes immediately in front of the water discharge outlets.

Many points remained unresolved by this analysis in the disposal area; these points must be clarified by future surveys and research. It is hoped that our observations of the removal and disposal of accumulated organic sludge in the port and harbor area, with emphasis on water quality control at the disposal area, contribute in some way to the environmental improvement of port and harbor areas in Japan and the United States.

IMPACT ASSESSMENT OF IN-PLACE CONTAMINATED SEDIMENTS ON WATER QUALITY: AN APPROACH

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ABSTRACT

In the past, environmental assessments of Corps of Engineers (CE) Civil Works water resource projects that involve dredging of contaminated sediments have addressed only the consequences of dredged material disposal. The environmental benefits that may be incurred from the removal of in-place contaminated sediments have not been considered. This deficiency in evaluating the environmental consequence of sediment removal has been due to the lack of a logical delineated approach to quantifying the impacts of contaminated sediments on water quality as well as the reluctance of regulatory agencies to consider contaminated sediment removal as a benefit. This paper presents a conceptual approach developed for the operations and maintenance Federal navigation projects for assessing the environmental consequences of in-place contaminated sediments. The approach, along with potential benefits, is delineated. Further, the concept has application to other water resource projects that involve contaminated sediments. The basic concept has recently been applied to a Civil Works project in the Grand Calumet River and Indiana Harbor Canal system, Indiana, USA. Results of this study are presented to show the steps necessary for implementing the concept and to illustrate potential uses of the data, along with restrictions on implementation and use.

INTRODUCTION

The CE, as one of the Nation's major construction agencies, has responsibility for the construction and maintenance of over 25,000 miles (40,000 km) of Federal channels, over 100 commercial harbors, and 400 small boat harbors. The CE annually removes 250 to 300 million cu yd (190 to 230 million cu m) of dredged material. A small, although significant portion of the sediments dredged is contaminated and requires special handling and disposal. These sediments may contain a multitude of toxic materials, including polycyclic aromatic hydrocarbons, polychlorinated biphenyls (PCBs), heavy metals, pesticides, and by-products of industry. These contaminated sediments are normally associated with the Nation's urban industrial waterways, where Federal channels act as catchment basins for sediments.

In the construction and maintenance of Federal channels, the CE must comply with Federal and state environmental legislation and evaluate the environmental consequences of dredging and disposing of these sediments. In evaluating the environmental impacts of the dredging and disposal of contaminated sediments, the major emphasis has been on the short-term impacts on water quality from dredging and the short- and long-term impacts on the environment from disposal. Minimum attention has been given to either the environmental effects of contaminated sediments in Federal channels on the water body or the environmental benefits that may accrue from sediment removal.

Strong public opinion against the removal and disposal of contaminated sediments has been and is still often expressed. Objections are based on the belief that the environmental consequences of sediment removal and subsequent disposal exceed the social and economic benefits gained from the project. Although polluted sediments are often located in highly industrialized and urban areas, they are neither stationary nor inert. These sediments continue to exert an influence on the water quality of the waterway through oxygen demand and release of nutrients and toxic substances, as well as supporting only a limited pollutant-tolerant community of poor species diversity. Further, the resuspension of these sediments by natural and man-induced causes will not only affect the overlying water column, but may also impact the water quality for miles outside the immediate area of concern.

Polluted sediments are not confined to Federal channels and major harbors in our urban and industrial areas. Spills from chemical and petroleum barges and small chemical and petroleum terminals have resulted in localized pockets of contaminated sediments in areas far removed from our major metropolitan areas. Runoff from agricultural areas and timberlands also introduces pesticides and nutrients to the Nation's waters, often resulting in river, reservoir, and estuary sediments becoming contaminated. Point discharge from feedlots, chemical companies, and city sewage treatment plants has also been a source of nutrients and contaminants that have affected sediments. Many of these polluted sediments are located within Federal water resource projects built and maintained by the CE. The effects of these sediments on the continued operation and maintenance of these projects, as well as proposed modifications to current use, can be significantly affected by the presence of contaminated sediments.

For a more complete assessment of cost versus benefits associated with maintaining specific water resource projects, the impacts of in-place sediments on the environment must be considered. If the CE can determine and quantify the impacts, the "true" cost of the project's social, economic, and environmental attributes can be determined.

LEGAL CONSIDERATIONS

One major portion of the CE planning effort in maintaining Federal channels is compliance with Federal and state environmental legislation and implementation of agency regulations. Often for Federal navigation projects, the major concern is with the requirements of Sections 401 and 404 of the Clean

Water Act of 1977 (CWA) and Sections 102 and 103 of the Marine Protection, Research and Sanctuaries Act of 1972 (MPRSA). Each of these sections deals with the disposal of dredged material and associated potential environmental impacts. Under Section 404, an evaluation of the effects of dredged material discharge into navigable waters of the United States is made based on the US Environmental Protection Agency 404(b)1 guidelines. For certain situations, a water quality certification (Section 401) from the affected state is required. This certification ensures that the project meets state water quality requirements. For those projects where disposal of dredged material will take place in the ocean, the requirements of Sections 102 and 103 of the MPRSA must be met. These, like the requirements of the CWA, are concerned with the environmental impacts due to disposal of the dredged material. Neither of these Federal acts specifically deals with the environmental impacts from in-place sediments, only those associated with disposal. However, for Federal projects, the National Environmental Policy Act (NEPA) and the Council on Environmental Quality implementing regulations require, in the evaluation process, identification and assessment of reasonable and feasible alternatives. This assessment must include an evaluation of the existing condition and the consequences of the no-action alternative.

Due to public concern, the major area of emphasis under these regulations has been on the short-term impacts of dredging on water quality and the adjacent areas and the impact of disposal of sediments on the terrestrial or aquatic environment. The costs and benefits associated with removal of sediments have dealt with social and economic issues, since they are easily obtained from the project sponsor. The environmental impacts, both positive and negative, of removing sediments have not been assessed due to the lack of a documented process that allows for a quantification of impacts. As a result, environmental documentation has generally addressed only the environmental cost to the project of sediment disposal. Although this addresses the public concern and meets the legislative requirements, the long-term environmental benefits that may be incurred from the removal of contaminated sediments are not factored into the project's cost-benefit ratio. For Federal projects that require mitigation under NEPA, the lack of considering the benefits gained by removing a contaminated source may result in unnecessarily increasing the economic cost of the project.

BASIC CONCEPT

The basic idea is to allow the project planner the ability to identify and quantify environmental impacts from in-place sediments on the water quality of the water body, thereby allowing for an accurate evaluation of the project cost versus benefits from removing the existing sediments. Various factors will influence this assessment, including sediment characteristics, concentration and type of contaminants in the sediments, system hydrodynamics, contaminant sources, and existing and proposed uses of the water body. These and other factors will significantly affect the identification and quantification of impacts. Although many of these factors can be determined through existing data and information, others will require data collection and analysis. Without a delineated approach that provides a logical and systematic procedure to assess in-place sediments, the results may be of limited value due to misdirected efforts or inadequate data and analyses.

ACTIVITIES

Assessment of in-place contaminated sediments has a number of applications. Listed are five potential applications where the CE has direct responsibility or is involved as a cooperating agency. Also included is a short description of the issues that can be addressed for each activity. Without exception, the evaluation of in-place contaminated sediments as part of the project's environmental studies would enhance the data base for evaluating the existing conditions and the proposed action(s).

Federal Operation and Maintenance Navigation

For those maintenance dredging activities that involve contaminated sediments, the benefits gained are currently calculated in economic terms. However, disposal of this material is based on both environmental and economic considerations. Due to Federal environmental legislation, environmental issues normally govern the means of disposal. Therefore, the analysis conducted is based on meeting Federal requirements (404/103) for disposal of the dredged material. Currently the assessment does not address the influence of in-place sediments on the water column and, therefore, the data base for evaluating baseline conditions is restricted to the disposal site(s). With a better understanding of existing sediment conditions, economic factors as well as the environmental benefits from removing and isolating these sediments can be calculated and used in evaluating the project cost-benefit ratio.

Permit Activities

As a regulatory agency, the CE is required under the CWA and MPRSA to evaluate and permit the disposal of dredged material within the navigable waters of the United States. A major component of this process is evaluating those environmental factors delineated under the two acts, including determining the need for the proposed activity. By incorporating in the assessment an evaluation of in-place contaminated sediments, the CE would enhance its ability to weigh the need for the project as well as the environmental cost and benefits.

Superfund Sites

For those sites classified as Superfund sites, the presence of a known contaminant(s) at a certain concentration has been deemed harmful to humans. As a result, actions to reduce or eliminate these contaminants are considered necessary. However, for many of the aquatic Superfund sites, data on the impacts of in-place sediments are limited to bulk sediment contaminant concentrations. Data are lacking to: (a) evaluate the benefits of alternative cleanup measures; (b) define "clean" (e.g., what are acceptable levels of contaminants in the sediments); and (c) determine the impact of the sediments on the environment if no action occurs. To quantify the impacts of in-place contaminated sediments, a data base to address items a, b, and c is required.

Reservoirs

Many of the Nation's reservoirs have received materials that contain high concentrations of nutrients and toxic materials from the surrounding watershed. The increase of nutrients through runoff from man-altered environments has had a significant effect on the levels of nutrients in reservoir sediments. With the development of anoxic conditions in the reservoir, many of these nutrients are released and can provide conditions conducive to noxious algal blooms. With the accumulation and release of nutrients over a period of years, the reservoir will become eutrophic, and this process may adversely affect the existing and proposed uses of the lake. Restrictions on water contact sports, fishing, and domestic water supply are only a few of the consequences resulting from the presence of elevated nutrients in the sediments. Also, reservoirs can be a receiving body for toxic materials discharged by industry or man-modified lands. Through identification of these man-induced materials and assessment of their impact, remedial actions, if necessary, can be determined and evaluated as to their effectiveness.

Toxic Spills and Hotspots

In its role as a regulatory agency, the CE must evaluate and authorize dredging and disposal activities in the navigable waters of the United States. For those situations where toxic materials may have been introduced into the aquatic environment, it is important to determine the environmental impacts from the presence of these materials. Without this information, delineating a remedial action is, at best, difficult. Both economic and environmental cost and benefits must be considered to determine the most appropriate cleanup measure.

BENEFITS

Five basic benefits can be incurred from the assessment of in-place sediments. These benefits, although not associated with each of the above-cited activities, will provide for as improvement in the CE's ability to construct and maintain water resource projects. These basic benefits are:

a. Quantifying existing conditions, thereby providing a baseline for decisionmaking.

b. Providing a baseline to assess the potential benefits and cost associated with each proposed alternative.

c. Quantifying project benefits incurred from removal or modification of in-place contaminated sediments.

d. Providing for quantification of project cost and benefits gained for the proposed action.

e. Providing a baseline for assessing the short-term as well as the long-term benefits and cost from various long-term management strategies.

APPROACH

The conceptual process of developing and implementing an assessment protocol for in-place sediments is presented as a three-phase approach. Each phase consists of a series of steps or essential activities that lead to the development of specific data and information necessary to determine the impact of the sediments on water quality. The intent of this process is to quantify cost and benefits associated with specific alternatives as they relate to impacts from in-place contaminated sediments.

Phase I

This phase is intended to serve as the first level of assessment. At a minimum, this phase requires the defining of assessment objectives (e.g., cleanup and alternative evaluation), thereby determining the level of data and analyses required for decisionmaking. Once the objectives for the assessment are defined, the next step is the identification and collection of existing data. Usually a wealth of information is available from various Federal and state sources. The intent under Phase I is to minimize field data-collection activities; thus, a decision is needed as to the sufficiency of the existing data for evaluating the impact of in-place sediments. If existing data are insufficient, data gaps are identified, validated, and screened based on factors such as potential for development and the time and resources needed to fill the gaps. If the needs are valid, a data-collection effort is planned. Unvalidated requirements result in either no further evaluation of the in-place sediments or a reassessment of the study objectives. Once the initial data requirements are met or, if necessary, additional data requirements are identified, Phase I is completed.

Phase II

This phase consists of collecting required additional data and conducting a data analysis of sufficient detail to evaluate the impact of in-place sediments as they relate to the objectives delineated under Phase I.

Phase III

This phase uses the results obtained under Phases I and II to conduct the detailed evaluation required to address the study objectives. This process will occur in conjunction with alternative evaluations that consider engineering, economic, social, and environmental cost and benefits.

In addition to Phases I through III, consideration must also be given to the implementation of any alternative or proposed action and monitoring of the results. Without a feedback mechanism, the validity of the analysis of both the impact of in-place sediments on water quality and the benefits from their removal or alteration cannot be fully known.

CASE STUDY

At the request of the US Army Engineer District, Chicago, the impact of in-place contaminated sediments on the water quality in the Grand Calumet River/Indiana Harbor Canal (GCR/IHC) system was investigated during the period 1985 to 1986 in conjunction with a study on disposal alternatives for PCB-contaminated sediments from Indiana Harbor (US Army Engineer Waterways Experiment Station 1987). It was the intent of the Chicago District to use the results of this study to identify and quantify the potential benefits gained from dredging contaminated sediments from a Federally maintained project, thereby removing a continuing contaminant source for Lake Michigan. The US Environmental Protection Agency was also interested in the approach used in the study for assessing cleanup alternatives for the GCR/IHC system. The approach used in this study was limited to the assessment of existing data. A brief discussion from the report of the study results (Brannon et al. 1986) is provided to illustrate the approach and its limitations and strengths.

The approach used for the evaluation consisted of obtaining and analyzing existing information obtained from Federal and non-Federal sources, including data files, in-house and published agency reports, and literature from scientific publications. The analysis focused on sediment-water interactions and their relationship to water quality, methods for estimating impacts of sediment-water interactions on water quality, and sediment and water quality data from the GCR/IHC system.

The scientific literature consistently identified the movement of suspended sediment as the major mechanism for transport of sediment-associated contaminants. Other routes of contaminant mobilization from the sediment are through release of adsorbed contaminants from resuspended sediments and diffusion of contaminants from in-place sediment. Based on the literature and system data, the relative importance of mechanisms controlling contaminant movement from sediment in the GCR/IHC is in the following order: transport of contaminants associated with particulates > transport of contaminants desorbed from suspended particulates > transport of soluble contaminants released from deposited sediment. Another mechanism for contaminant movement is through bioaccumulation. At present, this last mechanism is of minor importance due to the limited numbers of pollution-tolerant fish and low numbers of less pollution-tolerant fish species in the GCR/IHC.

Sediment oxygen demand (SOD) is an important oxygen consumption process and is also instrumental in turning on and off the sediment surface layer as a "valve" for oxidized and reduced materials. The SOD is also a key parameter in water quality models that include dissolved oxygen utilization and balance. From the data available for waterways in the Chicago area, it appears that SOD is frequently found to be quite high; this is not unexpected in streams that are moderately to heavily polluted. The values given in published reports for the GCR/IHC are much lower than values given for similarly polluted streams in the Chicago area and thus are probably too low. Therefore, it is not possible to state with any degree of certainty the existing SOD values for the GCR/IHC system without laboratory or field studies.

Diffusion rates of PCBs into the water column from deposited sediments were developed by estimating equilibrium partitioning values of PCBs in sediment interstitial waters and appropriate diffusion equations. The estimated diffusion rates of PCBs in the sediments indicated that, in the absence of disturbances, movement of soluble PCBs is relatively minor. On the average, 1 sq m of bottom sediment would annually contribute 0.025 ng of PCBs to the overlying water. This value would be increased in the presence of bioturbation, but would remain a fairly minor component of contaminant input into the overlying water.

Results of equilibrium partitioning calculations made using data specific for the GCR/IHC system indicate that Food and Drug Administration limits on PCB concentrations in fish tissue for human consumption will be exceeded; this is provided that fish remain in the Indiana Harbor Canal for a sufficient period to come to equilibrium with sediment PCBs. Unfortunately, equilibrium partitioning cannot be conducted on compounds other than hydrophobic organic compounds for which sediment data are available. As a result, this procedure is restricted in evaluating polar organic compounds, heavy metals, and those hydrophobic organic compounds known to be present in the Indiana Harbor Canal sediments, but for which sediment data are unavailable. In addition, a major weakness of the equilibrium partitioning approach is that the time necessary to reach equilibrium between sediment contaminants and the biota is unknown.

Based on a number of wastewater allocation models and water quality monitoring studies, estimates have been made on a number of pollutants from combined sewer overflows (CSOs) and urban runoff. However, pollutant loading estimates from other sources including waste fills are lacking. This information, along with data on toxic organic loadings from point and nonpoint sources, is essential to determine contaminant loading to Indiana Harbor.

To evaluate the benefits of dredging the Indiana Harbor Federal channel, knowledge of sediment sources and contaminant loading and how these contaminants move through the system is necessary. At present, this information is lacking; however, based on past studies of other harbor systems, it is anticipated that CSOs and urban runoff can be significant sources of sediments and contaminants during storm events. Further, these sources of contaminant and sediment may be the major long-term contributors to the Federal channel in the Indiana Harbor.

Under nondredging conditions, there are two major avenues for the resuspension and transport of sediment from the GCR/IHC system--normal ship traffic and storm events. Examination of data from bathymetric surveys for the years 1972, 1976, 1980, and 1984 indicates that Indiana Harbor Canal has reached a shoaled equilibrium with the channel thalweg provided by passage of boat traffic. A sharp decrease in the channel depth was found between the years 1972 and 1976, with progressively smaller depth changes since 1976. The 1984 survey shows only a small overall change from the 1980 survey, an indication that the total amount of shoal material has not changed but may only be redistributed.

The data base for the GCR/IHC has only limited data on contaminant releases during interactions between suspended sediment and water. Velocity data and information on sediment resuspension are also very limited. To determine the mass of contaminants transported from the sediments during dredging and nondredging conditions, it will probably be necessary to use mathematical models. Further, prediction of the ultimate fate of contaminants in the GCR/IHC system, required for evaluation of overall water quality, may be aided by the use of contaminant models, but additional field and laboratory data should be obtained prior to intensive contaminant fate modeling studies.

Results of this study have shown that the available data allow only rough estimates, such as those in the CE's Indiana Harbor Environmental Impact Statement, of the sediment loadings, sediment yield, and benefits that would accrue from dredging the Indiana Harbor Canal. Historical dredging data strongly suggest, however, that dredging the Indiana Harbor Canal would allow it to act as a sediment trap, retaining contaminated sediment that would otherwise be transported into Lake Michigan. Additional data must also be collected before analytical techniques more sophisticated than those already employed can be applied to the GCR/IHC system for either metals or toxic organics. More detailed hydrodynamic and suspended sediment transport data are also necessary to allow use of more sophisticated analytical techniques for evaluating sediment sources, sediment resuspension, and sediment transport. Therefore, the immediate detailed application of either hydrodynamic or contaminant models is not recommended.

SUMMARY AND CONCLUSIONS

This paper reviews a concept that can be used by CE planners to identify and quantify the environmental impacts from in-place contaminated sediments on a water body. The concept can be applied through a three-phase approach that allows quantification of cost and benefits associated with in-place sediments and proposed actions. By using a three-phase approach that incorporates the maximum use of existing data during Phase I, cost for field data collection and analyses can be minimized. Further, by using a phased approach, decision points can be incorporated during each phase for assessing the proposed benefits to be gained from collection and analyses of additional data, which may be disproportionate to the incurred cost.

In the GCR/IHC case study, the approach was limited to Phase I, with limited data collection under Phase II. Based on the analyses of existing data, it was concluded that insufficient data exist to quantify benefits. A report was prepared that delineated the findings and made recommendations on additional studies. To provide for flexibility, recommendations for future studies were given at three study levels. This approach allows the Chicago District the option of tailoring studies to meet specific objectives for maximum benefit at lowest cost.

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RECENT STUDIES CONCERNING THE CAPPING OF CONTAMINATED DREDGED MATERIAL

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ABSTRACT

Disposal of contaminated sediments in the marine environment through "capping" with cleaner materials is a management option that has been used extensively during recent years, particularly in the New England region. Most of the capping projects have been restricted to quiescent, shallow-water (20 to 30 m) environments; however, as a result of monitoring programs associated with these projects, a body of knowledge concerning the creation of capped disposal mounds has been developed that can be used to predict the consequences of extending such procedures to deeper waters. The application of capping technology to deeper water is extremely important, because disposal site designation programs currently under way throughout the United States are predominantly aimed at water depths of 100 m or greater. Recent field studies at the New York Experimental Mud Dump (EMD) site and the Foul Area Disposal Site (FADS) in Massachusetts Bay have utilized modern instrumentation and sampling procedures to examine the long-term stability of capped deposits in the open ocean and to predict the behavior of both contaminated and cleaner capping materials during disposal operations in water depths approaching 100 m. The results of these studies confirm that, with proper disposal management, capping in deeper waters should be considered as a feasible option for disposal of contaminated sediments.

INTRODUCTION

Capping of contaminated dredged material with sediment relatively free of contaminants has been used for a number of years as a management technique for reducing the potential environmental impact of open-water disposal. The approach, which has been used successfully in a number of areas, was first employed in 1977 by the New England Division of the Corps of Engineers at the New London Disposal Site (NLDS). This project took place in 20 m of water south of the Thames River in the eastern end of Long Island Sound. The success of that operation has led to continued application and field observations of the technique, including major disposal operations at the Central Long Island Sound (CLIS) disposal site and at the New York EMD site in open ocean waters. Additional studies, stressing laboratory observations on the effectiveness of capping, have been conducted at the US Army Engineer Waterways Experiment Station (WES).

As a results of these studies, a great deal has been learned relative to the effectiveness of capping in the marine environment. However, during each proposed capping operation, major issues must be addressed and fully understood for that specific project to ensure accurate prediction of the behavior of both contaminated and capping material. These issues include:

a. Thickness of the cap - related to the effectiveness of the capping material in isolating the contaminants, particularly the potential for leaching of contaminants and effects of bioturbation.

b. Placement of the cap - related to navigation control during disposal to ensure coverage of contaminated sediments, and to the mixing and displacement of contaminated sediment by the capping material.

c. Stability of the cap - related to the support of the cap by typical contaminated material (high in water content) and resistance to erosion and transport of capping material.

Previous studies of capping have indicated that, with careful management, the operation can be successful in relatively quiescent, shallow waters. However, the major issues with regard to capping in the United States are now related to the depth at which capping can be accomplished. Designation of new disposal sites in water depths greater than 100 m, where capping will be a management option, are currently under way in the New England region, at the FADS in Massachusetts Bay, in the Seattle area at the Everett Homeport disposal site, and potentially in the New York region at a site to the designated farther offshore than the EMD site.

Permits for capping of contaminated sediments at these deeper disposal sites will certainly require monitoring of the disposal operation and the resulting deposit. Recent advances in instrumentation and sampling procedures permit reliable monitoring of capping projects and effective management and control of the disposal operations. Examples of the instrumentation used for execution and monitoring of deeper capping projects include:

a. Precision navigation - ensures correct placement of contaminated and capping sediments and accurate sampling of abrupt transitions during monitoring programs.

b. Precision bathymetry - allows sequential monitoring of the mass balance of sediment at the disposal site to assess the effectiveness of capping and long-term stability of the cap.

c. Advanced acoustic measurements - plume tracking instrumentation that measures the dispersal of sediments during disposal while sidescan sonars and subbottom profilers provide accurate measurement of sediment distribution in the vicinity of the capped disposal mound.

d. Sediment profile photography - REMOTS provides the ability to assess the distribution and characteristics of near-surface sediments, particularly the cap material, with a resolution unattainable with acoustic measurements or conventional sampling procedures.

This paper briefly reviews the results of previous capping operations to place the current work in perspective and to emphasize recent measurements that address the feasibility of extending the capping option to deeper waters.

HISTORY OF CAPPING OPERATIONS

The first example of capping used as a disposal management strategy occurred at the NLDS in 1977 when contaminated sediments from the vicinity of dock areas were dredged and covered with progressively cleaner sediments as dredging proceeded from the head of the estuary to the mouth. Capping of the contaminated sediments was ensured, because the mass of material used for capping was more than 30 times greater than that of the contaminated material. However, such an abundance of capping material is not always available, and for capping to become a truly feasible management strategy, procedures for capping with much less material had to be developed.

The first field study of controlled capping of contaminated material with more reasonable amounts of capping material took place at the CLIS in 1979. During this project, two disposal mounds were formed, each with approximately 30,000 cu m of contaminated sediments from Stamford, Conn. These deposits were then capped, one with approximately 76,000 cu m of silt and the other with 33,000 cu m of sand dredged from New Haven harbor. This study produced several important conclusions, outlined below, which were applied to future capping projects.

a. Disposal of contaminated sediments must be tightly controlled. This is necessary to reduce the spatial distribution of material to be capped and can be accomplished through use of taut-wire disposal buoys or precision navigation control.

b. Disposal of capping material must be spread over larger area. Dispersal of cap material is necessary to ensure adequate capping of the margins of the contaminated deposit and is particularly important for silt capping material, which does not spread as evenly as sand.

c. Silt develops thicker cap than sand. Silt caps do not disperse as readily during disposal; however, the greater thickness is needed because the depth of bioturbation reaches deeper in silt than in sand.

d. Silt cap recolonized with fauna similar to surrounding silt environment; sand cap, with completely different species. Recolonization of both mounds occurred as expected, and impacts to the surrounding environment appear negligible.

e. Caps are resistant to erosion. Once stabilized, both the silt and sand caps have remained essentially unchanged for more than 8 years (including two hurricanes).

A second study, utilizing similar sediments, was conducted 2 years later with comparable results. In this study the placement of capping material was the most significant factor affecting the isolation of contaminated sediments. In spite of efforts to distribute the cap evenly, additional disposal of silt material was required to achieve adequate coverage.

Other capping operations that have been successfully accomplished since 1979 include:

a. Disposal and capping in borrow pits. This approach has been suggested as an alternative for New York Harbor, but is currently on hold pending studies of the environmental significance of the borrow pits.

b. Dredging of a depression, filling with contaminated sediments, and capping with displaced material. Successfully accomplished in Norwalk, Conn., but restricted to shallow-water environments. This approach has been proposed for disposal of PCB-contaminated sediments at the New Bedford Superfund site.

c. Open-water capping at the New York EMD site. Successful disposal of 522,000 cu m of contaminated material covered by 1,200,000 cu m of clean sand that has persisted on the open shelf for 7 years. Excellent management of continuous capping operations within the EMD site requires identification of cap material prior to issuing permit for disposal of contaminated sediments.

As a result of these studies, the factors affecting capping can be predicted with some accuracy, particularly the amount of material needed to create an effective cap and the controls necessary to dispose of the contaminated sediment and capping material in a stable deposit.

RECENT CAPPING OBSERVATIONS

Two major field studies recently completed at the New York EMD site and the FADS in Massachusetts Bay have made extensive use of new monitoring tools and procedures to develop integrated and comprehensive analysis of the environmental effects of capping contaminated sediments. The objectives of the study at the EMD were to assess the long-term (5 years) stability of the sand cap deposited over the contaminated sediments in the open-shelf environment. The objectives of the FADS study were to assess the behavior and distribution of sediments deposited under carefully controlled conditions in water 90 m deep to evaluate the feasibility of capping in such water depths. The following paragraphs provide an overview of the results of those studies as they apply to future capping operations in deep-water environments.

Experimental Mud Dump Site

During November 1986, Science Applications International Corporation, in cooperation with the New York District and under contract to the WES, conducted extensive field observations at the EMD. The objectives of this program were to:

a. Provide accurate bathymetric data to describe the overall topography of the Mud Dump Site (MDS).

b. Define conditions at the boundaries of the MDS.

c. Assess the long-term stability of the sand cap within the EMD.

d. Investigate bioturbation on the sand cap.

e. Make recommendations for a long-term monitoring program for the EMD and MDS.

The environmental sensor systems used to conduct these studies included:

a. Computerized Navigation and Data Acquisition System - used to provide accurate control of sampling and survey locations and to acquire precision bathymetric data for comparison with previous surveys.

b. Computerized Subbottom Profiler System - used to provide continuous record of cap thickness for comparison with cores obtained immediately following disposal.

c. REMOTS Sediment Profile Camera - used to map the distribution of small-scale dredged material layers, to detect the presence of the sand cap on the margins of the site, and to assess the status of infaunal recolonization on the cap material.

The precision bathymetric survey acquired during this project (Figure 1) was compared with data obtained by the New York District immediately following disposal of the cap material through development of contour difference charts. The early survey data were digitized and corrected, assuming no change in the ambient depth of the bottom, to allow comparison between pre- and post-capping topography and with the existing topography as determined by the current survey. Results of these comparisons indicated that a cap of approximately 1.5 to 2 m covered most of the contaminated material (Figure 2) and that this cap was essentially unchanged during the following 5 years (Figure 3).

This result was supported by the subbottom profile measurements that indicated a surface deposit of more than 75-percent sand over the disposal area (Figure 4) with a mean thickness of 1.5 m in the vicinity of the disposal mound (Figure 5). Subbottom profiles across the disposal site (Figure 6) demonstrated that the cap was continuous and that patches of fine-grained material that were observed on the surface of the mound were underlain by sand, suggesting intermittent deposition on the surface of the mound.

The REMOTS photography also indicated that the sand cap was in place over the disposal site. The "Benthic Process" map (Figure 7) shows clean, fine-grained, high-reflectance sand in the vicinity of the EMD covering an area of 500 by 700 m. However, the photographs taken within this area also show bed forms and, in some cases, alternating layers of sand and mud. These photographs suggest that there is some sediment resuspension and movement on the surface of the mound, but that the entire region must be in equilibrium, because there has been no significant loss of cap material over time.

The recolonization of the disposal mound also indicates that disturbance of the surface occurs, because Stage I (opportunistic) species are the predominant infaunal successional stage on the disposal mound (Figure 8). However,

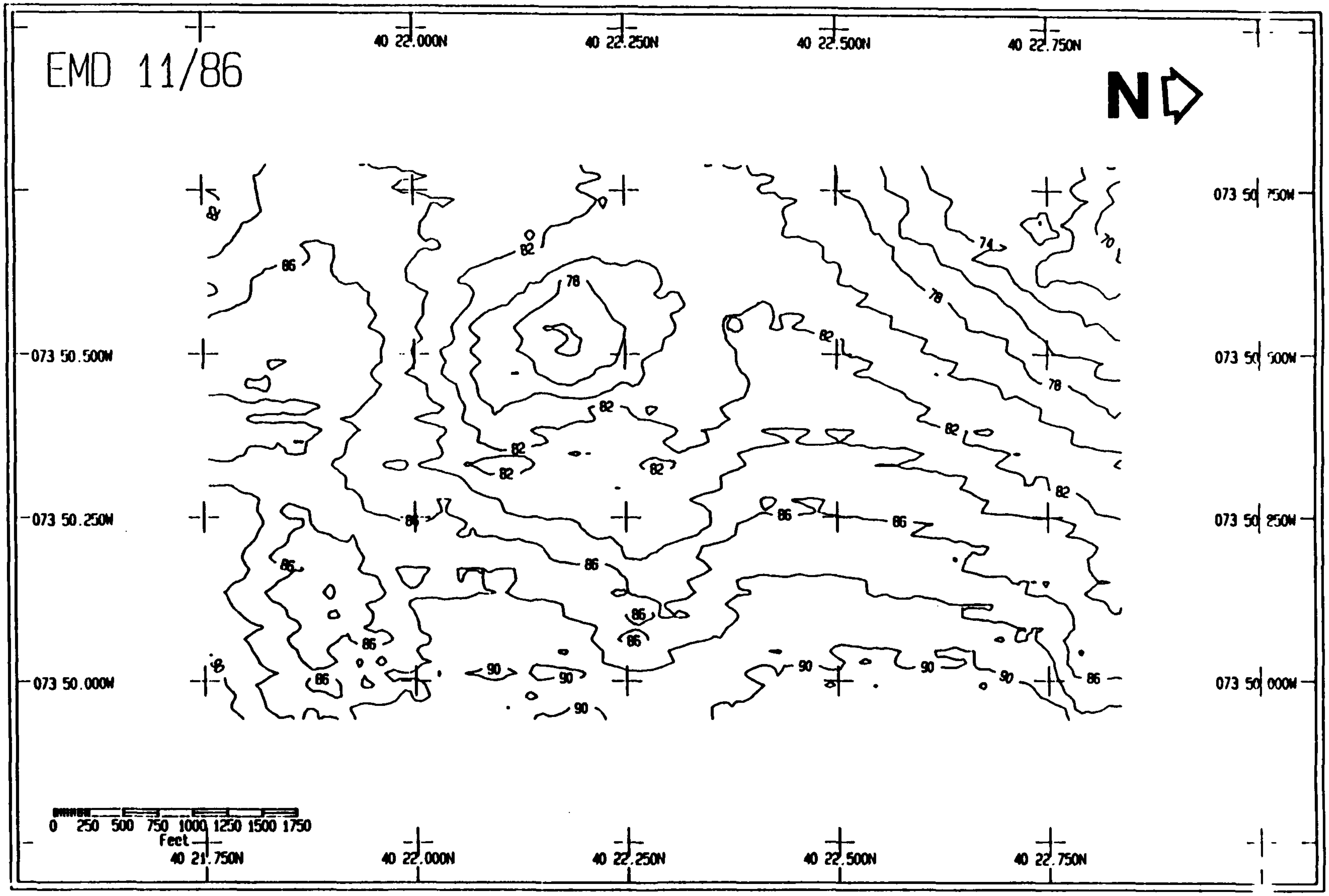

Figure 1. Contour chart at EMD 5 years after placement of the sand cap

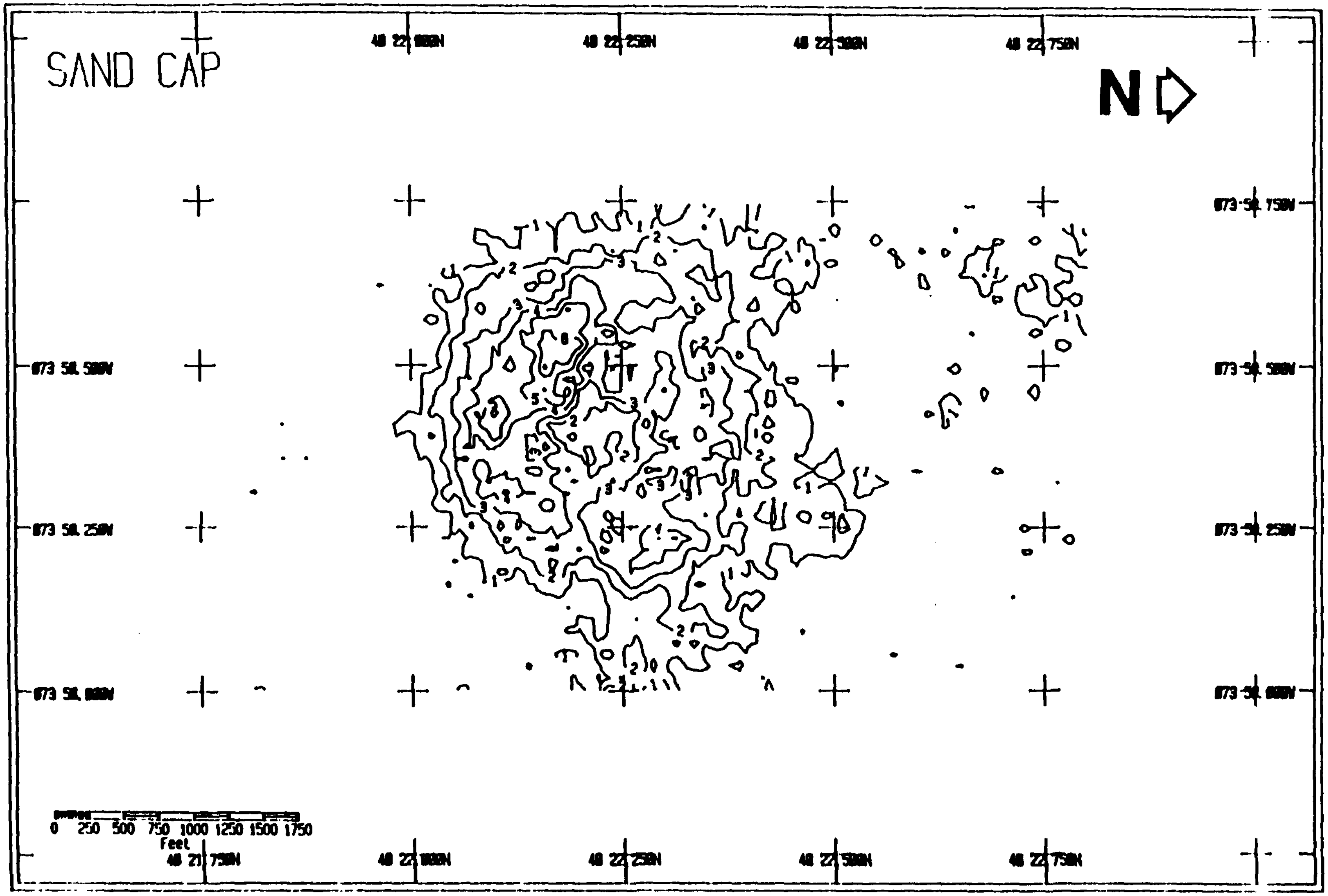

Figure 2. Change in contours at EMD resulting from placement of sand cap, August 1981

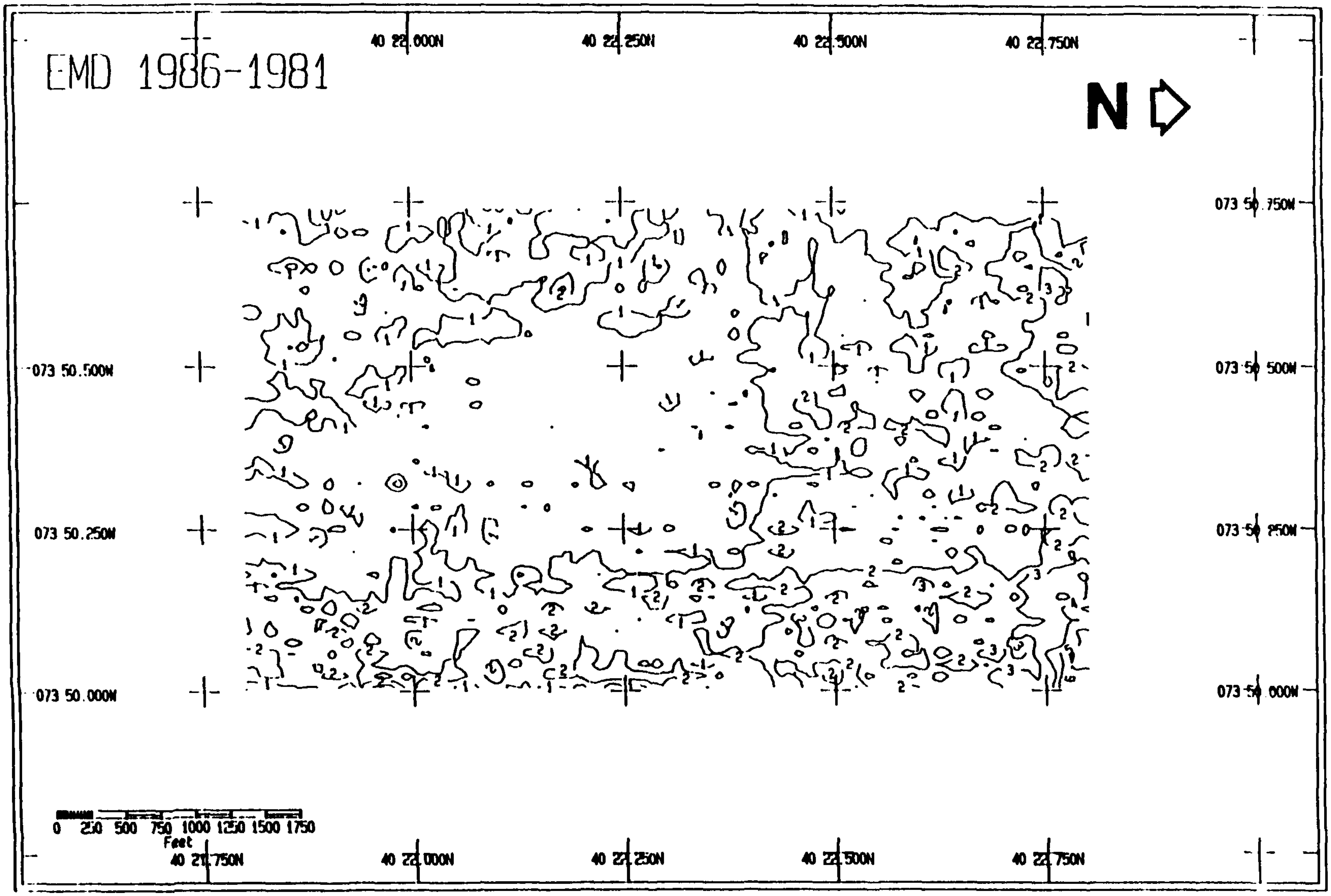

Figure 3. Change in contours at EMD over 5-year period: November 1986-August 1981

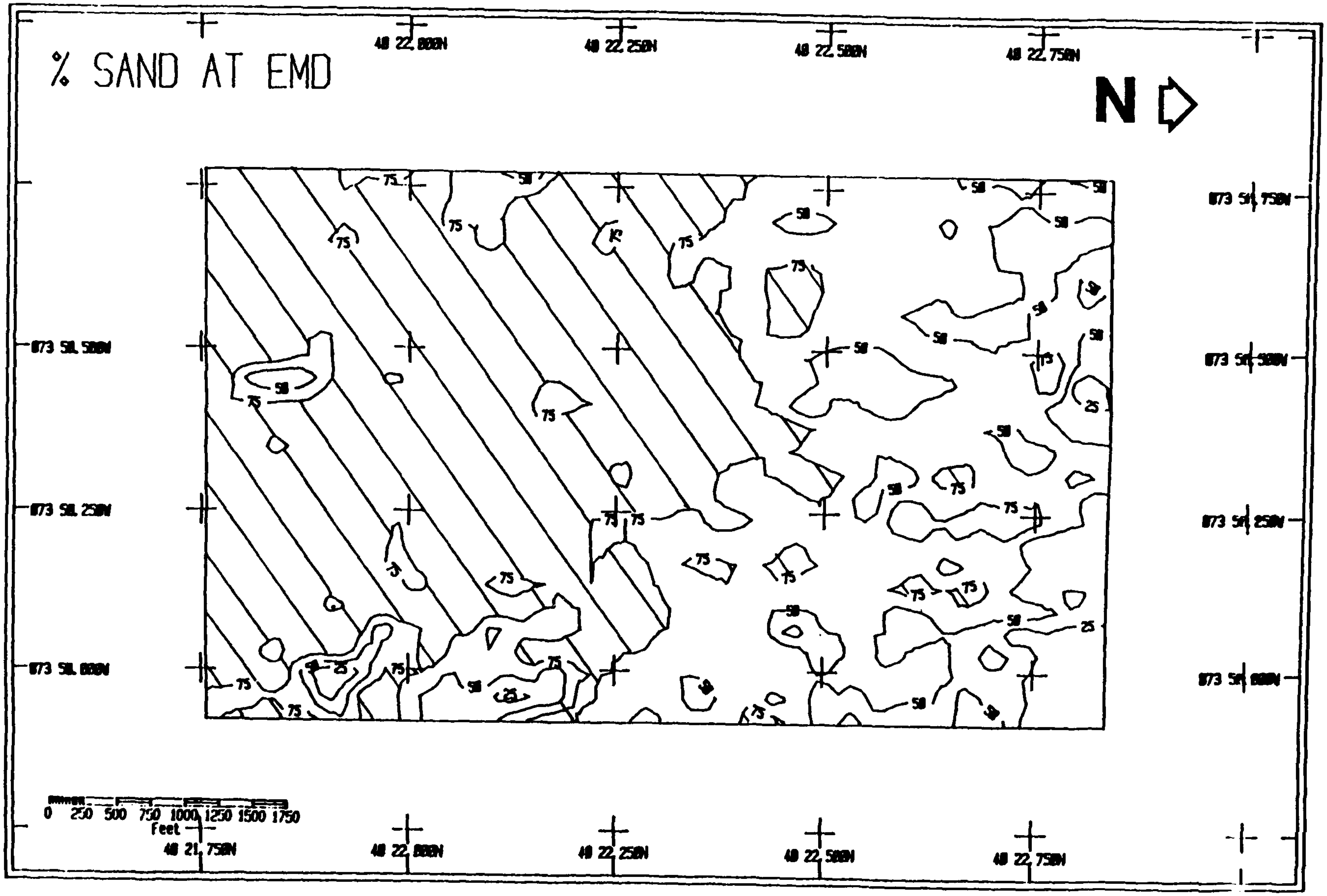

Figure 4. Distribution of percent sand at the EMD, November 1986

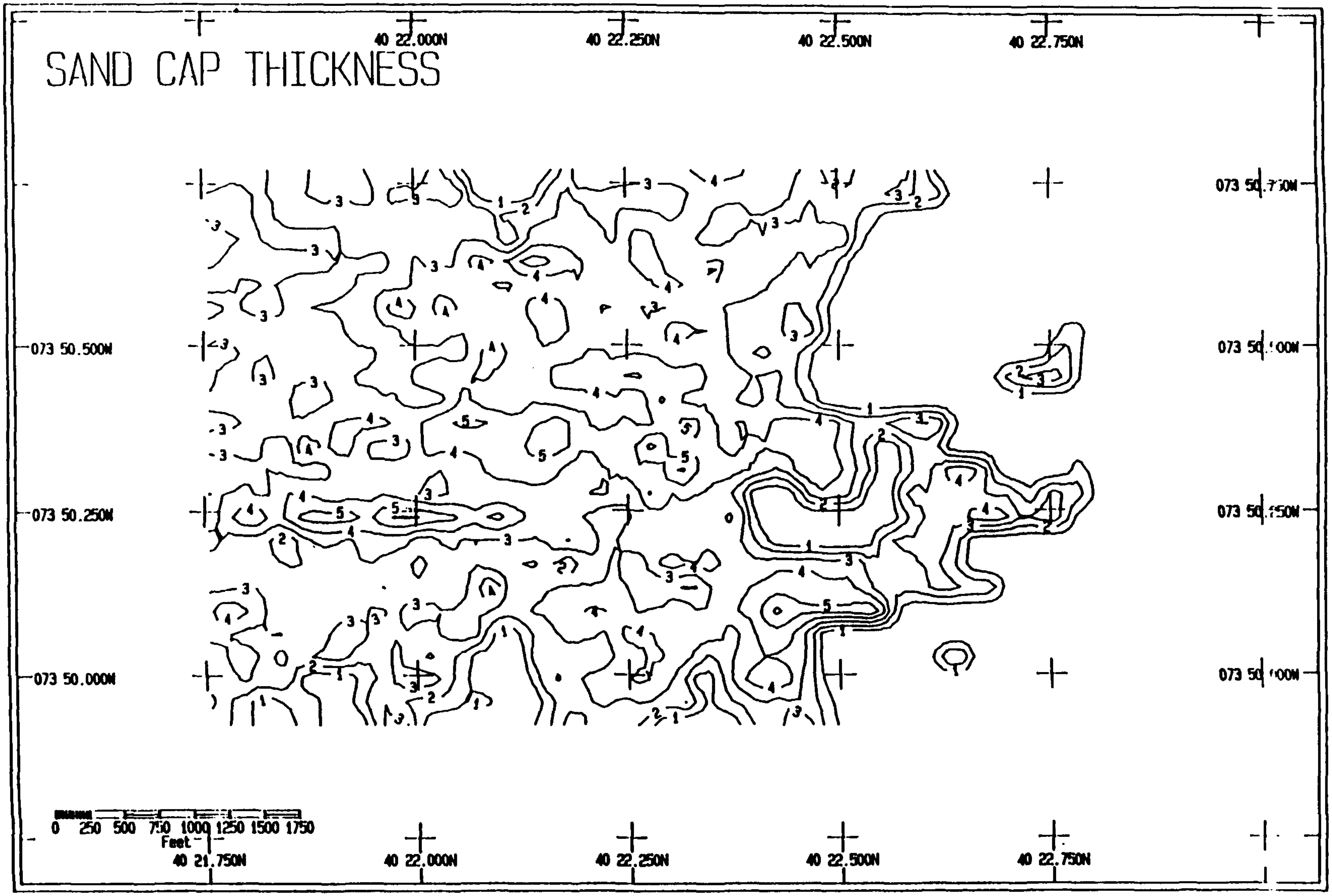

Figure 5. Thickness of sand cap at the EMD, November 1986

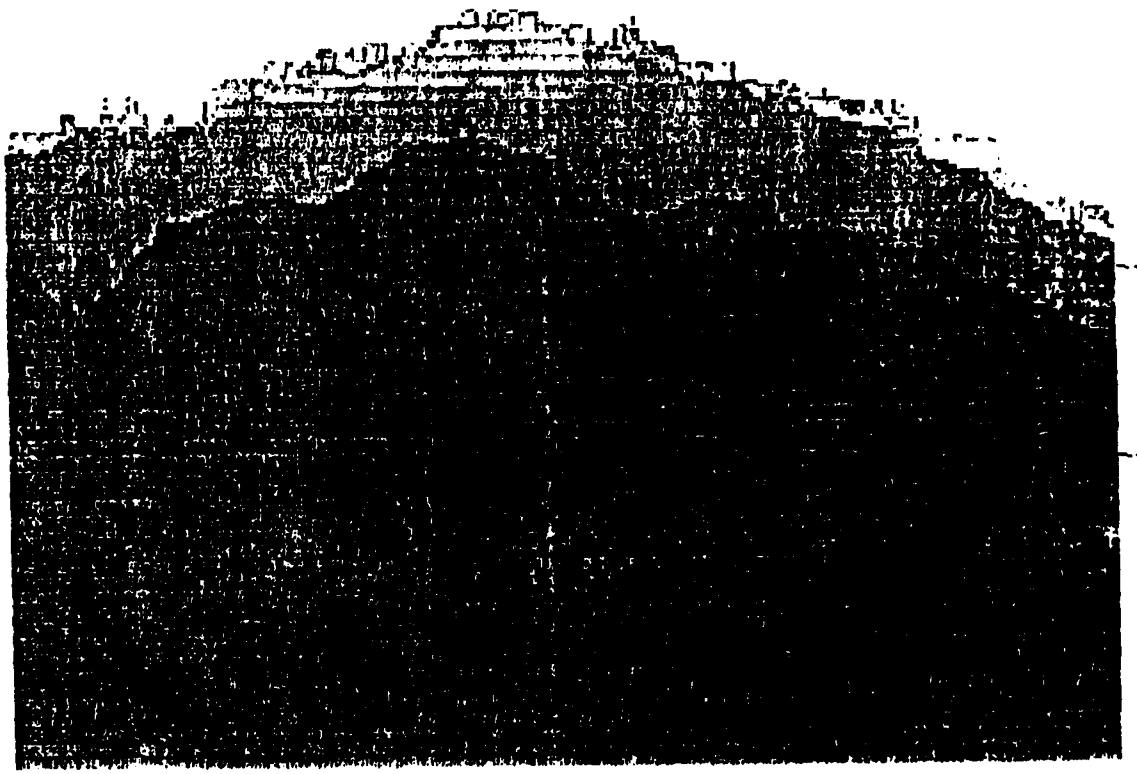

Figure 6. Representative trace of acoustic impedance at the EMD

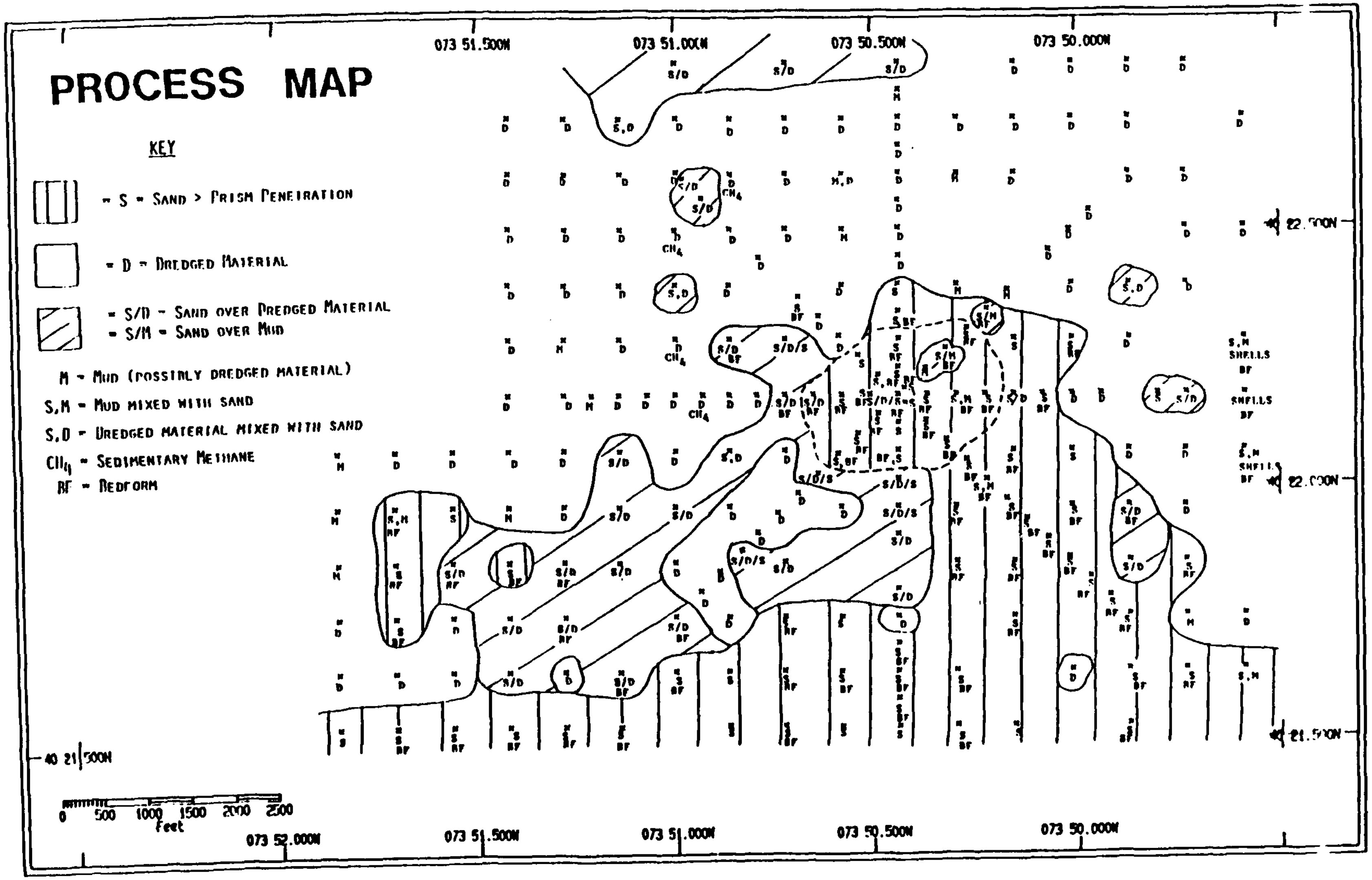

Figure 7. Distribution of sand cap at EMD as determined from REMOTS photography, November 1986

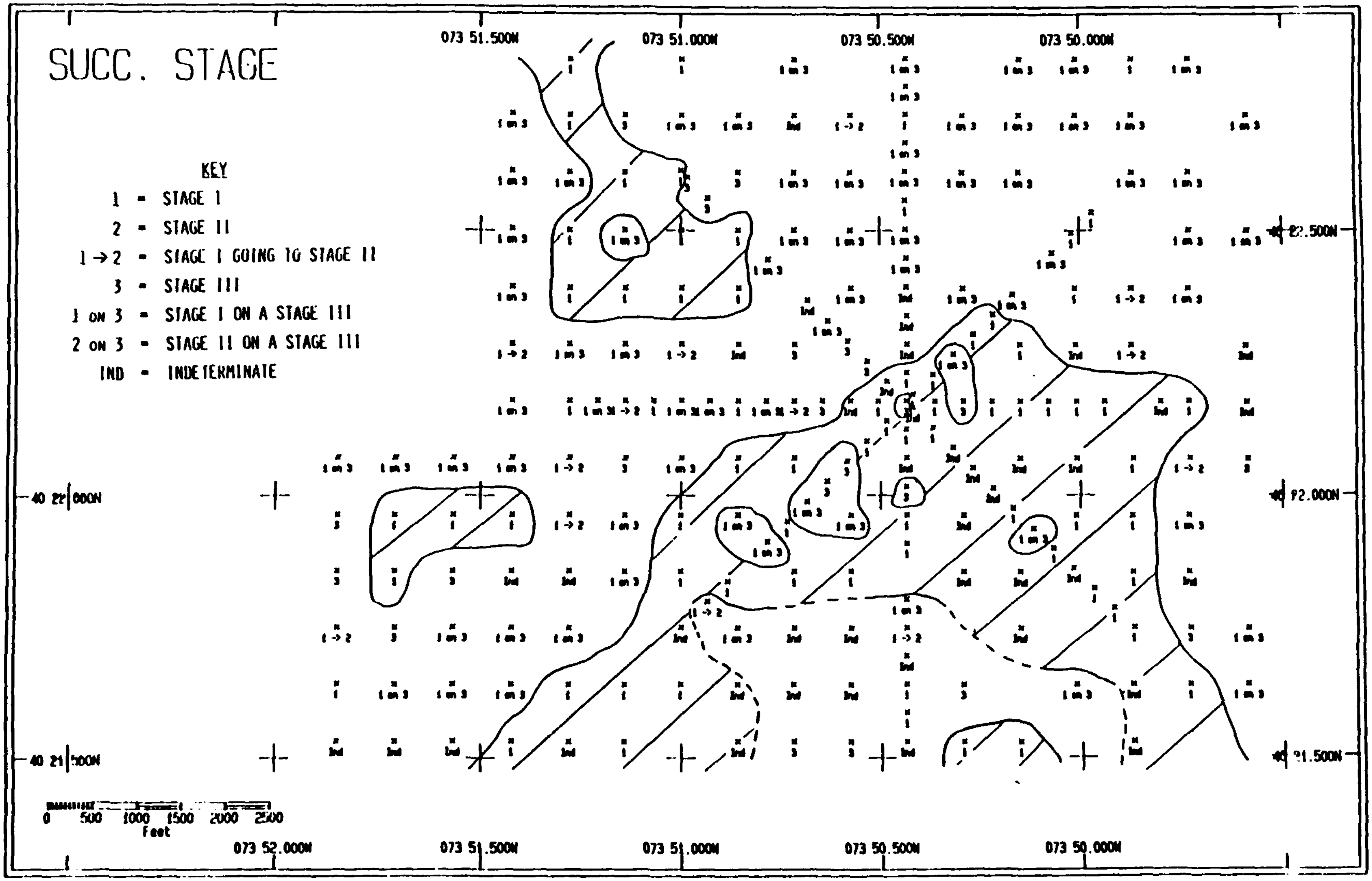

Figure 8. Distribution of infaunal successional stages at the EMD

it should be noted that Stage I species are present throughout the disposal site, suggesting relatively active bottom conditions. The presence of Stage I species on the sand cap means that bioturbation will penetrate only a few centimetres into the cap, and therefore, isolation of the contaminated material can be expected. On the flanks of the mound, where the cap thickness is not so great and some Stage III organisms are present, mixing of the contaminated sediment can be expected.

In summary, the cap at the EMD has persisted for a period of 5 years, with no significant loss of material. It has maintained equilibrium with the surrounding environment so that a thickness of 1.5 m over most of the disposal site remains as an effective cap for isolation of contaminated materials. The fact that this cap has persisted in relatively shallow (20 to 30 m), exposed waters suggests that containment of contaminated materials can be accomplished even in relatively high-energy environments.

Foul Area Disposal Site

During 1986 and 1987, extensive disposal site designation studies were undertaken at FADS, which included investigation as to the potential effects of capping operations in the 90-m water depths encountered. Disposal at FADS is generally conducted from disposal scows, and occasionally from hopper dredges. Sediment is transported to the bottom in the classical manner, resulting in the three phases of disposal which affect the behavior of dredged material:

a. The Convective Descent Phase, during which the majority of the dredged material is transported to the bottom under the influence of gravity as a concentrated cloud of material.

b. The Dynamic Collapse Phase, following impact with the bottom where the vertical momentum present during the Convective Descent Phase is transferred to horizontal spreading of the material.

c. The Passive Dispersion Phase, following loss of momentum from the disposal operation, when ambient currents and turbulence determine the transport and spread of material.

In shallow water, cohesive sediments disposed by clamshell/scow operations create a distinct mound formation with thin flank deposits, while sands or less cohesive, high water-content sediments characteristic of the contaminated material will produce a broader, more uniform deposit. At FADS, any mounding of cohesive sediments would be less prevalent because the deeper water causes more entrainment of water during the Convective Descent Phase and a larger radius of impact.

The fact that the dredged material reaches the bottom during the Convective Descent Phase is important for assessing the potential transport and spread of material during the disposal process. The rate of convective descent has been measured as approximately 1 m/sec during three separate disposal operations. Therefore, at the FADS site, where the average depth is approximately 90 m, the majority of material can be expected to impact the bottom within 2 min of disposal. Because the maximum current velocities measured at FADS were approximately 30 cm/sec, the worst-case transport of material during convective descent would amount to only 36 m. This is well within the error of positioning of the disposal vessels and, therefore, the effect of currents on the shape or distribution of the disposed contaminated dredged material or cap deposit would be negligible.

Regardless of whether the disposal operation is conducted with a hopper dredge or scow, both theoretical and observational data indicate that the majority of the dredged material will be transported to the bottom at FADS as a discrete plume during the convective descent phase. When this material reaches the bottom, the vertical momentum will be transferred to horizontal momentum during the dynamic collapse phase. Depending on the geotechnical properties of the sediment, one of two types of deposit will form. If the material consists primarily of cohesive silt, a concentration of cohesive clumps, interspersed with soft mud, will be created. This deposit will be surrounded by a deposit of mud that extends beyond the clump area for some distance. If the material is sand or noncohesive silt, the deposit can be expected to be more uniform. In either case, the overall spread of the material will be similar, because the potential energy available for both types of disposal is essentially identical and the transfer of vertical to horizontal momentum will take place in the same manner when the material impacts the bottom. The main difference in the deposit results from the distribution of kinetic energy between the large cohesive clumps, which will absorb a great deal of energy with little horizontal movement, and the more fluid muds, which will readily flow until that energy is dissipated.

The overall size and thickness of the resulting disposal mound depend on the amount of material disposed at the site and the navigation control exercised during the disposal effort. To ensure that disposal of contaminated dredged material occurred in a controlled manner, a taut-wire moored buoy was deployed at this site. Using such a buoy, restriction of the disposal operation to a 50-m radius was possible, and the input of dredged material could be considered as a point source. In this manner, overall management of the distribution of the contaminated dredged material was possible through controlled placement of the buoy.

Recent work using the REMOTS camera, completed in January 1987, has demonstrated that the disposal of dredged material under tight control at FADS resulted in a broad, low deposit spread evenly over an area similar to that covered by disposal in more shallow waters. The major difference in the deposits results from the greater spread of cohesive clumps, which inhibits formation of the topographic feature (i.e., disposal mound). Figure 9 indicates the distribution of dredged material as detected by the REMOTS camera following disposal of approximately 200,000 cu m. This operation resulted in a deposit with a thin layer of dredged material extending over a circular area with a radius of 500 m, a distance comparable to similar volumes deposited in the shallow water of Long Island Sound.

Figure 10 presents a schematic of the results of disposal in shallow water, as compared with the deeper water of the FADS. The major difference between the two regions results from the loss of kinetic energy through entrainment of water during the convective descent phase so that, in deeper water when bottom impact occurs, the lateral motion during dynamic collapse is substantially less than in shallow water. The result is a more uniform, broad deposit over essentially the same area of bottom.

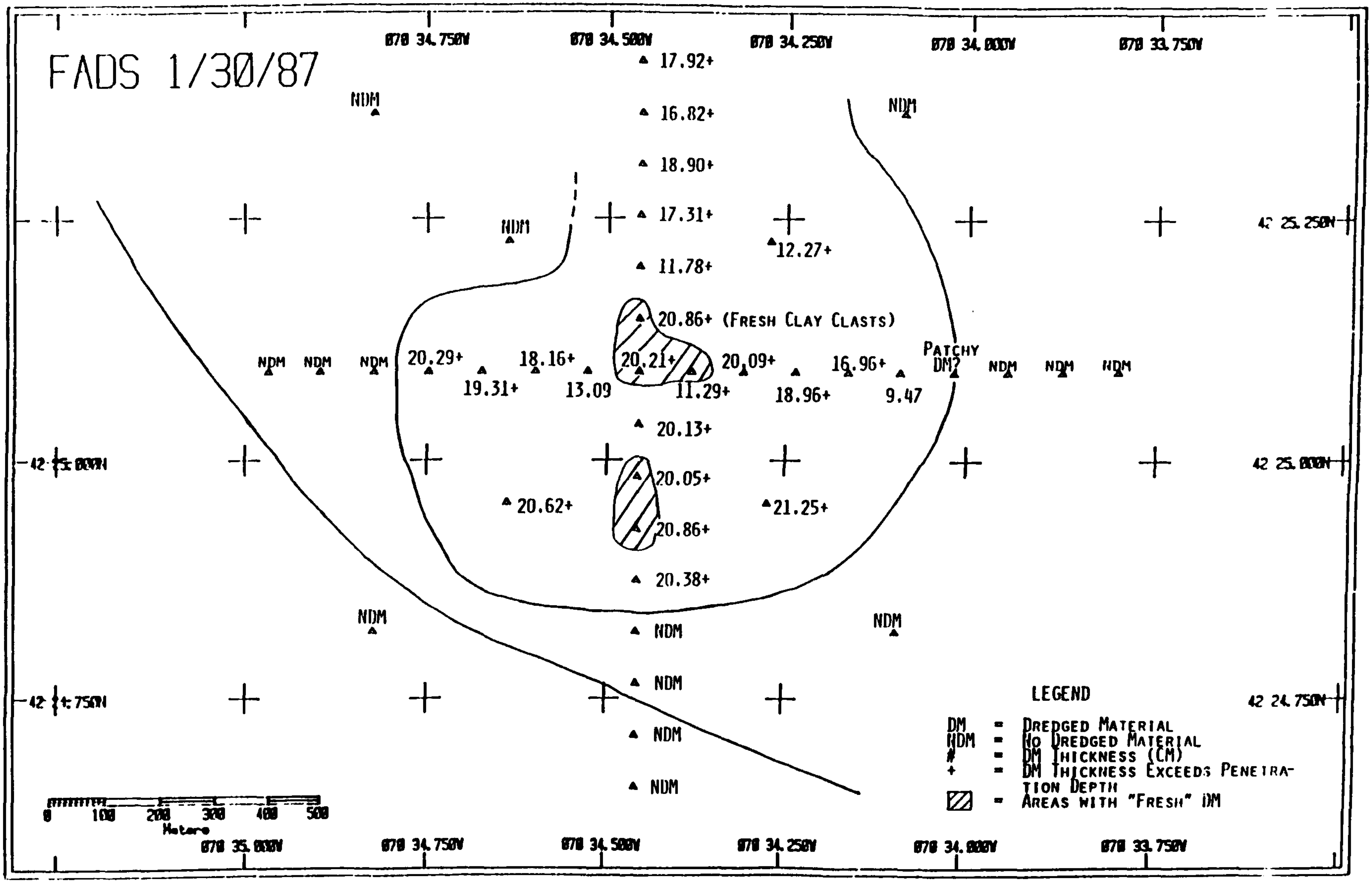

Figure 9. Distribution of dredged material at FADS as measured by REMOTS photography, January 1987

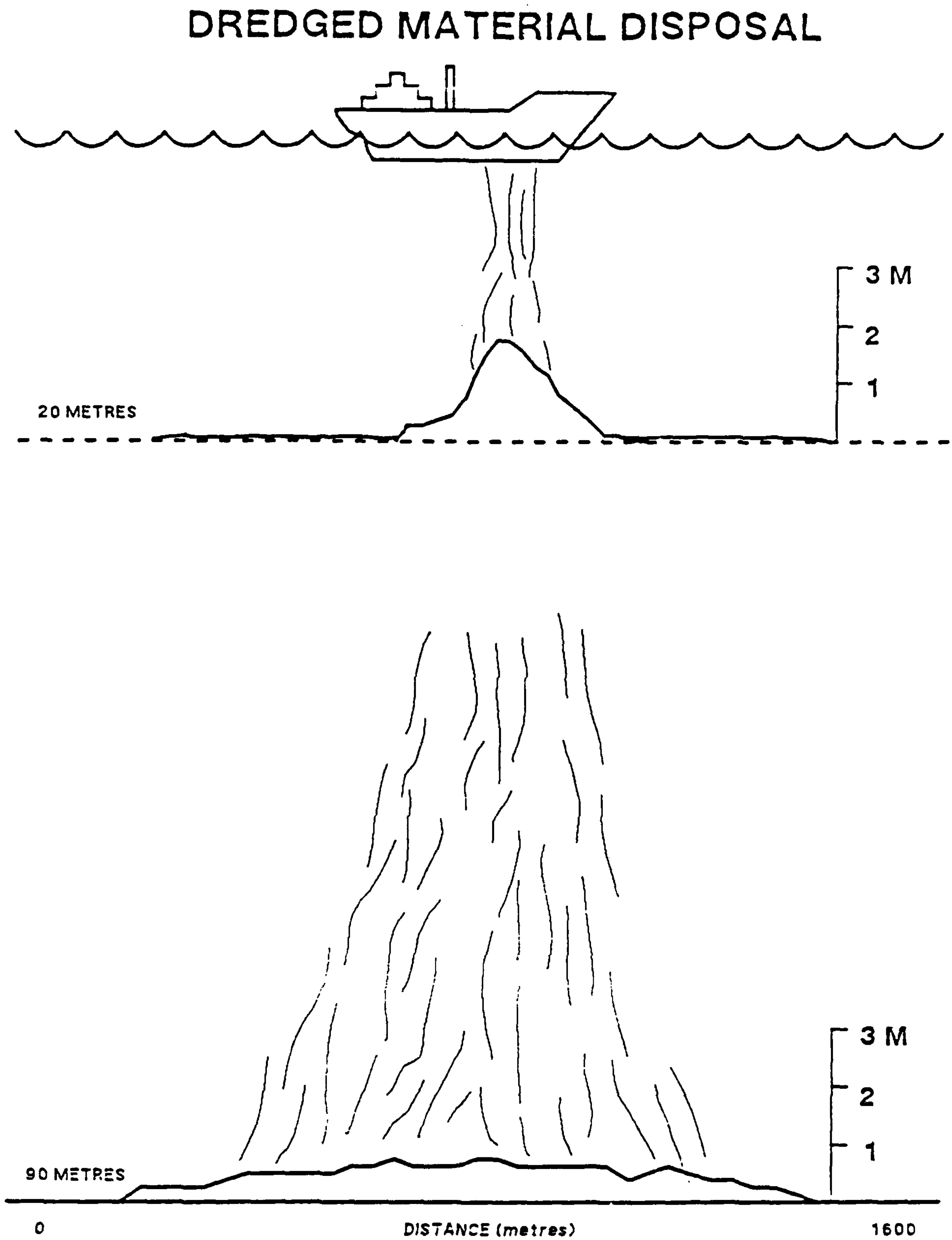

Figure 10. Comparison of dredged material deposit created in shallow (20-m) and deep (90-m) water

The effect of these phenomena on mitigating measures such as capping can have important implications for disposal management. Because the spread of material occurs mostly during the convective descent phase rather than the dynamic collapse phase, even small amounts of material will cover the same bottom area as larger volumes. Consequently, it would take essentially the same amount of material to effectively cap 100,000 cu m of contaminated material as possibly 250,000 cu m. Assuming such deposits covered an area of bottom with a 500-m radius, similar to the deposit created during the 1986 disposal operations, at least 1.1×10^6 cu m of material would be required to produce a deposit 1 m thick extending 100 m beyond the edge of dredged material. This is not an unreasonable quantity to cover a substantial project, but would be untenable for a small contamination problem. Table 1 presents the volume of material required to cap contaminated material covering a range of areas.

In summary, although capping has not been conducted at FADS, previous disposal operations have demonstrated the effectiveness of disposal control in restricting the spread of material. This is the single most important factor in a capping operation and, if the disposal location is a containment site, then given sufficient material, capping should be feasible.

CONCLUSIONS

Recent field monitoring programs of dredged material disposal in the marine environment using modern instrumentation have resulted in general confirmation that capping is a viable mitigating measure for disposal of contaminated sediment. Long-term studies of existing capped disposal mounds have demonstrated that these deposits are generally stable and in equilibrium with the existing environments even under relatively high-energy, open-ocean shelf conditions. Furthermore, with careful management of the disposal operation, it is clear that placement of the contaminated and cap material can be conducted effectively even in water depths approaching 100 m.

As in all ocean disposal operations, the development and implementation of a rigorous disposal management plan is essential to the successful accomplishment of capping. This management should include a continuous monitoring program, making use of the latest available technology, to ensure that both the operation itself and the resulting deposit conform to expected parameters.

TABLE 1. VOLUME ESTIMATES* OF CAPPING MATERIAL REQUIRED FOR A RANGE OF AREAS COVERED WITH DREDGED MATERIAL

Cap Thickness m	Radius of Dredged Material, m								
	200	300	400	500	600	700	800	900	1,000
0.5	142	251	393	565	770	1,005	1,272	1,571	1,901
1.0	283	503	785	1,131	1,539	2,011	2,545	3,142	3,801
1.5	424	754	1,178	1,696	1,901	3,016	3,817	4,712	7,603
2.0	565	1,005	1,571	2,262	3,079	4,021	5,089	6,283	7,603

* Volumes are × 1,000 m^3. Assumes that the cap material extends approximately 100 m beyond the dredged material.

AD-P006 836

RELATIONSHIP BETWEEN SEDIMENT POLLUTION AND MACROBENTHIC COMMUNITIES IN HIROSHIMA BAY, JAPAN

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ABSTRACT

Distribution of sediment, macrobenthos, and the anoxic water mass in Hiroshima Bay was investigated. The accumulation of organic matter in the sediment was considerable in the semi-closed bays, such as Kure and Edajima, and in the mouth of the Ota River. In Kure Bay, particularly, the benthic communities were of very poor condition or had disappeared, apparently due to the anoxic water mass. It is thought that the occurrence of the anoxic water mass in Kure Bay was mainly caused by the oxygen demand due to decomposition of the organic matter in the sediment, which can be determined from the distribution of the temperature, salinity, and dissolved oxygen and from the subtidal current.

INTRODUCTION

Background

Bottom-water anoxia is considerable in semi-enclosed bays, such as the Inland Sea and Mikawa and Tokyo Bays on the coast of Japan. The Inland Sea alone contains more than 10 small bays and seas, and for some of them, the occurrence of an anoxic water mass and its effects on the macrobenthos have been reported (Shimada 1983). Anoxic water masses have occurred in Hiuchi-Nada and Harima-Nada Seas during summers. In the summer of 1972, these seas experienced a great decline in fish and shellfish due to a large-scale anoxic water mass (Imabayashi 1983). Also, in Osaka Bay, it was reported that the benthic community was greatly affected by the anoxic water mass (Jo, Yamochi, and Abe 1978a, b).

A decline in fish and shellfish due to the occurrence of a large-scale anoxic water mass was also reported in Mikawa Bay (Aichi Prefecture Fisheries Experimental Station 1973, 1974), and a similar decline has become serious in Tokyo Bay. The occurrences and upwellings of anoxic water are called "blue tide" because they appear blue (or white) as a result of the surface flow with wind blowing.

In every area where an anoxic water mass has been noted, pollution from organic matter was evident; thus, it can be assumed that the oxygen demand of the organic matter caused the anoxic water mass occurrences. Therefore, in discussing the effects of sediment pollution on macrobenthos, we must consider the anoxic water mass occurrences as well as heavy metals and artificial organic matter. This paper summarizes a study of an anoxic water mass and its effects on the macrobenthic communities of Hiroshima Bay (particularly Kure Bay).

Description of Hiroshima Bay

Hiroshima Bay is located in western Japan, in the western portion of the Inland Sea. The surface area is 946-km^2 wide, with a volume of 24.2 km^3 (Figure 1). The bay is dotted with many small islands. The sea to the north of Itsukushima, Nomijima, Edajima, and Kurahashijima Islands is divided into two semi-enclosed bays, Edajima and Kure. The sea bottom is generally plain, with a limited portion of shoal along the seacoast and a sea valley along the channel.

The main rivers draining into the bay are Ota, Seno, and Yahata in the northern end of the bay and Nishiki, Kose, and Megumi in the western part of the midbay. The flux volumes in summer are approximately 6 million m^3 per day for Ota River, 4 million m^3 per day for Nishiki River, 1 million m^3 per day for Kose River, and under 0.3 million m^3 per day for the other rivers.

The flood tide enters the bay south of Kurahshijima Island, heads north, and enters Kure Bay, turning to the northeast. The ebb tide flows out, heading toward the opposite direction. Tide speeds are approximately 10 cm/sec in the northern end of the bay, approximately 20 cm/sec in the midbay, and 30 to 40 cm/sec at the mouth and channel of the bay (Figure 2) (Third District Port Construction Bureau of the Transportation Ministry 1980).

STUDY DESCRIPTION

Observations in 1982

Observations of water quality (June-October), sediment (August), and benthic communities were performed in 1982 at the stations shown in Figure 3.

Water temperature and salinity were measured by electric water thermometer and salinometer. Water was sampled from the surface and the bottom with an insulated water sampler. The sediment was sampled by divers with an acrylic core sampler. The upper 5-cm portion was separated. The samples were analyzed for organic content (by ignition loss, 900° C, 2 hr), chemical oxygen demand (consumption of potassium permanganate), and sulfide (distillation by steam-iodometry).

Benthic communities were sampled with a Smith-McIntyre sampler and sieved with a 1-mm sieve. Organisms were fixed in formalin.

Observations in 1983

From July through October, dissolved oxygen (DO) in the bottom water was observed at 1-week intervals at observation stations in the northern end of the bay (see Figure 4). Procedures for sampling were the same as in 1982.

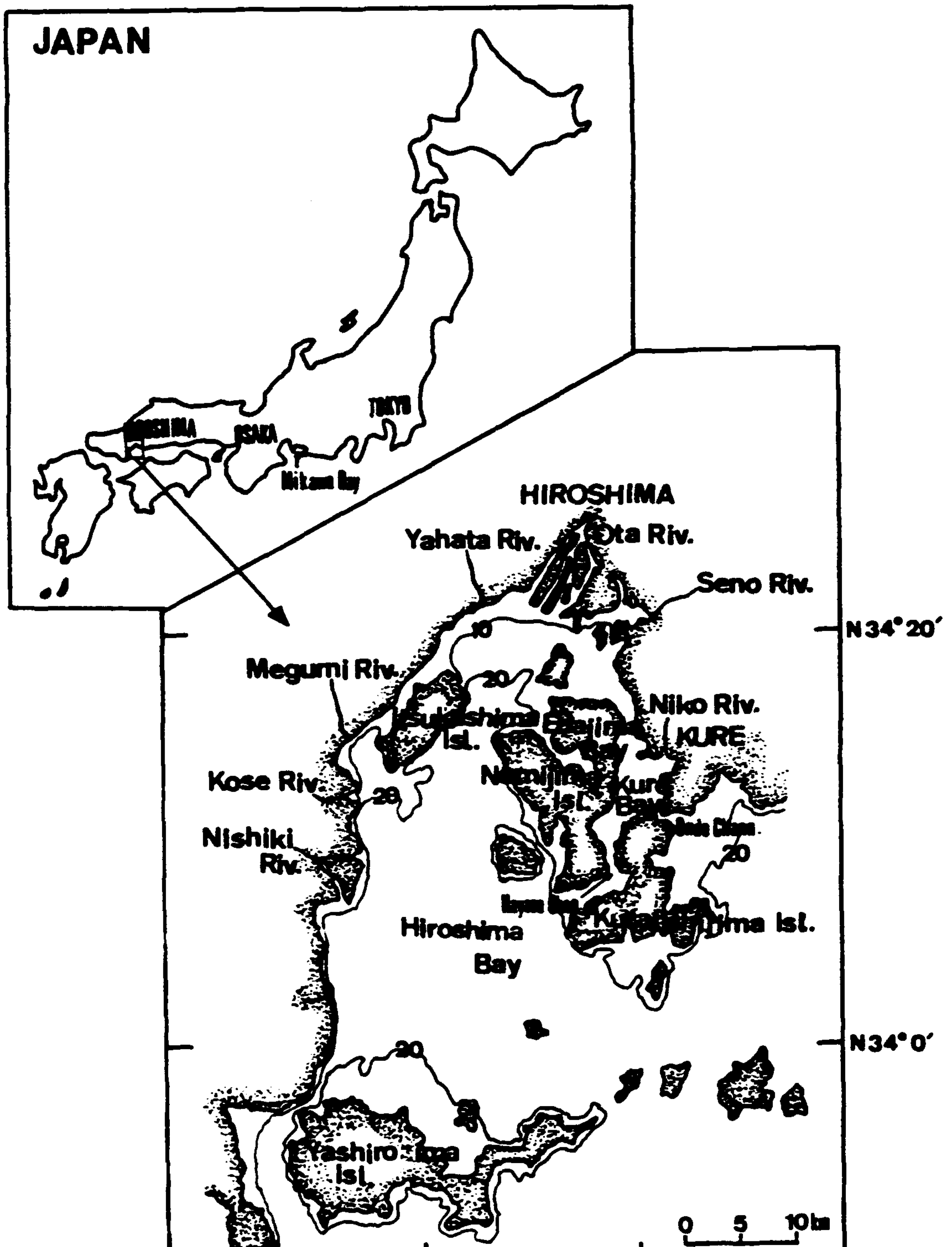
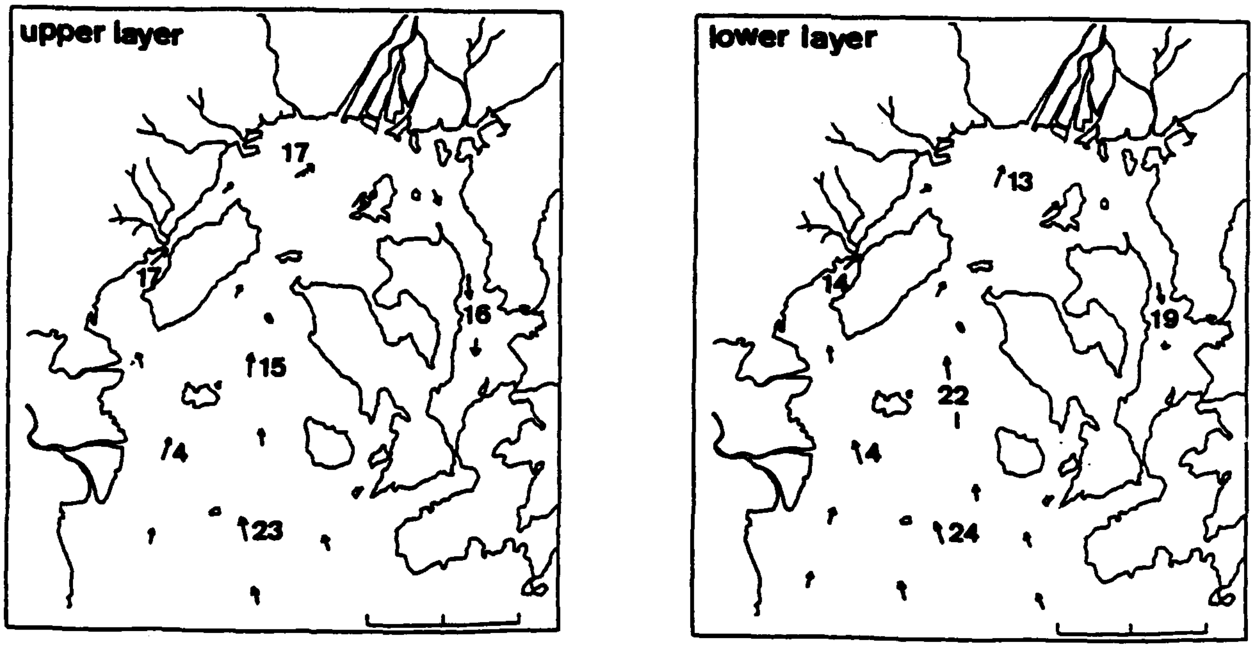
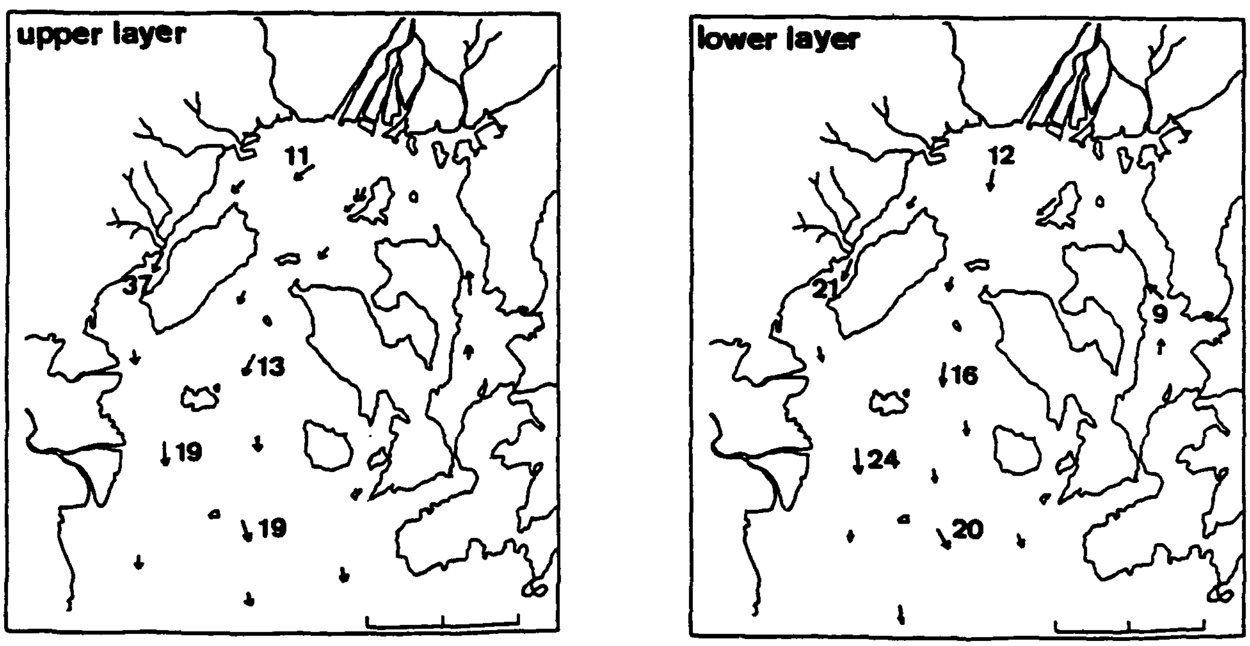


Figure 1. Study area, Hiroshima Bay



a. Flood tide



b. Ebb tide

Figure 2. Average tidal currents (centimetres per second) in Hiroshima Bay during the spring

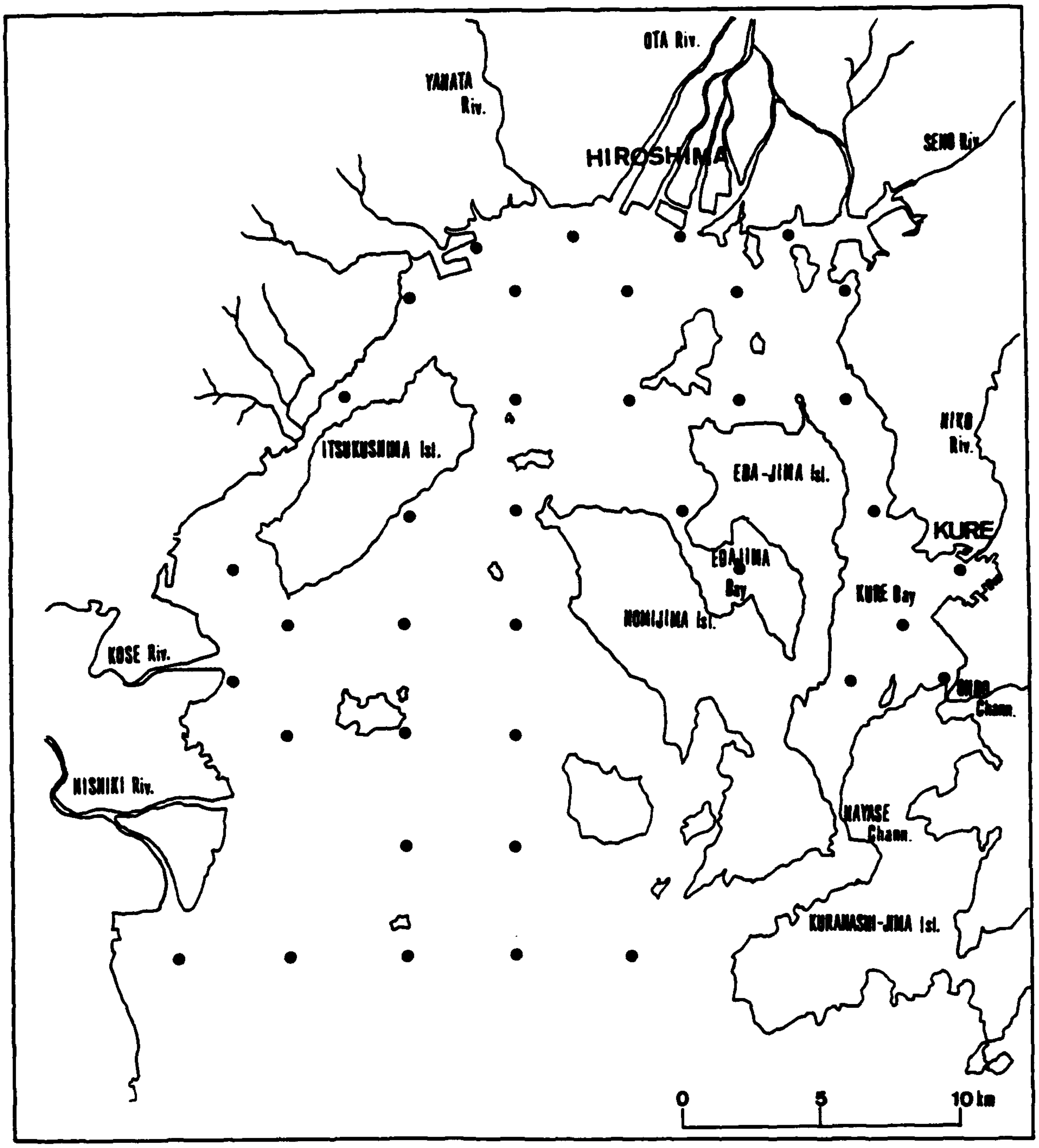


Figure 3. Observation stations in 1982

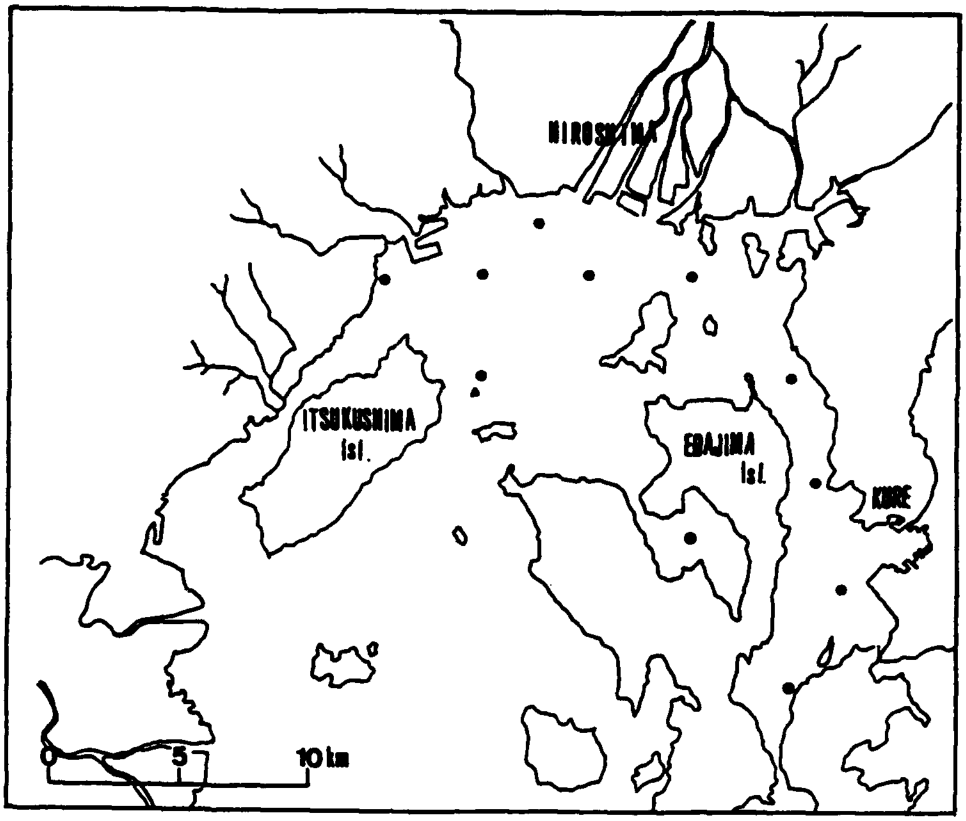


Figure 4. Observation stations in 1983

Experiments in 1984

At those observation stations shown in Figure 5, the sediment was sampled by divers with an acrylic core sampler and incubated with water from directly above it. The oxygen consumption rate was measured by analyzing diminished oxygen in the water under a constant temperature of 25° C for 5 days.

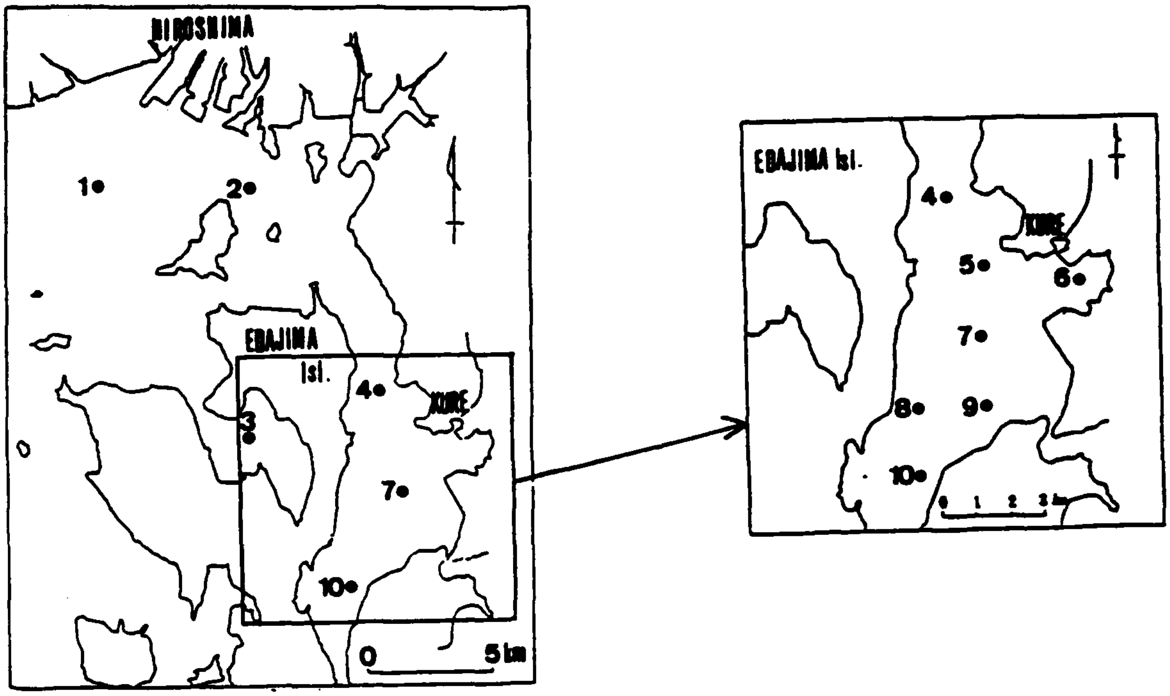
Observations in 1984-87

At the six observation stations shown in Figure 5a, observations were made of the water quality, the sediment, and the distribution of the macrobenthos. At the seven observations stations in Kure Bay (shown in Figure 5b), water quality was tested three times a month. The procedures were the same as in the preceding years.

RESULTS AND DISCUSSION

Observations in 1982

Dissolved oxygen in the bottom water during the period July 5-October 6, 1982, is shown in Figure 6. The observed patterns indicate that the anoxic water mass was frequently located in Edajima Bay and near the mouth of the Ota River in the northern end of the bay.



a. Stations for sediment core sampling (in 1984) and monthly observations (May 1985-February 1987)

b. Stations for observation of anoxic water mass, three times a month, July-October 1986

Figure 5. Observation stations during the period 1984-87

Patterns of ignition loss, chemical oxygen demand (COD), and sulfide in the sediment sampled during June-October 1982 are shown in Figure 7. It can be deduced from the high levels of COD and sulfide in Kure Bay, Edajima Bay, and near the mouth of the Ota River that the accumulation of organic matter in the sediment is significant in these areas.

DO Distribution, Summer 1983

Figure 8 shows the average DO concentrations in the sediment over the 12 samplings (conducted at 1-week intervals) during July 19-October 14, 1983. This indicated that Kure Bay is more likely to become anoxic in its innermost part.

Water Quality Changes, 1985-87

Figure 9 shows the changes in the water quality in Kure Bay during the period May 1985-February 1987 (average of values at three observation stations). The highest temperature in the upper water was recorded in August, with a lag of 1 or 2 months in the lower layer. The difference in temperature between the upper and lower layers was greatest during July and August. There was no outstanding transition in salinity except for the noticeable decrease in the upper layer during June and July due to heavy rain.

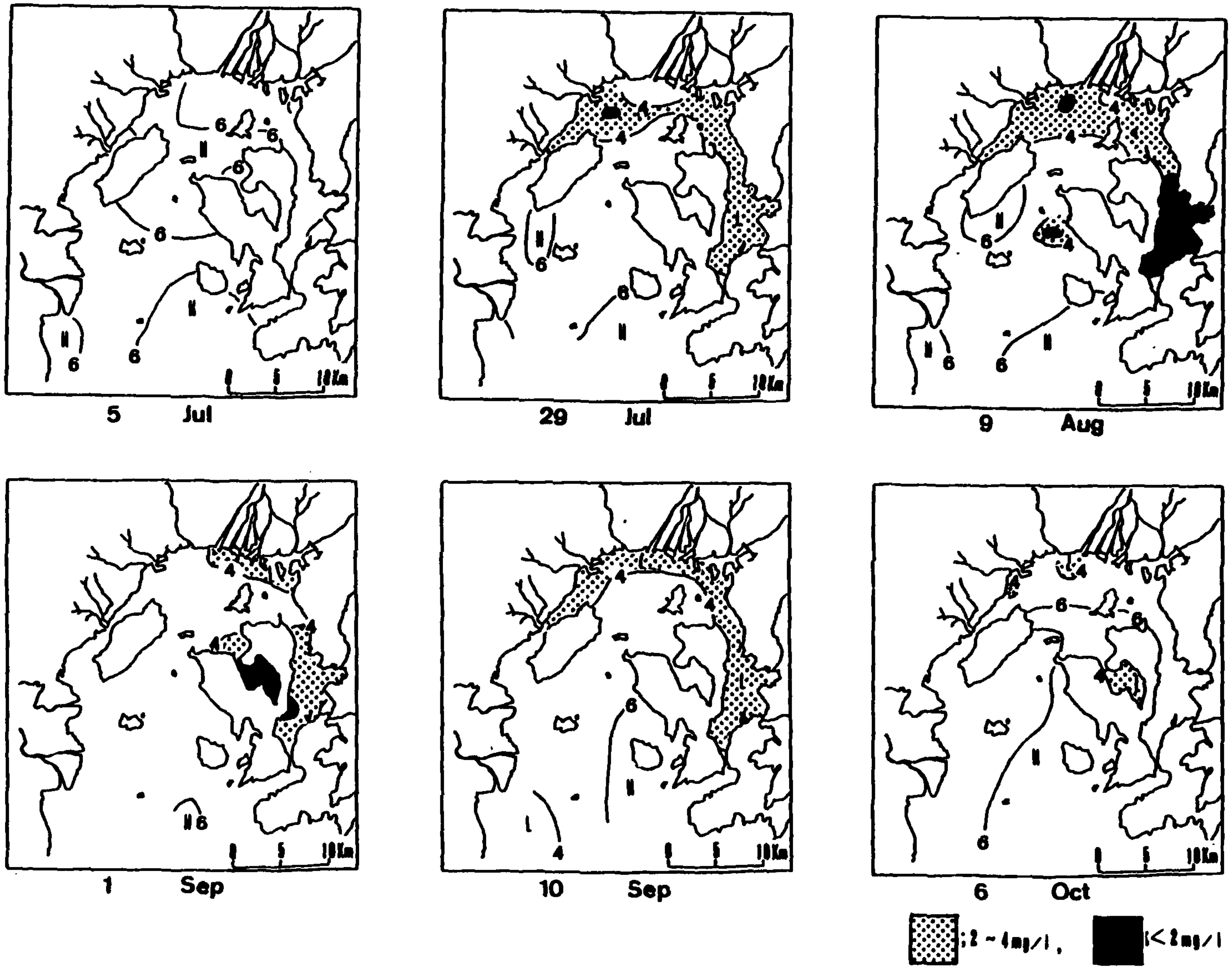
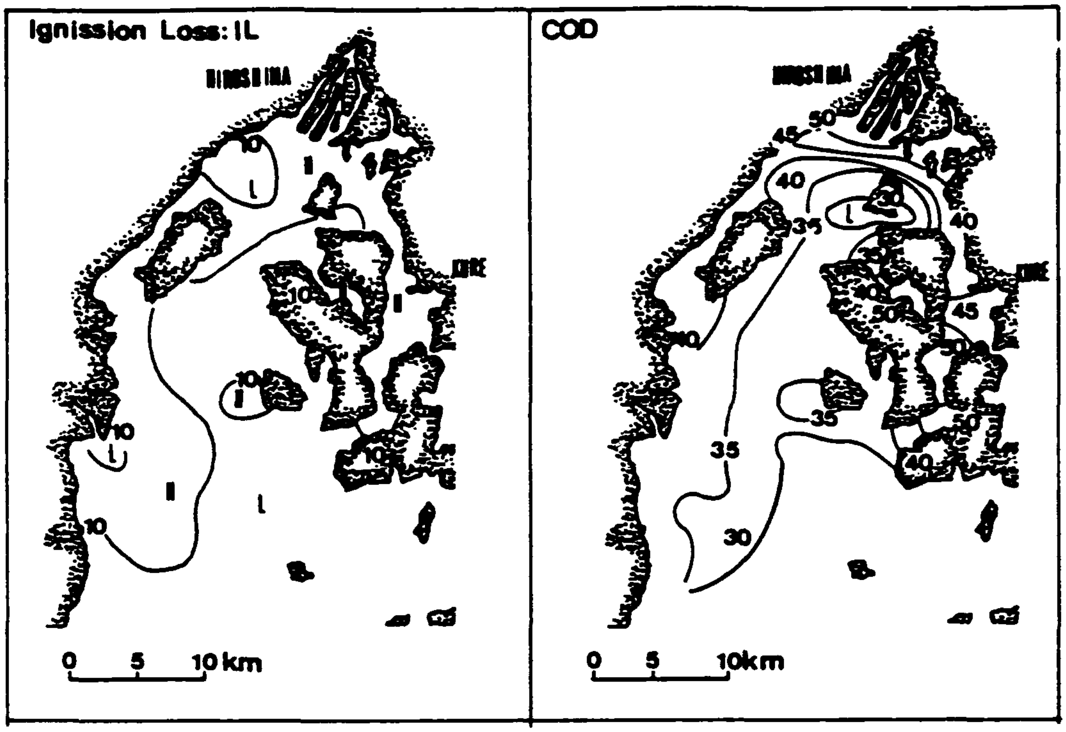
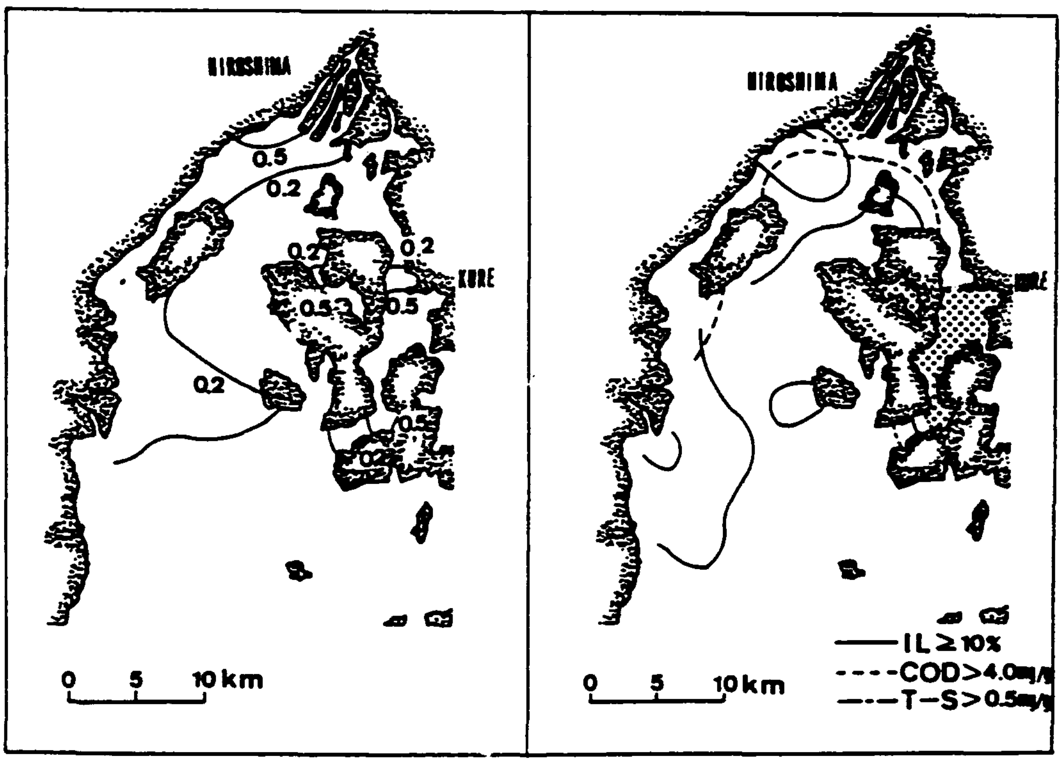


Figure 6. Pattern of DO concentration in bottom water, July 5-October 6, 1982



a. Ignition loss (IL) b. COD



c. Total sulfide (T-S) d. Composite

Figure 7. Patterns of selected sediment parameters in 1982

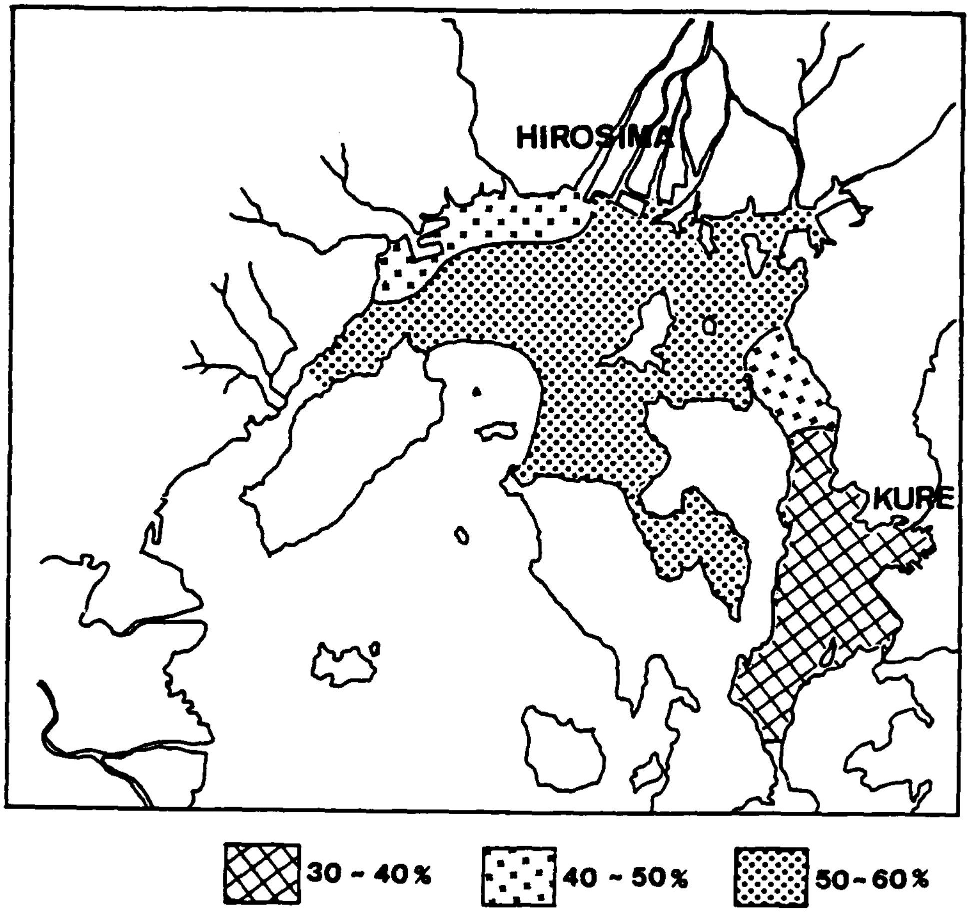


Figure 8. Deviation of DO concentrations in bottom water of Hiroshima Bay, July 19-October 14, 1983

Benthos Distribution, 1985-87

The distribution of the macrobenthos during the period June-October 1982 is shown in Figure 10. There were very few organisms in Kure and Edajima Bays.

The transition in the benthos distribution for May 1985-February 1987 is shown in Figure 11. Table 1 summarizes the data on benthos. In northern and southern Kure Bay and in the mouth of the Ota River, densities were highest. In the center of Kure Bay, however, and in Edajima Bay, lower densities were noted. Dominant organisms were Polychaeta, along with a few Mollusca and Crustacea.

Jo, Yamochi, and Abe (1978a) investigated Osaka Bay with regard to water quality and the distribution of the sediment and the benthic communities. They concluded that the areas lacking benthos existed where large accumulations of organic matter existed in the sediment, where an anoxic water mass can easily occur due to stratification.

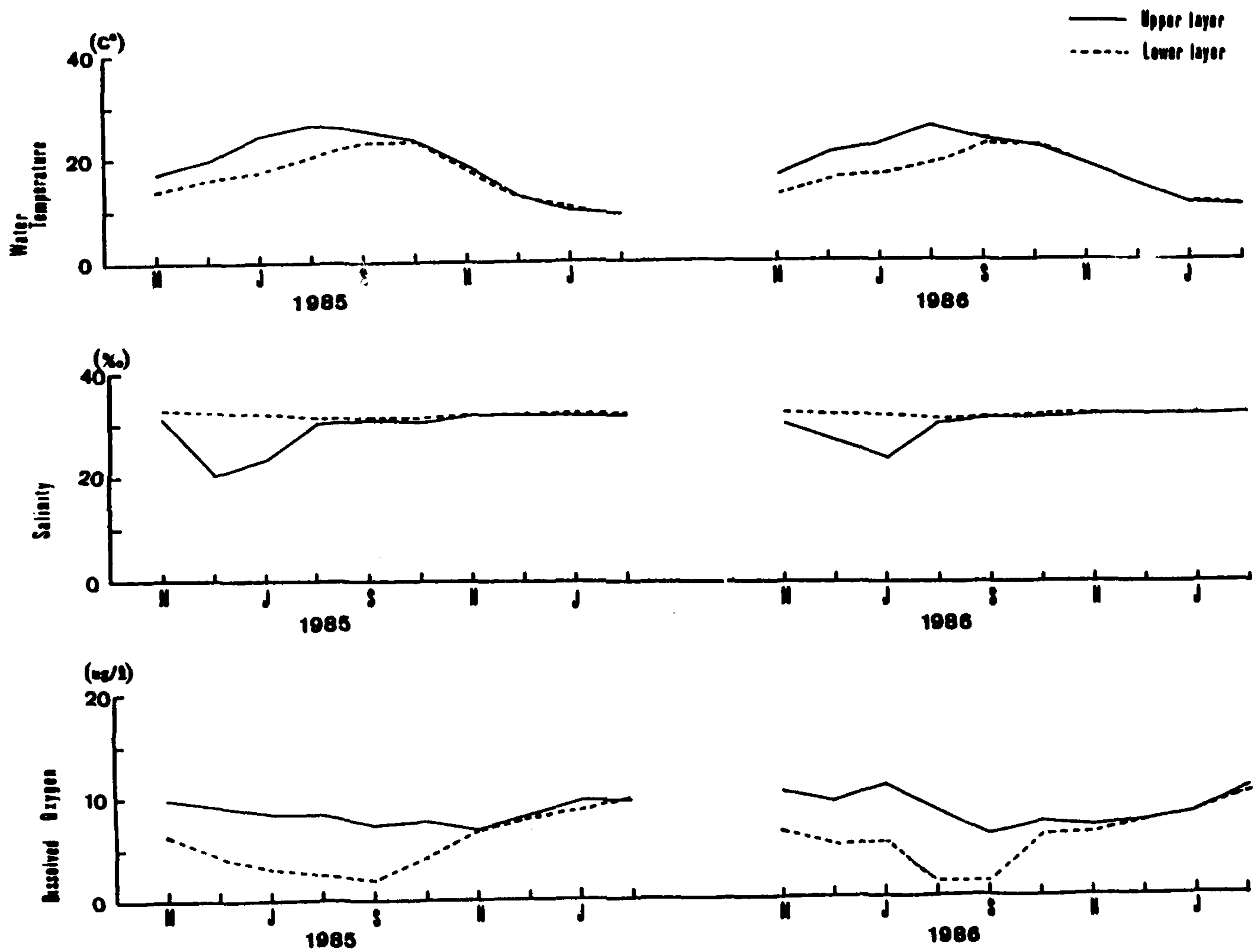


Figure 9. Fluctuations of average water quality in Kure Bay, May 1985-February 1987

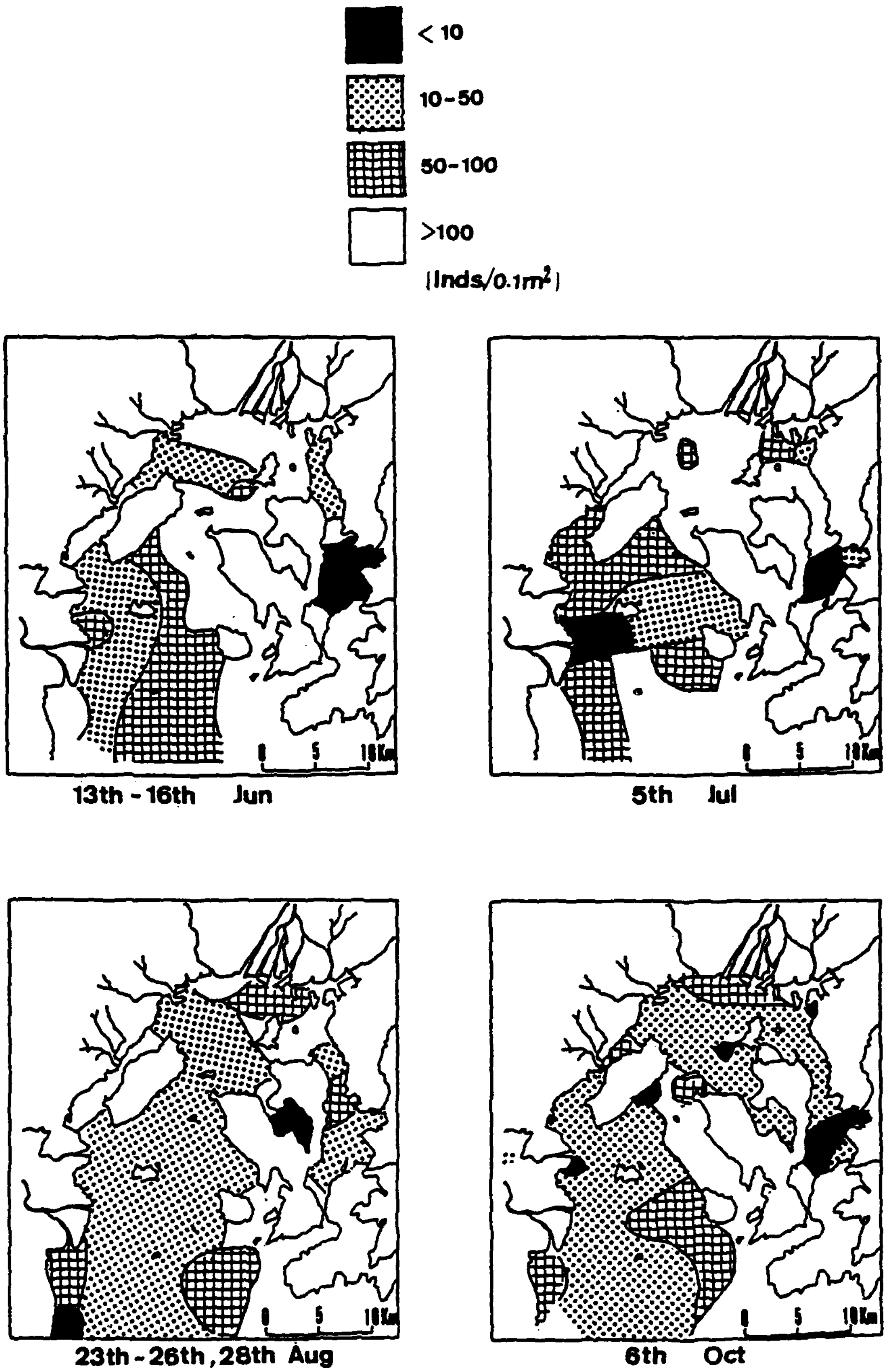


Figure 10. Distribution of macrobenthos, June-October 1982

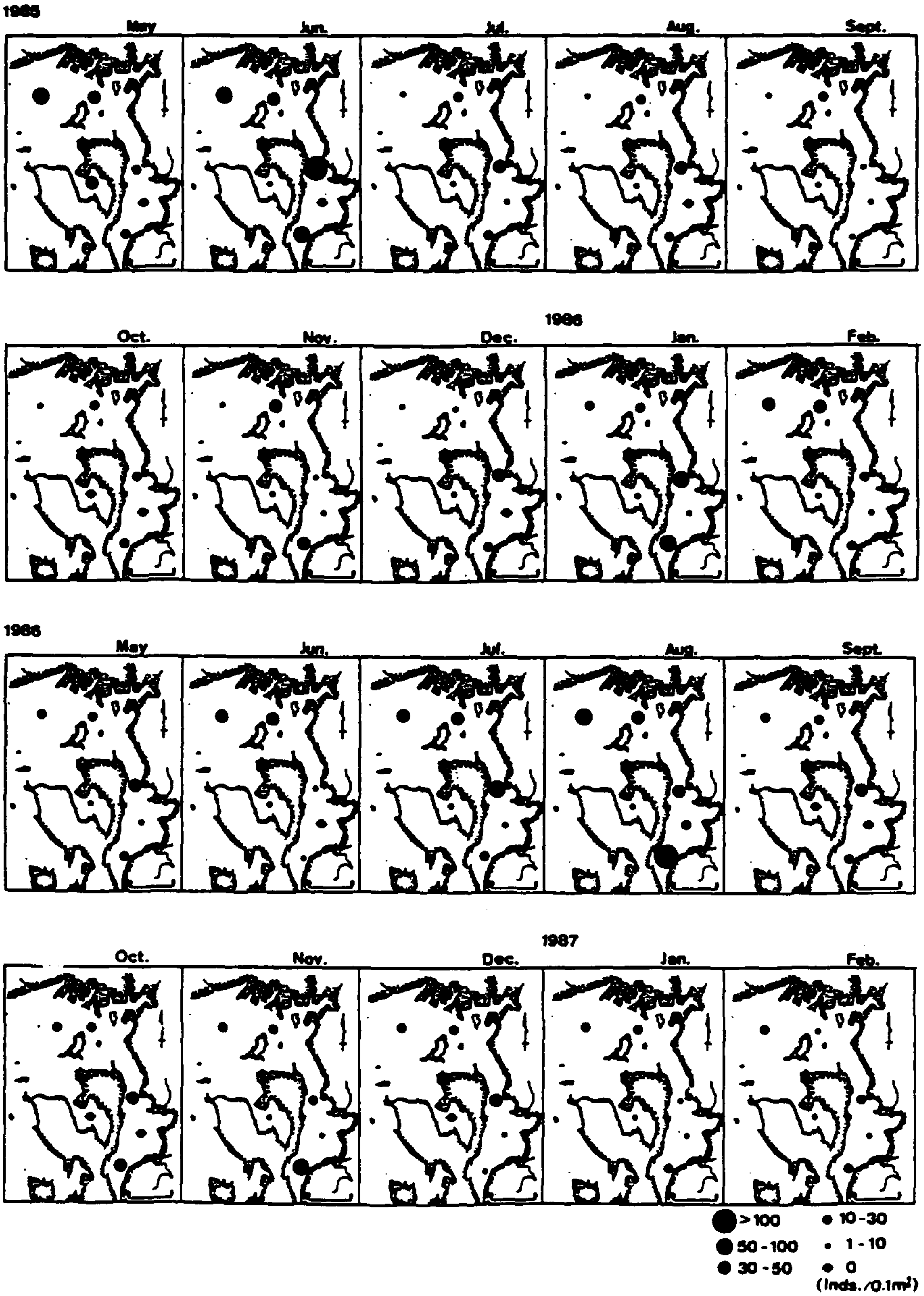


Figure 11. Distribution of benthic community (individuals/0.1 m^2) in Kure Bay, May 1985-February 1987

TABLE 1. SUMMARY OF BENTHIC COMMUNITIES, INNER HIROSHIMA BAY, MAY 1985-FEBRUARY 1987

Parameter	St. 1*	St. 2*	St. 3**	St. 4†	St. 7†	St. 10†
Number of species††	3-21 (9)	2-19 (10)	0-14 (3)	3-15 (8)	0-3 (1)	3-18 (9)
Number of individuals††	5-99 (28)	5-68 (26)	0-50 (6)	4-111 (34)	0-12 (3)	3-107 (30)
Diversity index (H')††	0.760-2.515 (1.77)	0.500-2.604 (1.95)	0-2.200 (0.72)	0.601-2.306 (1.38)	0-1.099 (0.31)	0.950-2.203 (1.67)
Percentage composition††						
Annelida	33.3-100 (74)	45.2-100 (79)	0-100 (77)	50-100 (87)	8.3-100 (85)	40-100 (81)
Mollusca	0-57.6 (14)	0-52.4 (10)	0-50.0 (8)	0-50.0 (8)	0-91.7 (15)	0-60.0 (16)
Arthropoda	0-25.0 (6)	0-33.3 (4)	0-87.0 (5)	0-50.0 (4)	--	0-36.8 (2)
Others	0-28.6 (6)	0-20.0 (6)	0-100 (10)	0-8.3 (2)	--	0-22.1 (1)
Dominant species	*Lumbrineris longifolia* *Paraprionospio* sp. *Prionospio ehlersi* *Sigambra tentaculata* *Theola lubrica*	*Lumbrineris longifolia* *Paraprionospio* sp. *Prionospio ehlersi* *Sigambra tentaculata* *Theola lubrica*	*Lumbrineris longifolia* *Paraprionospio* sp. *Theola lubrica*	*Lumbrineris longifolia* *Paraprionospio* sp. *Theola lubrica*	*Lumbrineris longifolia* *Paraprionospio* sp.	*Lumbrineris longifolia* *Paraprionospio* sp. *Sigambra tentaculata* *Theola lubrica*

* Located near the mouth of the Ota River (to the east and west), respectively.
** Located in Edajima Bay.
† Located in Kure Bay (northern, middle, and southern sections, respectively).
†† Values given represent the range and the average (in parentheses).

Imabayashi (1983) investigated the Hiuchi-Nada and Harima-Nada Seas and reported that there was a strong correlation between the number of species and the number of individuals in the benthos (its diversity index) and dissolved oxygen in the bottom water, which suggests that the anoxic water mass caused the change in the macrobenthos.

Table 2 shows the environmental factors at each observation station in the innermost part of Hiroshima Bay. In the center of Kure Bay, the average DO was almost the same as at the other observation stations. However, the lowest DO was lower than the other stations, and the sulfide concentration rate and DO consumption were higher. This could be the reason for the accumulation of organic matter in the sediment and the occurrences of anoxic water mass that caused the poor-condition benthos.

Anoxic Water Mass in Kure Bay, 1986

Figure 12 shows the variation of vertical profiles of water temperature during the period July 4-October 27, 1986. The difference in water temperature between the upper and lower water layers reached about 10° C in mid-August; in October, the temperatures were consistent. In contrast, the surface water with highest temperature, 26° C, at observation station 7 (St. 7) in southern Kure Bay, was noticeable compared with St. 4 in the northern part of the bay.

Salinity decreased in the upper water layer in mid-July because of heavy rain, and the same trend was recognized at the other observation stations (Figure 13).

According to the results of the investigation by the Third District Port Construction Bureau of the Transportation Ministry (1986), in Kure Bay, the ebb tide in the upper water flows out from the northern bay or the channel of Hayase; in the bottom water, it flows in at the southern bay and flows out from the northern bay. The flood tide in the upper and bottom water flows to the opposite direction to the ebb tide. The subtidal tide flows in at the channel and flows out from the northern bay. At St. 7 in the southern bay, the salinity in the sediment is higher than the other observation stations because of the inflow of water from the open sea through the Hayase channel.

The DO distribution in the bottom water in Kure Bay is shown in Figure 14. Anoxia could be recognized on July 4 and was the most serious from August 6, when the bedding water developed. On October 7, when the stratification of the water temperature and the salinity vanished, the anoxia in the midbay was quite high.

Primary Causes of Anoxia and Countermeasures

A schema of the DO balance and the primary causes of the anoxic water mass is shown as Figure 15. The anoxic water mass seems to originate from the seashore in northern Hiroshima Bay, but the anoxia is more pronounced in Kure Bay. The wind-driven surface flow, which was reported in Mikawa Bay (Aichi Prefecture Fisheries Experimental Station 1973, 1974) and in Tokyo Bay in 1986, cannot occur easily in Kure Bay. In addition, the subtidal current in

TABLE 2. SUMMARY OF ENVIRONMENTAL FACTORS, INNER HIROSHIMA BAY

Item	St. 1	St. 2	St. 3	St. 4	St. 7	St. 10
DO in the bottom water* (mg/ℓ)	2.0-9.1 (6.3)	3.1-9.0 (5.9)	1.8-10 (6.6)	1.6-10 (5.5)	1.1-10 (5.5)	1.6-10 (5.7)
Ignition loss in sediment** (%)	10-12 (11)	9.4-13 (10)	10-13 (12)	10-12 (12)	10-15 (12)	10-12 (11)
Sulfide in sediment** (mg/g dry)	0.10-0.48 (0.33)	0.12-0.73 (0.31)	0.24-1.0 (0.61)	0.16-0.56 (0.40)	0.85-1.3 (1.0)	0.10-0.83 (0.50)
DO consumption in sediment† ($g/m^2/day$)	0.82	0.57	1.64	0.49	2.45	0.42

Note: Station locations are described in Table 1. Values given are the range and the average (in parentheses).

* Results of monthly observations, May 1985-February 1986 and May 1986-February 1987.

** Results of four season observations, May 1985-February 1986 and May 1986-February 1987.

† Results of laboratory experiment with surface sediment sampled in 1984.

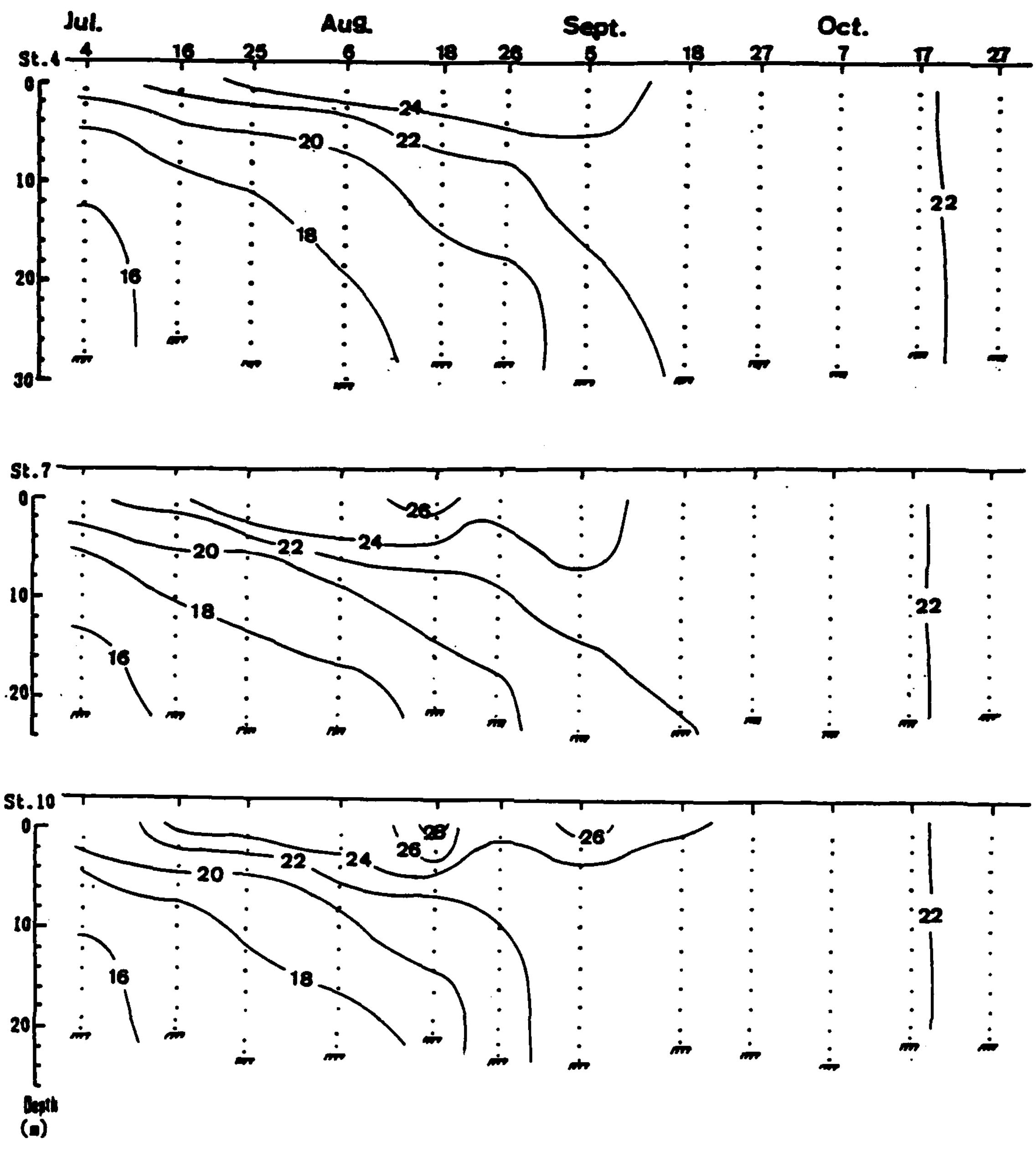


Figure 12. Variation of vertical profiles of temperature (degrees Centigrade) in Kure Bay, July 4-October 27, 1986

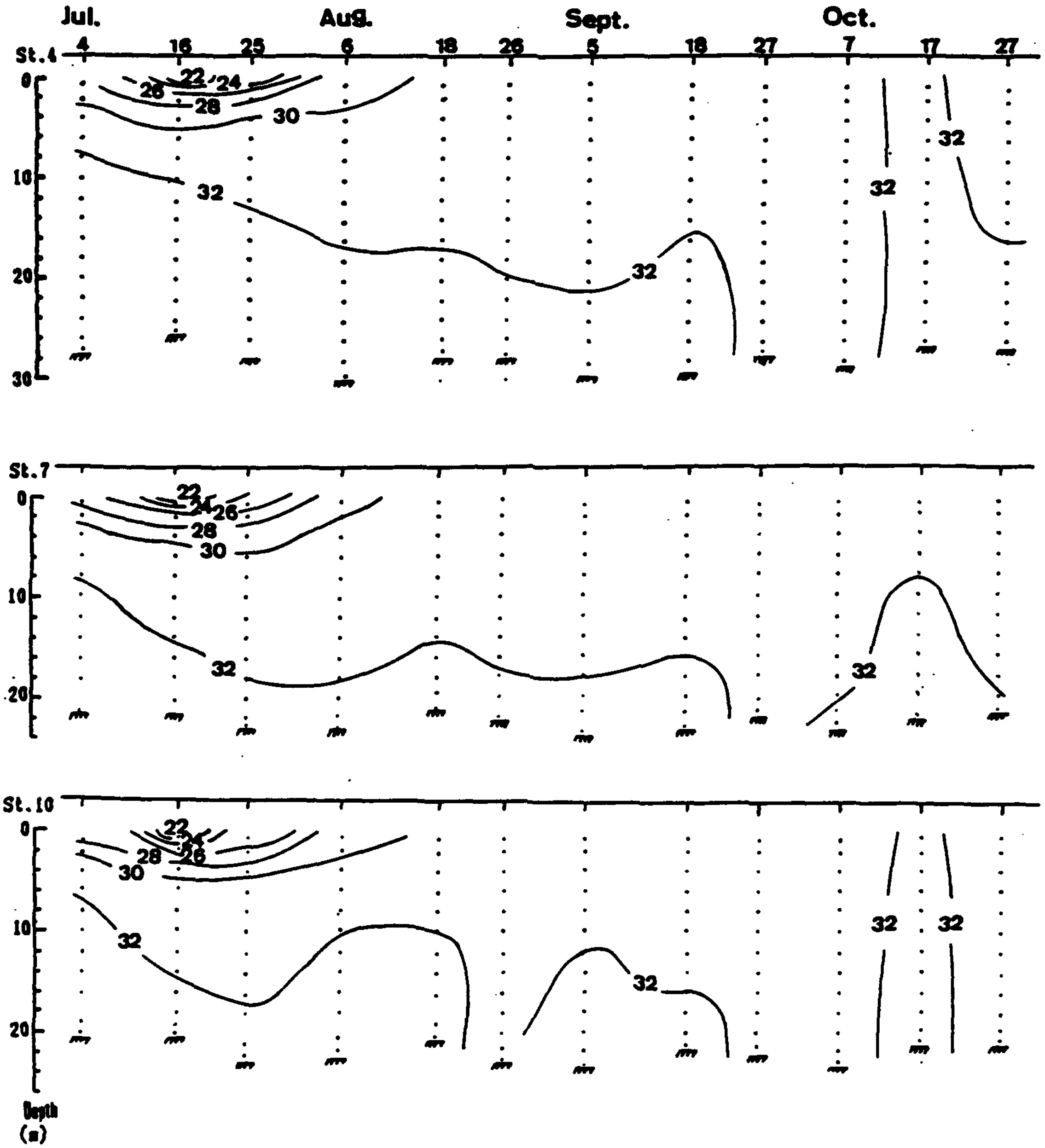


Figure 13. Variation of vertical profiles of salinity (percent) in Kure Bay, July 4-October 27, 1986

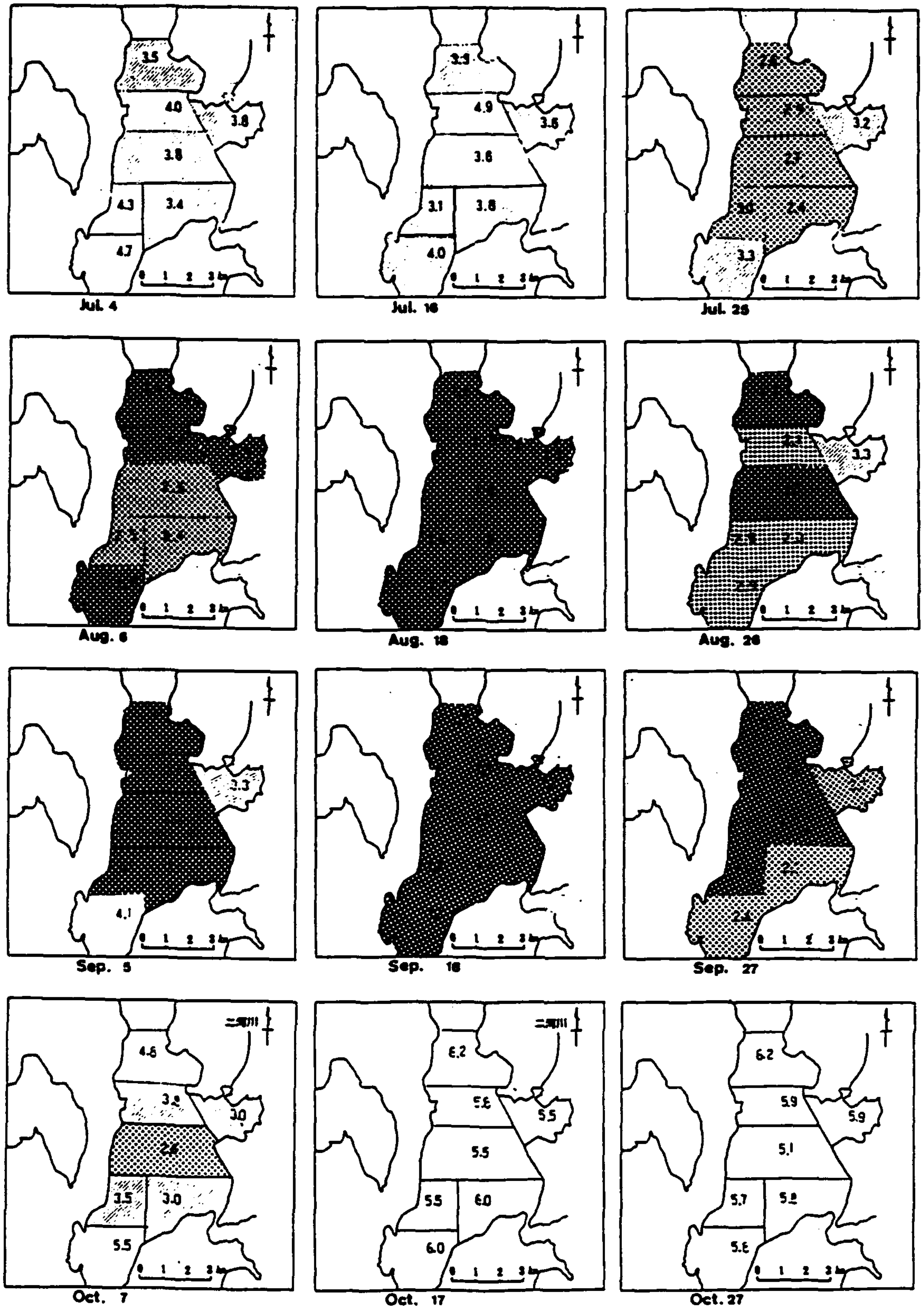
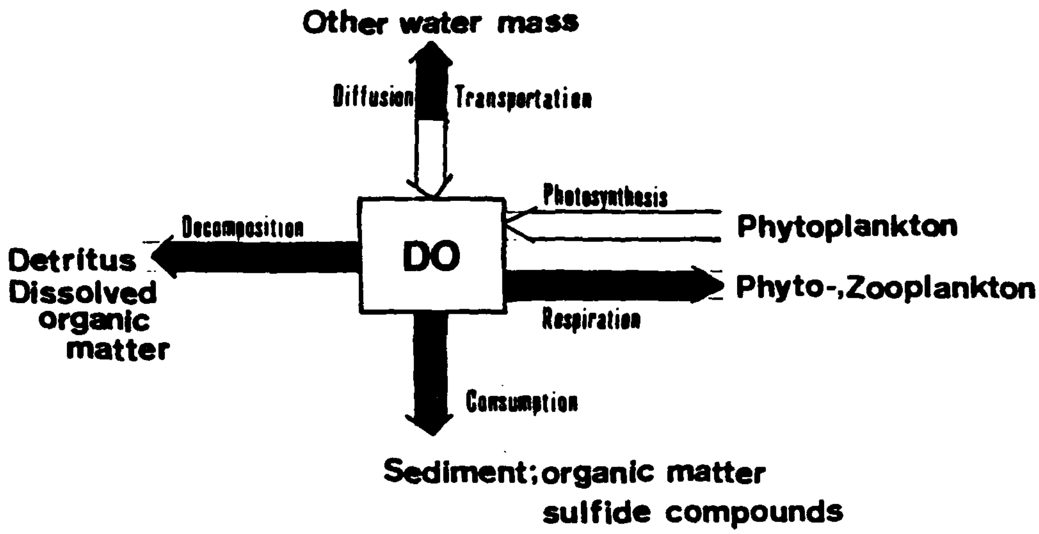
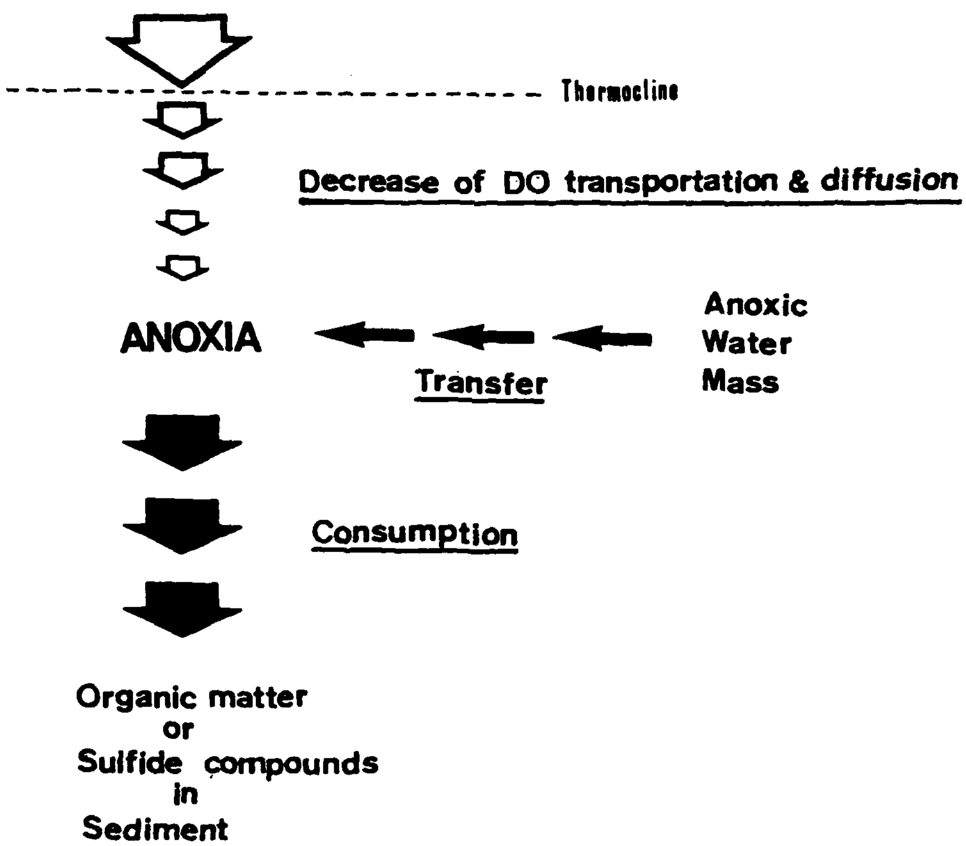


Figure 14. Distribution of DO in bottom water of Kure Bay, July 4-October 27, 1986



a. Dissolved oxygen balance



b. Causes of anoxia

Figure 15. Schema of anoxic water mass, Kure Bay

the bottom water in Kure Bay flows toward the north (Third District Port Construction Bureau of the Transportation Ministry 1986). Therefore, it was determined that the anoxic water mass in Kure Bay occurs within the bay.

The reduced oxygen supply in the upper water and the development of stratification are probably due to the strengthening of the stratification in Osaka Bay; however, in Hiuchi-Nada Sea, it is probably due more to the decreased oxygen supply because of the stagnated coldwater mass under the second thermocline than to the oxygen consumption in the sediment.

In Kure Bay, the anoxia is the most serious when the stratification becomes moderate, and that means the reduced oxygen supply does not cause the occurrence of the anoxic water mass daily. The consumption of oxygen in the sediment in Kure Bay was measured as 2 g O_2 per square metre per day, which is higher than the value for Hiuchi-Nada Sea (0.5 g O_2 per square metre per day (Ochi and Takeoka 1986), which has a great influence on the occurrence of the anoxic water mass. Because the temperature of the bottom water was the highest in late September, water temperature probably accelerates DO consumption.

As a result of this study it was concluded that the occurrence of the anoxic water mass in Kure Bay is greatly affected by the accumulation of organic pollutant in the sediment, which also contributed to a depauperate benthic community. Thus, the most effective way to reduce the anoxic water mass is to decrease and control the accumulation of organic pollutants in the sediment. This will be very important for the long term.

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PILOT DREDGING STUDY, NEW BEDFORD HARBOR, MASSACHUSETTS, SUPERFUND PROJECT

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ABSTRACT

Testing of sediment from the northern portion of New Bedford Harbor, Massachusetts, has revealed that most of the area is contaminated by polychlorinated biphenyls (PCBs). In August 1984, the US Environmental Protection Agency (USEPA) published a Feasibility Study of Remedial Action Alternatives for this area, which proposed five cleanup alternatives. Four of these dealt specifically with dredging the area to remove the contaminated sediments. In response to comments received, the USEPA asked the US Army Corps of Engineers (USACE) to perform additional studies to better evaluate the engineering feasibility of dredging as a cleanup alternative. This study is a joint effort of the US Army Engineer Division, New England, Waltham, Mass., and the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. This paper describes a proposed pilot study of dredging and dredged material disposal alternatives to support the engineering feasibility study. This study would be a small-scale field test of several dredging and disposal techniques carried out onsite between December 1987 and June 1988. The study will evaluate three types of hydraulic dredge and two disposal methods. The pilot study will be extensively monitored, in order to obtain sufficient data to support the technical objectives of the pilot study and to ensure that both public health and the environment are protected. Pilot study operations will be modified or stopped if significant increases in the level of contaminants are detected at the Coggeshall Street Bridge.

INTRODUCTION

Site Description

New Bedford Harbor, a tidal estuary, is situated between the city of New Bedford on the west and the towns of Fairhaven and Acushnet on the east at the head of Buzzards Bay, Massachusetts. The site can be divided into two geographic areas. The most northern portion of the site extends from the

Coggeshall Street Bridge north to Wood Street in Acushnet. The remainder of the site extends south from the Coggeshall Street Bridge through the New Bedford Hurricane Barrier and into Buzzards Bay. Geographic boundaries include the shoreline, wetlands, and peripheral upland areas.

PCB contamination in New Bedford was first documented by both academic researchers and the Federal Government between the years 1974 and 1976. Since the initial survey of the New Bedford area, a much better understanding of the extent of PCB contamination has been gained. The entire area north of the Hurricane Barrier, 985 acres, is underlain by sediments containing elevated levels of PCBs and heavy metals, including copper, chromium, zinc, and lead. PCB concentrations range from a few parts per million to over 100,000 ppm. Portions of western Buzzards Bay sediments are also contaminated, with concentrations occasionally exceeding 50 ppm. The water column in New Bedford Harbor has been measured to contain PCBs in the parts per billion range.

Background Information

In August 1984, the USEPA published a Feasibility Study of Remedial Action Alternatives for the Upper Acushnet River Estuary above the Coggeshall Street Bridge. Sediments from this area of the New Bedford Harbor Superfund Project contain much greater PCB concentrations than the remainder of the harbor. The study proposed five alternatives for cleanup of the contaminated sediment. Four of these alternatives dealt specifically with dredging the estuary to remove the contaminated bottom sediments. Disposal options included an intertidal disposal site, partially lined for one option and fully lined for a second, disposal in an upland site, and disposal in cells constructed in the estuary and covered with clean material.

Public and interagency comment on these dredging and disposal alternatives prompted the USEPA to ask the USACE to perform additional predesign studies for dredging and disposal alternatives to develop the technical information necessary to evaluate the engineering feasibility of these alternatives. The Engineering Feasibility Study (EFS) began in October 1985 and is scheduled to be completed in March 1988. It addresses two questions: (a) what are contaminant release rates from dredged material disposal alternatives, and (b) what are contaminant release rates from dredging alternatives?

The technical approach used in the EFS to evaluate disposal alternatives is based on strategy outlined in a USACE publication.* This strategy incorporates findings of research conducted by the USACE, USEPA, and others over the past 10 years, and on worldwide experience in managing dredged material disposal. It consists of a suite of tests developed specifically for the unique nature of dredged material that, when applied to New Bedford Harbor sediment, will allow for site-specific evaluation and conceptual design of available disposal alternatives.

The other part of the question for the EFS is evaluation of dredging alternatives, i.e., can the contaminated sediment be effectively removed from

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* Francingues, N. R., et al. 1985. "Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls," Miscellaneous Paper D-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

the estuary by conventional or specialty dredging equipment without unacceptable migration of contaminants to the environment? Unlike the disposal issue, testing protocols and a prescribed strategy have not been developed for estimating contaminant release from a dredging operation itself. The EFS addresses the questions of sediment resuspension and contaminant migration during the dredging operation by reviewing past studies of dredging projects, characterizing the hydraulic conditions in the Upper Estuary, performing flume tests to physically model sediment deposition and resuspension, estimating contaminants associated with suspended sediment based on limited laboratory tests, and incorporating the results into a numerical sediment migration analysis.

Much of the information needed to evaluate the design of proposed dredging and disposal alternatives for the New Bedford Harbor Superfund Site (above the Coggeshall Street Bridge) can and will be provided by the EFS. This information will be critical to the record of decision (ROD) for selection of the remedial action alternative. However, the EFS approach uses laboratory (bench-scale) studies, literature reviews, and desktop analyses to assess engineering feasibility and to develop conceptual designs. The sound engineering approach for evaluation of alternatives and verification of design parameters is to perform pilot-scale evaluations after laboratory studies and before final selection and design of a prototype system. This is particularly true for the New Bedford Project where dredging and disposal of highly contaminated sediment must be considered innovative application of alternatives, where dredging equipment must be evaluated without benefit of field-verified laboratory testing protocols, and where a data base on the impact of site-specific factors on design is currently not available. A pilot study will reduce the uncertainty in the choice of alternatives for the ROD and in the final design and will allow smoother transition from alternative selection to final design and thence to construction. For these reasons, the USEPA and the USACE are proposing that a pilot study be performed at New Bedford to evaluate proposed dredging and disposal alternatives in the field.

Study Objectives

The pilot study will provide the opportunity to evaluate different dredges, dredge operating procedures, disposal methods, and control techniques under site-specific conditions of New Bedford Harbor. The information gathered during the pilot study will improve our ability to address the critical issues being evaluated by the EFS. Listed below are the specific technical objectives of the pilot study.

a. Determine the efficiency of dredging for removal of PCB-contaminated sediment from New Bedford Harbor.

b. Evaluate actual sediment resuspension and contaminant release during field conditions for selected dredging equipment, operational controls, and turbidity containment techniques.

c. Refine and scale-up laboratory data for design of disposal/treatment processes for contaminated dredged material from the site.

d. Develop and field test procedures for construction of contained aquatic disposal (CAD) cells for contaminated dredged material under site-specific conditions.

e. Evaluate containment of PCBs in diked disposal areas and CAD cells filled with contaminated dredged material.

f. Assess solidification techniques for contaminated dredged material with respect to implementability.

g. Establish actual cost data for dredging and disposal of New Bedford Harbor sediment.

Additional Benefits

Conduct of the proposed study would result in related benefits, as described below.

a. Construction techniques for the confined disposal facility (CDF) and the CAD can be tested in the field for site-specific conditions.

b. Information on air emissions during dredging and disposal can be evaluated.

c. Other regulatory agencies and the public will become more involved in seeking a solution for cleanup of the site. Requirements for complying with other environmental laws and regulations will be addressed early on and allow smoother review and approval for the final cleanup action.

d. Experience gained with the pilot study will expand information on dredging and disposal alternatives and benefit evaluation of remedial action alternatives for the lower harbor as well as the upper estuary.

e. The pilot study will reduce uncertainty in the ROD for selection of the final alternative by showing that dredging will or will not cause major environmental consequences. Without the pilot and the site-specific evaluation it provides, the project could, at a tremendous cost, proceed through final design, contract award, contractor mobilization, and initial construction only to be stopped because of unforeseen, undocumented adverse environmental impacts.

PILOT STUDY DREDGING AND DISPOSAL OPERATIONS

Project Description

The pilot study will involve the evaluation of three types of hydraulic dredges and two disposal methods. Approximately 15,000 yd^3 of material will be removed and disposed of during the study. Approximately 7,500 yd^3 is contaminated sediment, with PCB levels in the 100-ppm range. The dredging and disposal process involves placing the contaminated sediment in the bottom of the disposal site and then capping it with a layer of clean sediment.

A confined disposal facility and confined aquatic disposal will be evaluated during the study. These disposal methods are described in detail later in this section. Both disposal sites are located within the boundaries of the Superfund Site.

An extensive monitoring program will be implemented to detect any contaminant releases during pilot study operations. This program is designed to obtain data to support the technical objectives of the study and to ensure that public health and the environment are protected.

Study Site

Dredging and disposal operations will be conducted in and adjacent to a small cove located just north of the Coggeshall Street Bridge on the New Bedford side of the Acushnet River. The general area is shown in Figure 1, with the dredging and disposal areas shown in Figure 2. Water depths in the cove are approximately 0.5 ft at mean low water (mlw), and the mean tide range is 3.7 ft with the spring range being 4.6 ft. Tidal currents within the cove are negligible.

Description of Dredged Material

Two dredging areas will be located in the cove. Approximately 10,000 yd^3 of material will be removed from area 1 and 5,000 yd^3 from area 2 (see Figure 2). Material from area 1 will be placed in the CDF. Area 1 will then be used as the CAD site and will receive the material from area 2.

Thirteen sediment cores and seven grab surface samples have been taken from within the cove. The top 2 ft of each core was analyzed for PCBs. Levels in the 0- to 12-in. horizon ranged from 250 to 1.70 ppm. The PCB levels in the 12- to 24-in. horizon ranged from 105 ppm down to the detection limit.

The seven grab samples, which consist of the top 6 in. of material, were combined to form a composite sample; standard and modified elutriate tests were performed on this material. Additional core samples will be taken from the dredging areas prior to the start of work. The number of cores and type of analyses are described in the section on the monitoring program.

Dredging Equipment

Three hydraulic dredges will be used during the pilot study: a hydraulic pipeline cutterhead dredge, a horizontal auger dredge known as a Mudcat, and the hydraulic pipeline dredge with a special attachment called a Matchbox. These hydraulic dredges operate on the principle of the centrifugal water pump. A vacuum is created on the intake side of the pump, and the atmospheric pressure forces water and sediments through the suction pipe. The dredged materials are then hydraulically pumped via pipeline to the disposal site in a slurry consisting of 10 to 40 percent solids.

These three pieces of equipment were selected based on their performance in the following critical areas:

a. They will be able to efficiently and effectively remove the layer of contaminated sediment.

Figure 1. New Bedford Harbor pilot study area

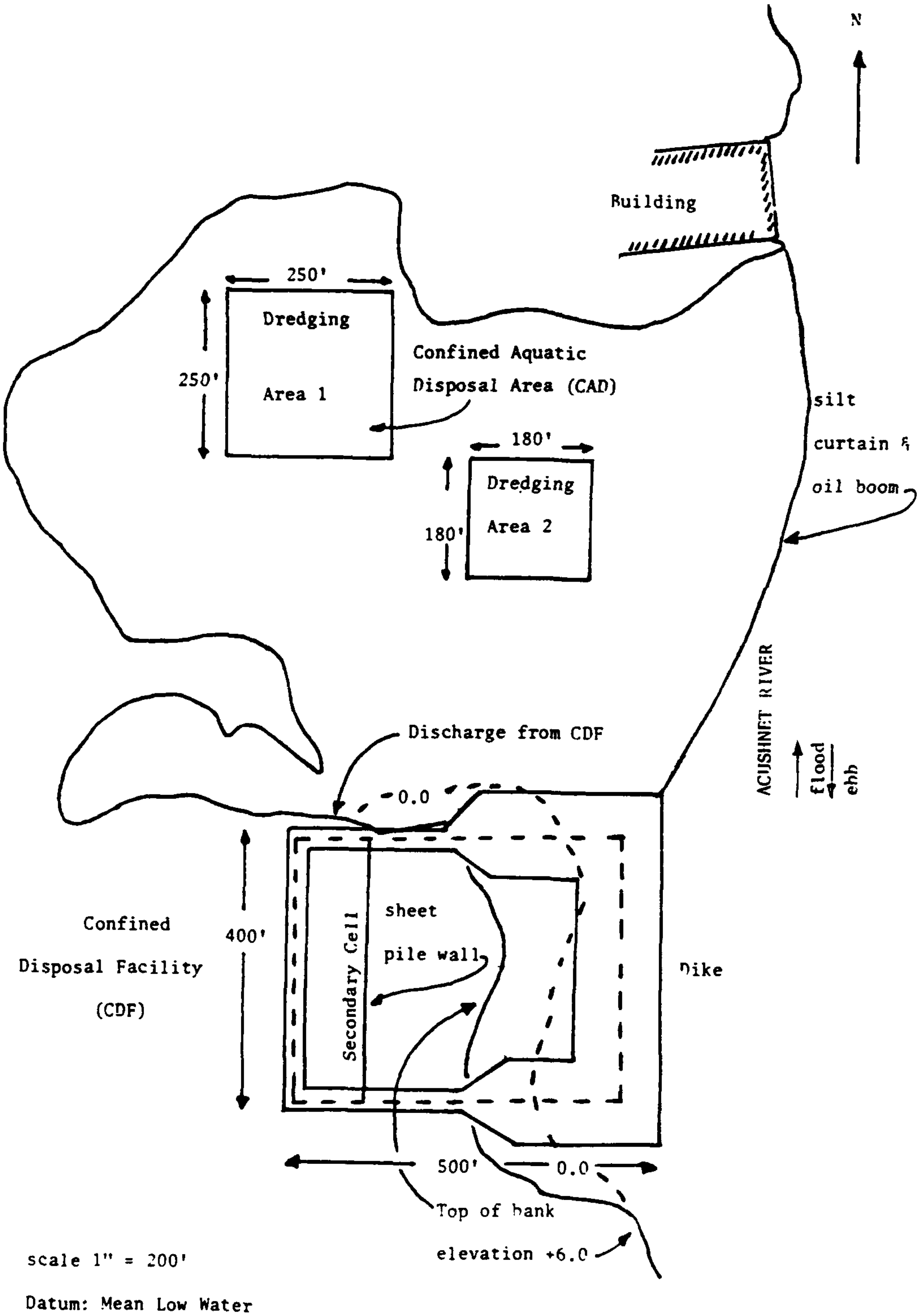


Figure 2. Dredging and disposal areas, New Bedford Harbor pilot study

b. They will minimize the resuspension of sediment while operating.

c. They will be able to operate in the shallow water that is prevalent in the Upper Estuary.

Confined Disposal Facility

A physical description of the CDF is provided by the tabulation below.

Parameter	Value
Area of site	250,000 ft^2
Area of site currently below high-water line	125,000 ft^2
Top elevation of dike	+12 mlw
Top elevation of dredged material	+8 mlw
Surface area at elevation +8 mlw	
Primary cell	145,000 ft^2
Secondary cell	32,500 ft^2
Quantity of material excavated from site	17,500 yd^3
Quantity of dredged material to be placed in site	10,000 yd^3
Quantity of dike material	24,500 yd^3

Site Construction

Approximately 24,500 yd^3 material will be used in constructing the 1,700 ft of dike that surrounds the site, 700 ft of which is located below the high-water line. This 700-ft-long section of dike will be constructed on a geotechnical fabric due to poor foundation conditions. The fabric is installed by placing it on the existing bottom along the dike alignment. Granular fill is then added in 2-ft lifts. Some bottom material will be displaced and resuspended during the construction process; however, the quantity is expected to be small when compared with other pilot study operations. The monitoring program will be ongoing during this phase of the project, and a silt curtain will be in place around the site to contain any sediment that may be resuspended.

The construction of the CDF will also require the excavation of the upland portion of the site where existing elevations vary between +6 and +10 mlw. This area will be excavated to elevation +5.0 mlw, requiring the removal of approximately 17,500 yd^3 of material. This material will be tested for the presence of PCBs, metals, and volatiles, as well as suitability for use in dike construction. It is anticipated that some of the material can be used in dike construction. The remaining clean material would be used in reconstructing the athletic field with approximately 5,000 yd^3 being stockpiled onsite and used as an additional cap for the CDF site.

Material to be used in dike construction would be brought to the site by truck. Trucks should average 30 round trips per day during January, February, and March 1988. The choice of truck routes will be coordinated with the city of New Bedford to minimize impacts to the surrounding neighborhoods. Traffic control features such as signs, police, and flagmen will be used throughout the work period.

Site Operation

The CDF is divided into a primary and secondary cell. The dredged material enters the primary cell in a slurry consisting of 10 to 40 percent solids. The slurry will be discharged through the submerged diffuser, which will be attached to the end of the dredge pipeline. This device is designed to release the slurry parallel to the bottom of the site and at a reduced velocity. Here the solids are allowed to settle out, and the excess water flows over a weir into the secondary cell. The primary cell has the capacity to hold approximately 25,000 yd^3 of slurry. It is estimated that only 20,000 yd^3 of slurry will be produced in removing the 5,000 yd^3 of contaminated sediment from dredging area 1; therefore, it is possible to retain all slurry in the primary cell until all the contaminated sediment has been removed. This mode of operation will not provide the desired estimate of effluent quality for prototype facilities under typical operating conditions. Therefore, an adjustable-height weir will be lowered to allow overflow into the secondary cell, so that monitoring can be done during the latter stages of contaminated sediment dredging.

The excess water will be mixed with cationic polymer emulsions (Magnifloc 1586C, Nalco 7126, or similar) as it enters the secondary cell. Tests performed for the EFS indicate that as much as 82-percent additional suspended solids reduction can be achieved in the secondary cell following polymer flocculation. The secondary cell fills with water until elevation +9.0 mlw is reached; then it flows over another weir structure back into the cove. It is estimated that an effluent suspended solids concentration of 70 mg/ℓ can be attained. A small portion (10 to 50 gal/min) of the water leaving the secondary cell will receive additional treatment. A pilot-scale filtration and carbon absorption system will be employed to evaluate the feasibility of this type of treatment.

Approximately 5,000 yd^3 of contaminated sediment will have been placed in the site initially. This material is the top 2 ft of sediment from dredging area 1. This material will have been capped with an additional 5,000 yd^3 of clean sediment taken from the 2- to 6-ft layer of dredging area 1.

It is estimated that a 1-ft layer of material with a sludgelike consistency will be present in the secondary chamber at the completion of dredging. We plan to solidify this material in place by mixing it with portland cement to demonstrate application of in situ stabilization. This process will hydrate or lock in the pore water.

Contaminant release from the CDF discharge during dredging operations is calculated directly from the dredge flow rate, settling test data, and the suspended sediment contaminant concentrations and dissolved contaminant concentrations observed in the modified elutriate test.

The CDF is being constructed on property owned by the city of New Bedford. The USEPA will lease the property from the city until a final decision is made regarding cleanup of the Superfund Site. The CDF is a temporary facility that may be left in place, removed, or incorporated into the overall cleanup plan that is eventually chosen for the Superfund Site.

The remaining sections of the city property adjacent to the CDF will be modified during the construction process. During the pilot study and for the duration of the lease, the site will be fenced off and constantly monitored. The USEPA will be responsible for maintenance and repairs to the facility. The site will be capped with an additional layer of material in either late fall 1988 or spring 1989. This additional cap material will be obtained from the dikes surrounding the site, material stockpiled onsite, and from offsite.

Confined Aquatic Disposal

Site Construction

The CAD cell (dimensions, 250 by 250 ft; bottom elevation, approximately -6.5 mlw) will be created at dredging area 1 during the dredging that provides the material for the CDF.

Site Operation

Approximately 2,500 yd^3 of contaminated sediment from the top 2 ft of dredging area 2 will be placed along the bottom of the CAD cell. The material will be discharged through the submerged diffuser. The contaminated sediment will be placed in a 2-ft layer and then capped by a 2-ft layer of clean material removed from the 2- to 4-ft layer of dredging area 2.

Controls During Operations

Pilot study operations will be halted during severe weather conditions. Additional controls that can be implemented during the various phases of the study are discussed in the following paragraphs.

Construction of CDF

A silt curtain will be deployed around the work area during the construction of the dike section located in the water. As an additional control, work could be restricted to the flood tide. Such a restriction would be imposed if monitoring detected elevated levels of contaminants during the operation.

Dredging and CAD

All dredging and disposal into the CAD cell will take place within the cove, as shown in Figure 2. The discharge from the CDF will also be within the cove. A silt curtain and oil boom will be deployed across the mouth of the cove during the entire operation (Figure 2). An additional control that will be implemented if needed involves restricting the various operations to flood tide periods. Additional downtime could also be provided between operational periods (intermittent operations). The operation of the dredges can also be modified. The depth of cut, rotation of cutterhead, and swing speed of the dredge ladder can all be reduced on the cutterhead dredge. The depth of cut, rotation of horizontal auger, and rate of advance can all be reduced on the Mudcat.

The need to implement any of these operational controls will be determined by the monitoring that is ongoing during all phases of the project. Decision criteria, which are described later, will be used to evaluate the need for additional controls.

MONITORING PROGRAM

Objective

This monitoring program was designed by personnel from the WES and the USEPA's Environmental Research Laboratory, Narragansett (ERLN), Rhode Island. The objective of the monitoring program is to provide information that can be used to (a) evaluate the effectiveness of the dredging and disposal techniques employed, (b) predict the magnitude and areal extent of water quality impacts during a full-scale operation, (c) select optimum monitoring protocols, and (d) regulate pilot study operations. Results of this program will be used to evaluate the risks and potential benefits of a full-scale dredging and disposal operation relative to other proposed options for decreasing the contamination effects of PCBs and metals in New Bedford Harbor.

The level of effort described in this section is meant to acquire sufficient data to meet the four objectives listed above. However, the program is intended to be flexible. Monitoring of certain activities can be expanded if initial results indicate such a need. The program includes physical, chemical, and biological evaluations of sediment, harbor water, effluent from the CDF, and leachate from the CDF. Air monitoring is not addressed in this section. The ERLN has designed the biological monitoring that will be performed during the pilot study.

Program Description

The monitoring program is divided into four major tasks associated with evaluating impacts and measuring the success of the pilot project. Each of these tasks has two or more subtasks, as outlined below.

- a. Preliminary sampling
  - (1) Water quality characterization
  - (2) Sediment characterization
- b. Evaluation of the CDF
  - (1) Effluent water quality
    - (a) During active filling
    - (b) Storm runoff, postfilling
  - (2) Leachate water quality
- c. Evaluation of CAD
  - (1) Disposal into CAD cell

(2) Contaminant migration

d. Evaluation of dredge types/disposal techniques

(1) Removal efficiency

(2) Comparison of dredge types/disposal techniques

(a) Plume extent

(b) Far-field water quality

Preliminary Sampling

Preliminary sampling will be used to refine the proposed techniques for this specific project area and to determine the natural range of specified physical, chemical, and biological response variables that occur within the system. Data will also be collected to verify results of certain predictive tests or models (e.g., settling tests, elutriate tests, and plume behavior).

Water Quality Characterization

The basic sample component for water quality assessments will be hourly water samples taken over one tidal cycle and pooled into ebb and flood composites. Samples will be taken on five sample dates at four stations (see Figure 3) and will be opportunistically chosen for normal and worst-case conditions (e.g., spring tide-high discharge, storms). The Coggeshall Street Bridge station is the focal point relative to the decision criteria. At this station, stream discharge will be measured for each sampling event, and samples will be composited proportional to flow from two cross-sectional subareas and three water depths. Samples from the other stations will be taken at three depths where conditions allow. A sampling event will consist of ebb and flood composites of hourly samples at each station. These samples will be analyzed for:

a. Suspended solids.

b. Temperature.

c. Salinity.

d. Whole water PCB (total, aroclors, congeners).

e. Metals on 50 percent of samples (cadmium, copper, lead).

f. Total organic carbon (TOC) on 10 percent of samples.

g. Filterable PCB (total, aroclors, congeners) and metals on 25 percent of samples.

Biological testing during this preliminary phase will include the following tests. A description of these tests is also provided.

Figure 3. Sampling stations for pilot study

a. Sperm cell test on all samples.

b. Sperm cell and physical/chemical tests on noncomposited hourly samples on two sample dates at Coggeshall Street station ($2 \times 6 \times 2 = 24$).

c. Two- and seven-day tests on expected worst-case and expected normal conditions.

d. Mussel deployments for worst and normal, sampled on days 0, 3, and 28.

The mussel has been demonstrated to be a reasonable biological monitor whose sensitivity to chronic impact makes it an effective early warning system for other biological components of the marine ecosystem. Prior to construction and at the initiation of each subsequent phase of the pilot study, mussels will be transplanted to four stations (see Figure 3). Tissues will be analyzed chemically on mussels collected for transplants at time zero. Collections will be made 3 days following the initiation of each phase of the pilot study, with the mussel tissue being chemically analyzed. The first biological measures (mortality, actual growth, scope for growth) will be made on mussels collected at day 7. Both chemical tissue analyses and biological indicators will be measured after 28 days of exposure.

As shown in Figure 3, four caged mussel stations will be established: three in the transect from Coggeshall Street Bridge to the Acushnet River side of the hurricane barrier and a control station in Buzzards Bay. Four replicates will be taken per station, with the number of individuals per replicate as identified below.

a. Scope for growth: 10/cage.

b. Growth and survival (marked and measured individuals): 10/cage.

c. Bioaccumulation: 30/cage.

d. Total: 50/cage.

e. Redundancy: 50/cage.

The sea urchin (*Arbacia punctulata*) sperm cell toxicity test is a proven, effective, indicator of ambient water toxicity. This test provides rapid estimates of toxicity. It will be used to evaluate the toxicity of various ambient waters north of the Coggeshall Street Bridge throughout the study and the effluents from the CDF.

Whole (undiluted) receiving waters will be tested from each site. Discharge waters from the CDF will be tested as an effluent. There will be five experimental concentrations (diluted with site control water).

Three replicates will be tested for each receiving water sample or effluent concentration. Two controls will be selected for each test series: a site control (clean seawater collected at the south end of West Island, Massachusetts) and a Narragansett Bay seawater control.

The 2-day red algae (*Champa parvula*) reproductive test, the 7-day mysid (*Mysidopsis bahia*) reproductive, growth, and survival test, and the 7-day sheeps head minnow (*Cyprinoden variegatus*) growth and survival test will be conducted during the pilot study to evaluate toxicity in the receiving waters or the effluent discharge from the CDF.

Whole (undiluted) receiving waters will be tested from each site. Discharge waters from the CDF will be tested as an effluent. There will be five experimental concentrations (diluted with site control water).

A minimum of two replicates will be provided for the algal tests, and three for the fish tests. A minimum of eight replicates will be used for the mysid reproductive tests. Five plants, 15 fish, and 5 mysids will be used in each replicate.

Two controls will be selected for each test series: a site control (clean seawater collected at the south end of West Island, Massachusetts) and a Narragansett Bay seawater control.

Sediment Characterization

Six sediment cores will be taken to a depth of 6 ft below the surface from each area to be dredged. These cores will be split into samples representing six horizons (0-0.5 ft, 0.5-1.0 ft, 1.0-1.5 ft, 1.5-2.0 ft, 2.0-2.5 ft, and 2.5-3.0 ft) (6 cores × 6 horizons × 2 areas to be dredged = 72). This is being done to determine the depth at which clean material is found. Physical and chemical parameters to be measured on these samples include:

a. Water content, specific gravity.

b. Atterberg limits, grain size.

c. PCBs (aroclors, congeners), TOC.

d. Metals (cadium, copper, lead, chromium, and selected others) (one core per site on <64-μ fraction).

e. Elutriate tests on composites (standard and modified).

Biological tests will include the *Ampelisca* toxicity test on whole sediments and sperm cell tests on water from the *Ampelisca* test.

The tube-dwelling amphipod *Ampelisca abdita* will be used to evaluate sediment contamination. This organism has been shown to be sensitive to contaminated fine-grained sediments. The toxic response will be mortality and emergence. The replication scheme will be: three chambers per treatment, with 30 *Ampelisca* per chamber. The control sediment will be the relatively uncontaminated sediment from Central Long Island Sound.

For each dredging area, one sample will be composited by depths of 0 to 1, 1 to 2, and 2 to 4 ft. A modified elutriate test will be run on each sample to predict effluent quality from the CDF. A standard elutriate test will be run on each sample to predict soluble contaminant release from the CAD construction and the dredging operation. Each elutriate test will be run in triplicate. Makeup water for the elutriate tests should be collected from the Upper Acushnet River Estuary.

Evaluation of the CDF

The confined disposal facility will be evaluated for (a) the effects of different treatment techniques on the concentration of contaminants in the effluent and (b) the long-term migration of contaminants within the leachate. Effluent treatment techniques will be evaluated relative to one another and to water quality standards and existing water quality conditions. Effects during construction of the CDF are addressed in task 4 under operational evaluations.

The format used in the following sections consists of a statement of the question being addressed, followed by the appropriate null hypothesis. A sampling program designed to test each null hypothesis is then detailed along with recommended numbers of samples, stations, and statistical analyses.

Effluent Water Quality During Active Filling

The question to be answered is: Are techniques available that can be used to reduce contaminant concentrations in effluent from a CDF into which contaminated New Bedford Harbor sediment is disposed? (Secondarily, are observed treatment levels substantially different and economically practicable to justify full-scale application of these techniques?)

The null hypothesis is: The concentration of specific contaminants in the effluent and the toxicity of effluent from the CDF will be unchanged by the treatment method.

The CDF effluent will be treated by dividing the CDF into two cells, with primary settling in the first cell and chemically assisted clarification in the second cell. Effluent quality will be evaluated by chemically analyzing both filtered and unfiltered effluent to determine contaminant loadings in the suspended and dissolved phases. Relative toxicity of treated effluents will also be determined using bioassay techniques.

Effluent contaminant concentrations will be analyzed for the following treatments:

Treatment	Data To Be Collected*
Primary cell - initial filling phase	1,2
Primary cell - late filling phase	1,2
Secondary cell - initial filling phase	2
Secondary cell- late filling phase	2,3
Filtered	2
Carbon-treated	2

* Data types are:
1 = Suspended solids only - 24 hourly samples for 5 days.
2 = Ten 24-hr composites of suspended solids, whole water and filterable PCBs, metals on 50 percent of samples, TOC on 10 percent of samples, and sperm cell test on subset (some on chemically fractionated samples).
3 = Most sensitive of 2- and 7-day tests on final effluent.

Mean contaminant concentrations in the effluent and the toxicological response will be compared by treatment using analysis of variance (ANOVA).

Effluent Water Quality -
Storm Runoff Postfilling

The question to be addressed is: What are the concentrations of any contaminants released to stormwater runoff?

The null hypothesis is: Contaminant concentrations in stormwater runoff are not elevated.

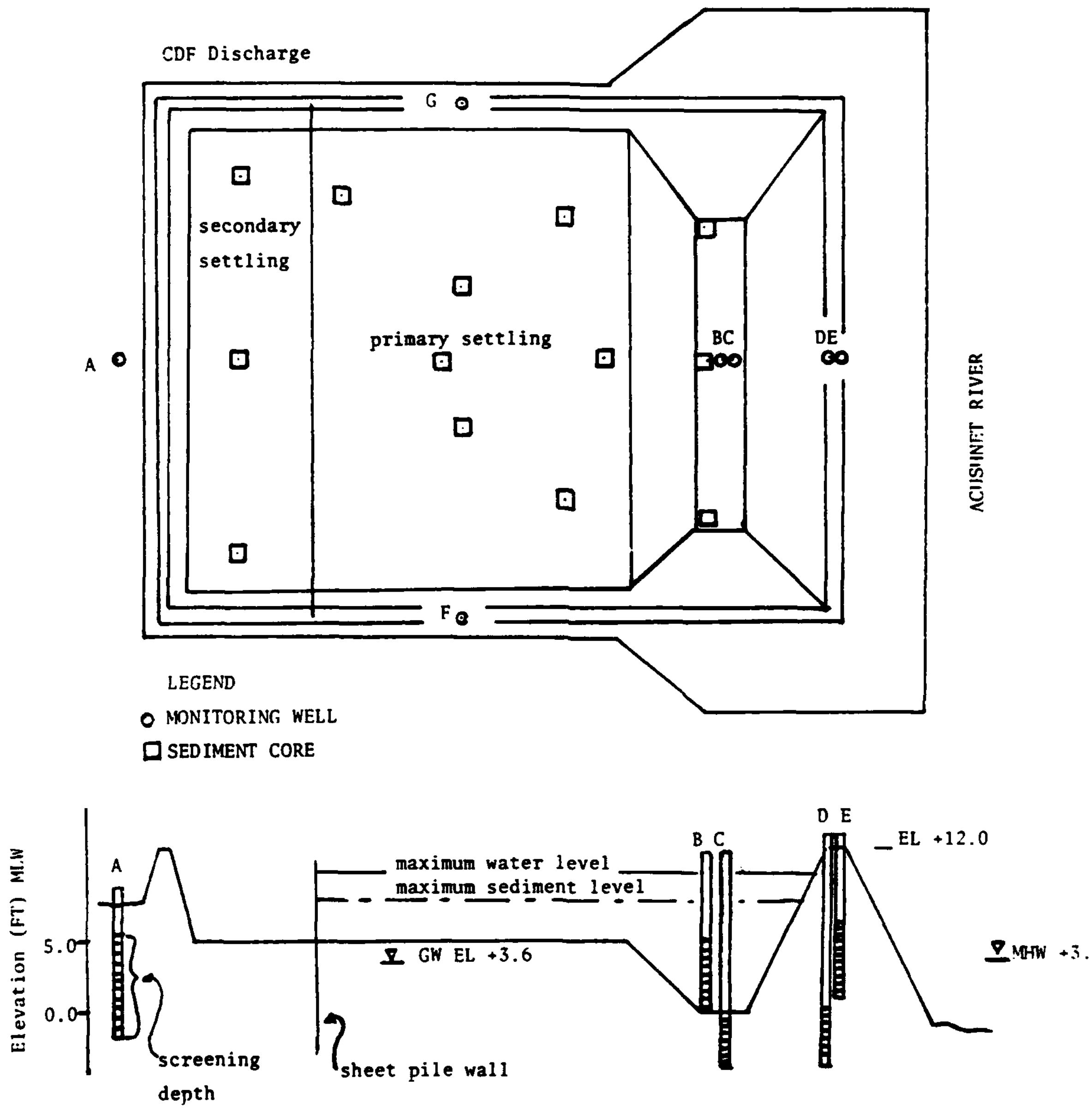
Following completion of disposal into the CDF and initial dewatering, effluent quality during storm runoff conditions will be determined. During a storm event, effluent samples will be collected hourly until flow has peaked. For 10 of these samples, determinations will be made of suspended solids, PCBs (whole water and filterable), pH, salinity, and temperature. These data will be used to predict performance and effectiveness of the CDF for sequestering contaminants.

Leachate Water Quality

The question is: What are the concentrations of any contaminants released to the leachate?

The null hypothesis is: Contaminant concentrations in leachate are similar to local ground water and do not increase with time.

Seven monitoring wells will be installed in and around the CDF (see Figure 4). These will be sampled for background contaminant concentrations before dredged material is placed in the site. The wells will also be sampled periodically over the life of the CDF. Undisturbed core samples of dredged material will be taken from the CDF and the pore water analyzed.



Note: Exact screening depths to be determined during well drilling.

Figure 4. Confined disposal facility

The monitoring wells will be sampled and the filtered samples will be analyzed at least three times prior to dredging. One sample will be taken immediately prior to initiating dredging. Samples from the wells will be collected three times per week while the CDF is being filled and weekly for the first month after the CDF is filled. Six of the samples collected during that time period will be analyzed for PCBs, TOC (10 percent of samples), pH, salinity, and metals (50 percent of samples). The remainder of the samples will be archived and analyzed, if necessary, to characterize rapid changes in groundwater quality. The wells will continue to be sampled quarterly for 2 years.

In addition to the monitoring wells, sediment cores will be taken from the sediment in the CDF according to a pattern similar to that shown in Figure 4. Sediment and pore water from these cores will be characterized chemically and physically, to include PCBs, selected heavy metals, and water content. These cores will be collected after initial consolidation of the filled CDF and after drainage of free water from the surface of the CDF.

Mean contaminant concentrations by well and sampling date will be analyzed using ANOVA.

Evaluation of CAD

CAD will be evaluated for the ability of the operation to place a contaminated layer of material in the bottom of the excavated cell and cap this contaminated layer with a layer of clean material. Upward migration of contaminants within the completed CAD cell will be assessed by analyzing contaminant concentrations in sediment horizons approximately 50 and 400 days following CAD cell construction.

Disposal Into the CAD Cell

The evaluation will address the following question: Can contaminated sediment be isolated by excavating a disposal cell, filling the bottom half with the contaminated material, and filling the top half with a layer of clean material?

The null hypothesis is: Contaminants in the bottom layer of sediment in the completed CAD are greater than those in the cap material and similar to contaminant concentrations measured in surface (0 to 50 cm) sediments before dredging.

Sediment core samples will be taken in the area to be dredged before construction and at the CAD site following construction and initial consolidation. The cores will be divided into sediment horizons, and each horizon will be analyzed for contaminant concentrations and toxicological response.

The following samples will be taken:

a. Predredging: One hundred 2-ft cores composited to 20 (taken to characterize contaminant concentrations of the material to be dredged).

b. Post-CAD construction (~50 days postconstruction): One hundred 5-ft cores divided into 6-in. horizons and composited to 20 samples per horizon.

Each sample will be analyzed for PCBs, metals, and *Ampelisca* toxicity. Mean contaminant concentrations by location will be analyzed using ANOVA.

Contaminant Migration

The question is: Following construction of the CAD cell, will contaminants from the contaminated bottom layer be transported up into the cleaner cap layer?

The null hypothesis is: Contaminant and toxicological response levels of sediment horizons down through the CAD remain unchanged through time.

Sediment core samples will be taken in the CAD site approximately 1 year following construction. The cores will be divided into sediment horizons, and each horizon will be analyzed chemically and toxicologically for contaminant concentrations. Results of this subtask will be compared with those of the 50-day samples taken in the previous subtask.

Approximately 400 days postconstruction, one hundred 5-ft core samples will be taken, divided into 6-in. horizons, and composited to 20 samples per horizon. Each sample will be analyzed for PCBs, metals, and *Ampelisca* toxicity.

Mean contaminant concentrations and toxic response by horizon and date (50 days versus 400 days postconstruction) will be analyzed using ANOVA.

Evaluation of Dredge
Types/Disposal Techniques

Each type of dredging equipment and each disposal technique (CAD versus CDF versus no dredging) could behave differently with respect to its effects on water quality during construction and operation. Additionally, the effectiveness of each dredge type may be different with respect to its ability to remove primarily contaminated sediment without substantial overdredging. Studies carried out in this task will assist in determining whether any equipment or technique should be preferred because of greater efficiency or relatively low water quality impacts.

Removal Efficiency

The question to be addressed is: Can optimum dredging depth be predicted and controlled with sufficient accuracy to remove the entire contaminated layer from a dredging area? What amount of overdredging is necessary to meet this goal?

The null hypothesis is: Contaminant levels in sediment cores taken from the dredging area following dredging are the same as levels before dredging.

Sediment core samples will be taken in the dredging area immediately before and following the final dredge pass predicted to reach uncontaminated sediment. If substantial contaminated material still remains in the dredging area, a deeper dredge cut will be made and the area retested until contaminant levels similar to reference levels are attained.

Sampling will be designed to collect ten 3-in. cores from the dredging area and analyze (within hours) for total PCBs.

Mean contaminant concentrations between sets of sediment cores will be analyzed using ANOVA.

Plume Extent

The question to be addressed is: Are any tested dredge types or disposal techniques preferred because of their ability to minimize water column suspended sediment plumes?

The null hypothesis is: Suspended sediment plumes are similar for each dredging or disposal activity.

During operation of the three different dredge types and during disposal into the CAD cell, the development and extent of plumes will be determined with suspended sediment samples.

A longitudinal transect will be established extending downcurrent of the dredge or CAD cell. Samples should be taken along this transect in the center of the plume at distances of 50, 100, 400, and 800 ft from the dredge, as well as on either side of the silt curtain. Twelve additional sampling stations will be located along three perpendicular transects, as shown in Figure 5. Current measurements will be taken frequently. If water current magnitudes are not sufficient to move the plume in one general direction, a uniform sampling grid (Figure 5) will be used. Sampling should stop when the limit of the plume is reached, except that one additional sample should be taken outside the plume. Plume sampling will be executed for at least three events for each type of dredging equipment. Discrete samples should be taken at hourly, or more frequent, intervals at middepth during the time period that the dredge is operating. The duration of sampling should avoid periods when dispersion of the plume will be interrupted by the silt curtain. Therefore, sampling will begin soon after the dredge starts on a given day. Samples will be analyzed for suspended solids, PCBs, and metals (50 percent of samples only). In addition, a transmissometer will be towed outside the silt curtain at hourly intervals. Sampling stations will be located using electronic positioning equipment.

Measurements will be taken of plumes produced by the following activities:

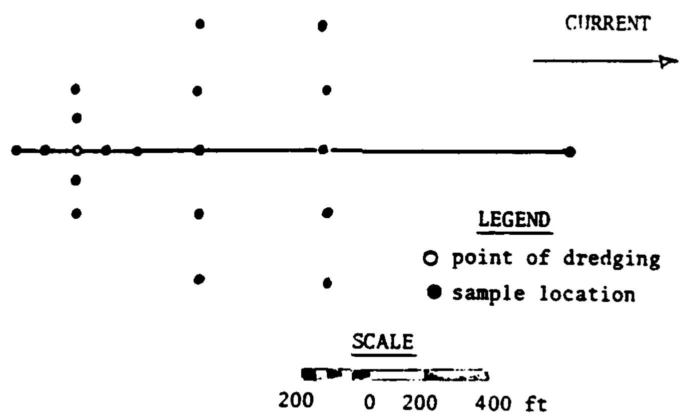
a. Dredge type 1.

b. Dredge type 2.

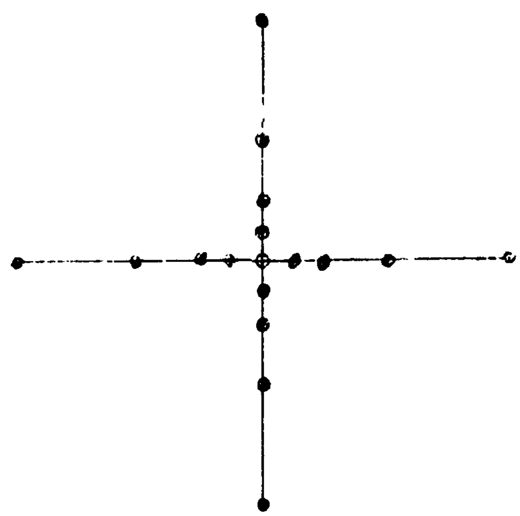
c. Dredge type 3.

d. Disposal into CAD cell.

The following information will be recorded for each type of dredge: position of dredge, depth of water, pump power, pumping rate, slurry concentration, depth of cut, width of cut, speed of forward progress, and where appropriate, cutterhead swing speed and rotation rate.



a. In the presence of significant current velocities



b. In the absence of significant current velocities

Figure 5. Plume sampling plans

An appropriate dredge head sampling apparatus will be installed on each of the dredges used. Selected samples from the dredge head will be analyzed for suspended solids, PCBs, and metals. These samples will be selected to represent differing dredging techniques and operating conditions and will be composited over an operating day.

Analysis of plume data will yield a qualitative description of plume geometry and a quantitative measure of the rate of sediment resuspension from the dredge head. Sediment and contaminant concentration isopleths will be constructed to show the horizontal distribution of the sediment plume caused by each dredge type and operation technique. If current velocities are sufficient to transport the plume downcurrent, the product of the current velocity and the sediment and contaminant concentration distribution in a cross section of the plume will be used to calculate a mass flux rate. This mass flux rate can be used to calculate the rate of sediment and contaminant resuspension from the dredge. A correlation between dredge operation variables and the rate of sediment and contaminant resuspension will aid in specifying dredging methods to minimize contaminant release during dredging.

Far-Field Water Quality

The question to be addressed is: Are any pieces of dredging equipment or disposal techniques preferred because of their ability to minimize far-field water column suspended sediment and toxicological impacts?

The null hypothesis is: Suspended sediment, dissolved and particulate contaminant concentrations, and toxicological response are similar by station for each piece of equipment or technique used and are similar to reference conditions.

Samples will be taken at four stations (Figure 3). Stations were selected based on the predicted extent of the plume. Sampling will occur during both operational and nonoperational periods. Nonoperational periods, both planned and those that occur as a result of delays, will be used as reference conditions. There is no adequate spatial reference that can be sampled simultaneously, and the use of sampling either before or after the project as a reference would incorporate unknown seasonal influences that could be factored out only with years of data.

The operations to be tested are:

a. Nonoperational (immediately before and after the project and between each construction phase).

b. CDF dike construction.

c. Dredge type 1.

d. Dredge type 2.

e. Dredge type 3.

f. Disposal into CAD cell.

As discussed with regard to preliminary sampling, the Coggeshall Street Bridge station is the focal point relative to the decision criteria. A sampling event will consist of ebb and flood composites of hourly samples at each station following the same procedure described under preliminary sampling. These composite samples will be analyzed for the following:

a. Suspended solids.

b. Temperature.

c. Salinity.

d. Whole water PCB (total, aroclors, congeners).

e. Metals on 50 percent of samples.

f. TOC on 10 percent of samples.

g. Filterable PCBs (total, aroclors, congeners) and metals on 25 percent.

Toxicological tests on these samples will include:

a. Sperm cell test on all samples.

b. Two- and seven-day tests:

(1) Once during CDF construction.

(2) Three times during filling of CDF.

(3) Once during disposal into the CAD cell.

(4) Twice following project completion.

c. Mussel deployment at each station:

(1) Once during CDF construction.

(2) Once during CDF filling.

(3) Three-day sample for each dredge type and nonoperational period.

(4) Once during disposal into the CAD cell.

(5) Twice following project completion (spring-dry, spring-wet).

Mean suspended solid concentrations, dissolved contaminant concentrations, and toxicological response between dredging operations will be analyzed using ANOVA.

Supporting Data Collections

Several data sets will also be collected to assist in interpretation of study results. These will include rainfall and wind velocity and direction, tidal gage measurement, and freshwater discharge.

Sequence of Monitoring Events

The sequence of events is described below. However, it should be noted that the actual sampling will likely be somewhat different because of unknown factors, such as equipment breakdowns.

The preliminary sampling will consist of five events, as described earlier. Two events took place in July 1987 and the remaining three will be carried out in late September and early October 1987.

Construction of the section of the CDF located below the high-water line will extend over approximately a 6-week period. The critical period is at the start of the operation when the geotechnical fabric and the initial lifts of fill will be put in place. The first sampling event will take place 3 days prior to the start of work. Sampling will continue for the first 4 days of the operation. Five sampling events will take place during the construction period when work is not going on. A sampling event will take place once a week for 5 weeks during the remainder of the operation.

It is anticipated that each dredge will operate for a 3- to 5-day period in the contaminated sediment with a 5-day shutdown period between work periods. A sampling event would be carried out 3 days prior to the start of dredging. Sampling would take place during the first 4 days of operation for each dredge and three times during the shutdown period between dredges. Two sampling events will also take place while clean cap material is being placed in the CDF.

An evaluation of removal efficiency, rate of sediment resuspension at the dredge head, and plume generation will be ongoing during this same time period for all the dredges.

While the dredges are operating in dredging area 1, the effluent being discharged from the CDF will also be sampled. The effluent going from the primary cell into the secondary cell will be analyzed for 10 consecutive days while dredges 1, 2, and 3 are working in the contaminated sediment. This effluent will also be analyzed for 10 consecutive days while cap material is being pumped into the site. The discharge from the primary cell into the estuary will also be analyzed for a 20-day period. The split stream of effluent entering the filtration and carbon absorption plant will be analyzed for a 10-day period. Effluent will not be discharged back into the harbor while dredges are operating in contaminated sediment.

Samples would be taken during the first 4 days that the dredge is operating in the contaminated material. Samples would then be taken once a week for 5 weeks. This period would include the downtime prior to placing cap material on the CAD cell, while the cap material is being placed, and several weeks after the operation has been completed.

An evaluation of the plume created by this disposal operation will al be ongoing. This sampling will begin when the disposal operation starts and will continue for at least 3 days.

Following completion of the project, one sampling event per week will be conducted for 5 weeks.

DECISION CRITERIA

The previous section described the monitoring program that will be ongoing during all phases of the pilot study. This section describes how the data acquired through the monitoring program will be used to determine if pilot study operations are causing an unacceptable risk to public health or the environment that will necessitate a modification in operating procedures or a termination of the project. This approach was developed by Mr. David Hansen of the USEPA ERLN.

Background Conditions

Decision criteria cannot be based on the enforcement of existing state or Federal water quality standards for PCBs because concentrations in harbor water currently exceed standards even in the absence of dredging. In addition, decision criteria cannot be based on the accumulation of biologically available PCB concentrations to the 2 μg/g FDA action level for seafood because PCB concentrations in indigenous organisms presently exceed this level. Decision criteria based on detection of toxicity in site waters or sediments are not practical, because sediments and water are toxic in the absence of dredging.

Approach to Developing Criteria

Given these existing conditions, our approach is to develop decision criteria that are based on the premise that this remedial action will provide a solution to what is a long-term environmental problem. This approach accepts the risk of a short-term moderate increase in the release of contaminants or associated toxicity, as long as the goal of long-term cleanup is achieved. It is estimated that the release of PCBs and metals at the Coggeshall Street Bridge will be low and within the range of background conditions. The monitoring plan is specifically designed to validate these predictions.

Preoperational monitoring data sets will provide baseline levels of the variability of contaminant concentrations, toxicity, and bioaccumulation. These data will allow us to determine if sample intensity or design should be modified to improve precision of data prior to operational phases. Once the operational phases begin, collection of identical data sets will allow discrimination of statistically significant increases in contaminants, toxicity, or bioaccumulation. In addition, the magnitude of the increase must be greater than a factor of 2 above preoperational phases. If both of these occur, the operation will be halted and the rate of return to predredging conditions will be monitored. Provided that the return to predredging conditions is acceptably rapid, the operation can recommence. This procedure will be used during each operational phase. If conditions produced by an operation are unacceptable in both magnitude and duration, additional engineering solutions will be required before operations can begin anew.

Monitoring Decision Matrix

The following actions are to be included:

a. Characterize predredging conditions.

(1) Determine conditions existing at the site prior to operational activities. Particular emphasis will be placed on water exchange at the Coggeshall Street Bridge.

(2) Select appropriate sample intensity and location for operational phases.

(3) Develop a document that lists numerical decision criteria developed from the preoperational monitoring. In addition, the document will summarize available data from preoperational monitoring and statistical methodologies for analyses of data from operational phase monitoring. This document may be revised as additional information becomes available over the course of the pilot study.

b. Characterize conditions during construction of the CDF dike, dredging with disposal in the CDF, dredging with disposal in the CAD cell, downtime during dredging activities, and postoperational phases.

(1) During each of these phases and during the use of each type of dredge, monitoring activities will characterize site conditions.

(2) Site conditions, during each of these operational phases, will be statistically compared with predredging conditions.

c. Apply decision criteria.

(1) If no statistically significant increase is detected in data from any monitoring activities, the project will continue. To ensure that preoperational conditions are representative for the site, conditions between operational activities will also be monitored and statistically compared with preoperational and operational phases to ensure that no increase has occurred.

(2) If a statistically significant impact is detected that is greater than a factor of 2 above the preoperational phase for any operational phase in monitoring data from the Coggeshall Street Bridge, that phase will be stopped and the rate of return to preoperational conditions will be monitored.

(a) If the conditions rapidly return to those of the preoperational phase, the operation can be continued. "Rapidly" will be defined in the decision criteria and will be based on the preoperational monitoring data and the known flushing rates of the Acushnet River. After the operation resumes, additional monitoring is required to confirm that any further impact is minimal.

(b) If conditions fail to return to those of the preoperational phase, an engineering solution to limit impacts must be instituted.

(c) If conditions fail to rapidly return to those during the preoperational phase following implementation of engineering solutions, it is possible that preoperational monitoring did not adequately characterize background conditions during the actual time of operation. For this reason, it may be desirable to resume the operation with planned shutdown times to demonstrate that interoperational monitoring does not result in continued increases in detectable impacts.

(d) Finally, if data from environmental monitoring demonstrate that the above conditions cannot be met and that long-term, far-field impacts are likely to result from continued operations, the project will be stopped.

Representatives from appropriate Federal and state agencies will form a group that will be responsible for reviewing the monitoring data as they become available. After reviewing these data, the group would make decisions as to the daily operations during the pilot study.

Example Monitoring Scenario

Day 1

The sampling plan, sample analysis, and toxicity testing described in the section on far-field water quality would be carried out.

Day 2

The review group described above would convene to review the 24-hr data sets and consider the following options.

a. Decision criteria violated by 24-hr data sets.

(1) Discontinue operation?

(2) Discontinue sample collection for 7-day static renewal bioassay?

(3) Continue 24-hr sampling regimen until toxicity and chemical pulse drop to levels acceptable according to the criteria?

(4) Consider amplitude (time versus intensity) of chemical/toxicity pulse?

(5) Consider containment strategies?

(6) Reinitiate operation?

b. No violation of decision criteria - Continue operations and sampling, flood and ebb tide composite samples for 7-day static renewal bioassays, and 24-hr sample regimen.

Day 3

Collect first set of mussels and analyze for chemistry and scope for growth.

Day 4 - Decision Point

Decision criteria violated by tissue residues and/or scope for growth: Proceed through steps a1-a6 (as for Day 2) as appropriate.

Days 5-7

Follow steps a1-a6 (Day 2) if violation occurs in 24-hr turnaround data sets. Follow step b (Day 2) if no violation occurs.

Day 8 - Decision Point

Decision criteria violated by bioassay/mussel results: Repeat steps a1-a6 (Day 2) as necessary.

Day 28

Collect remaining mussels for actual growth, scope for growth, and tissue residue analysis.

Decision Point

REHABILITATION OF ESTUARIES IN TAKAMATSU HARBOR

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Civil Work Division
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K. Nikaido, H. Takagi
Engineering Committee
Japan Sediments Management Association

ABSTRACT

The objectives of this project were to recover the natural environment of Senbagawa District around Takamatsu Harbor and to prevent possible marine contamination by dredging the organic sediment containing polychlorinated biphenyls (PCBs) precipitated in the estuaries of the Senbagawa River. Based on the results of a sediment survey, dredging was recommended for sediment with 10 ppm PCB content and an ignition loss of 20 percent or above. This involved a quantity of 82,000 m^3, covering an area of approximately 47,000 m^2. The related tasks (dredging, transporting, unloading, dredged material solidification, disposal, and covering) are described. Reference values established for the treated and discharged spillwater were: pH, 5.8 to 8.6; suspended solids, 10 ppm or below; and PCB content, 3 ppb or below.

BACKGROUND

Japan is composed of four major islands (Figure 1). Kagawa Prefecture is located in the northwestern portion of Shikoku Island, facing both the Inland Sea and the Pacific Ocean. The Takamatsu Harbor is the main harbor of Takamatsu City. The harbor was originally constructed as a pier of the inner city, together with the Takamatsu Castle (Figure 2). The harbor at one time played a vital role as the connection to Honshu Island. The Seto Bridge is to be opened in 1988 to traffic between Takamatsu City and Honshu Island.

The history of the paper manufacturing industry in Kagawa Prefecture dates to the Nara era (A.D. 710-794). Many paper manufacturing companies were situated along the Senbagawa River flowing into the Takamatsu Harbor and, following the introduction of paper manufacturing machines around 1904, these companies began using PCBs. The paper manufacturing process requires a large volume of water. The PCBs discharged with the wastewaters have precipitated on the bottom of the Senbagawa River, eventually contaminating a total water area of 73,000 m^2 (16,000 m^2 in the upper reaches of the river and 47,000 m^2 in the lower reaches and estuaries).

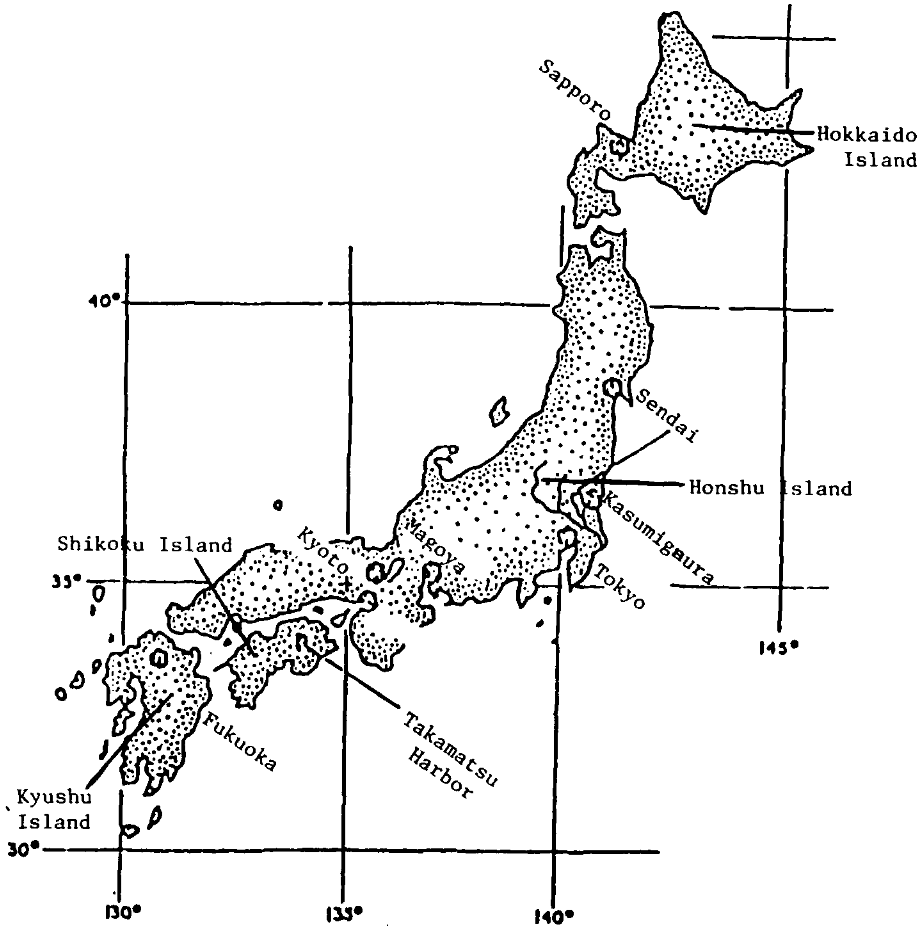


Figure 1. Location of Takamatsu Harbor

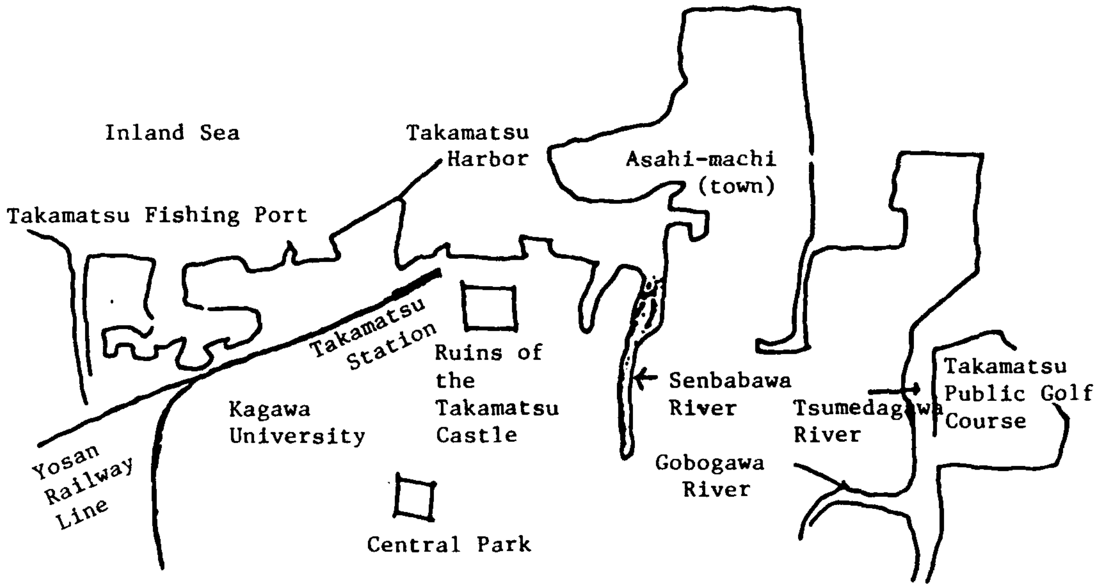


Figure 2. Dredging area

When it was acknowledged that PCBs would affect human health through marine products, their use had already been prohibited in Japan. On October 28, 1975, the Environment Agency established a tentative standard of 10 ppb or below for residual PCBs in the sediment.

To ensure the safe removal of sediment, Kagawa Prefecture conducted surveys, analyses, and studies in 1975, 1976, and 1979 and executed sediment removal operations from 1984 to 1987 in accordance with the work execution plan developed in 1984.

SEDIMENT SURVEY

To address the aforementioned environmental problems, sediment surveys were conducted with 50-mesh at 42 locations between 1975 and 1979.

Sediment samples from the upper and middle reaches had an odor of hydrogen sulfide, the luster of black oil, and were muddy, with 240 to 370 percent water content, 170 to 204 percent liquid limit, 32 to 37 percent plastic limit, 21 to 30 percent ignition loss, and 14 to 106 ppb PCB concentration. The sand, silt, and clay content of the sediment was 4 to 14 percent, 48 to 54 percent, and 37 to 43 percent, respectively, by particle distribution (Table 1).

Figure 3 shows the vertical distribution of PCBs from the upper reaches to the estuaries of the Senbagawa River. The PCB concentration at the upper reaches was from 400 to 500 ppm, which decreased toward the estuaries. The survey results indicated that, fortunately, because of the rapid sedimentation of PCBs, they had not been distributed to a wide area. According to the vertical distribution, the PCB concentration in the surface layer has decreased since the prohibition of PCB usage; however, the concentration in the deep layer shows an increasing curve. In the deeper layers, the concentration decreases in a parabolical curve and finally approaches zero at a certain depth, suggesting that PCB sediments started accumulating at this level.

SEDIMENT REMOVAL CRITERIA

There are no official criteria in Japan regarding the removal of polluted sediments. However, tentative standards have been set for total mercury (T-Hg) and PCBs. For PCBs, the reference is 10 ppm (mg/kg).

In the present dredging project, in addition to the reference PCB concentration, a 20-percent ignition loss reference was used because of the extreme turbidity of the Senbagawa River caused by organic contaminants. Based on these references, the contaminated area to be dredged was specified in the following manner.

As shown in Figure 4, the removal depth was determined in accordance with the vertical distribution of PCBs and the ignition loss, because of their parabolical decrease from the surface layer to the bottom layer. As shown in Figure 3, the layer containing a PCB concentration ≥10 ppm is much deeper in the upper reaches than in the lower reaches of the river. Therefore, as far as the upper reaches are concerned, it was possible to confine the bottom sediments by providing an alternative waterway. For the other reaches, however, what is called the partial-filling/partial-dredging method was employed to remove the sediments.

TABLE 1. RESULTS OF SEDIMENT PROPERTIES ANALYSIS

Parameter	Upper Reach	Middle Reach Bottom Layer	Middle Reach Surface Layer	Lower Reach/ Estuaries
Soil				
Appearance	Black	Black	Black	Black
Odor	Like ditch mud	Like ditch mud	Like hydrogen sulfide	Like ditch mud
pH, H_2O	8.01	7.96	7.80	8.00
pH, KCl	7.79	7.76	7.50	7.85
Water content, %	293	241	371	158
Weight per unit volume, g/cm^3	1.047	1.025	1.016	1.122
Liquid limit, %	204.3	-185.6	169.3	118.6
Plastic limit, %	35.9	37.2	32.5	23.0
Plastic index	168.4	148.4	136.8	94.7
Specific gravity	2.112	2.101	2.229	2.342
Particle distribution				
Conglomerate (≥2,000 μ)	0	0	0	0
Sand (74-2,000 μ)	4.0	4.0	14.0	4.0
Silt (5-74 μ)	53.0	54.0	48.5	48.0
Clay (≤5 μ)	43.0	42.0	37.5	48.0
Eutrophic substance				
Ignition loss, %	27.1	29.4	21.9	21.0
CID Mn, mg/g	109	96.9	108	64.2
COD Cr, mg/g	413	484	277	220
BOD,* mg/g	<500	<500	<500	<500
T-N, mg/kg	5.510	6.320	5.220	2.860
T-P, mg/kg	540	400	692	114
Sulfide, mg/g	12.1	6.0	5.6	3.7
n-hexane extract, mg/g	15.9	10.8	5.0	3.3
Toxic substance				
T-Hg, mg/kg	0.81	0.93	0.98	0.70
Cd, mg/kg		3.9	2.7	
Pb, mg/kg		228	196	
Cr^{6+},** mg/kg		<0.02	<0.02	
As, mg/kg	21.3	9.5	14.2	18.3
CN, mg/kg		<0.7	<0.7	
Org-P, mg/kg	<1.0	<1.0	<1.0	<1.0
PCB, mg/kg	10.6	14.1	30.6	9.89
PCB dissolution test, mg/kg	ND†	ND	ND	ND

* Concentration with wet sediment.
** 10 percent by weight dissolution concentration.
† Not detected (≤0.0005 ppm).

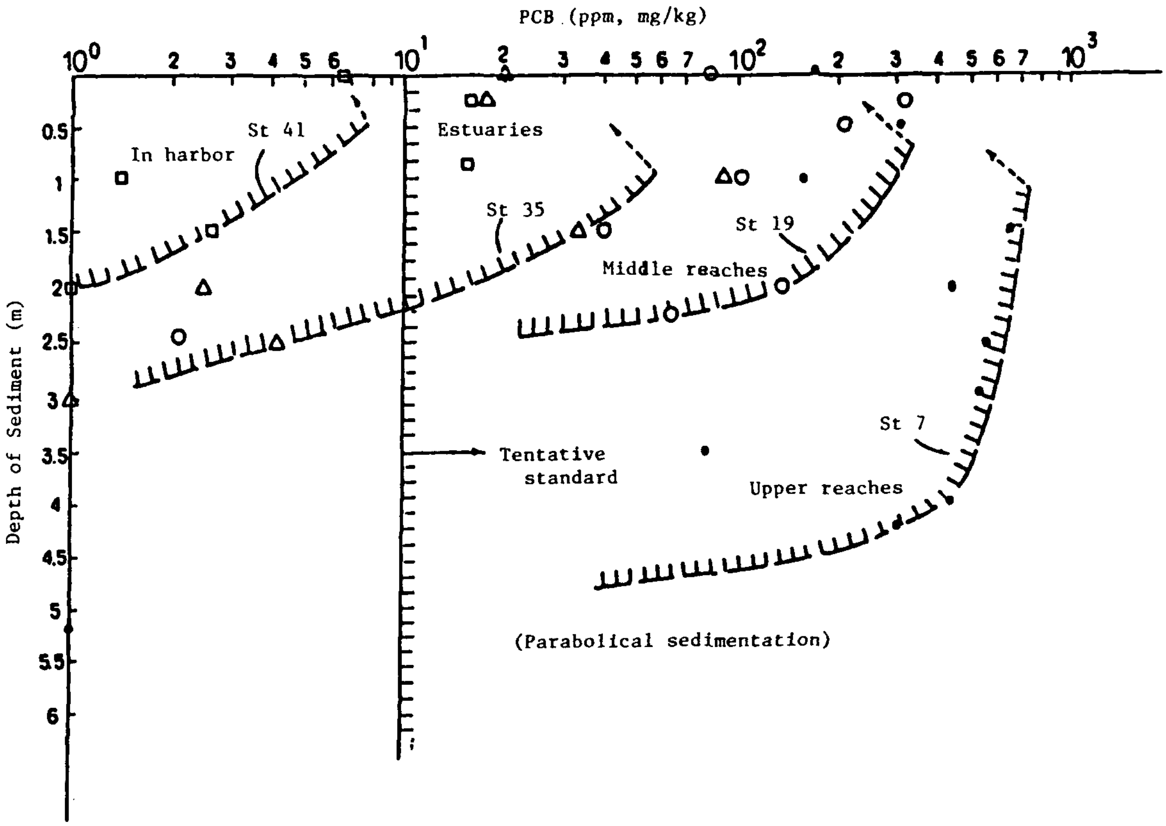
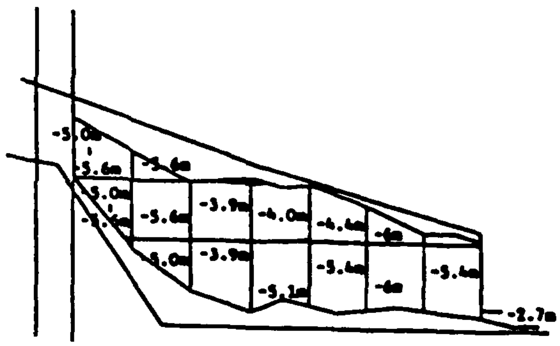


Figure 3. PCB vertical distribution in contaminated area

Figure 4. Plan view of the dredging project of Senbagawa District at Takamatsu Harbor



The removal depth of those reaches was as follows (with TP indication):

a. Middle and lower reaches, -3.9 m to -5.1 m.

b. Estuaries, -4.4 m to -5.4 m.

DESCRIPTION OF DREDGING

Dredging and Disposal Areas

Figure 5 shows the landfill area in the upper reaches of the Senbagawa River and the dredged area in the lower reaches and estuaries. Size of the dredged area was approximately 47,000 m^2, with a volume of 82,000 m^3. Of this volume, 20,000 m^3 was used for landfilling in the upper reaches, and the remaining 62,000 m^3 for landfill at a subdivision in Tsumeda District (Figure 6).

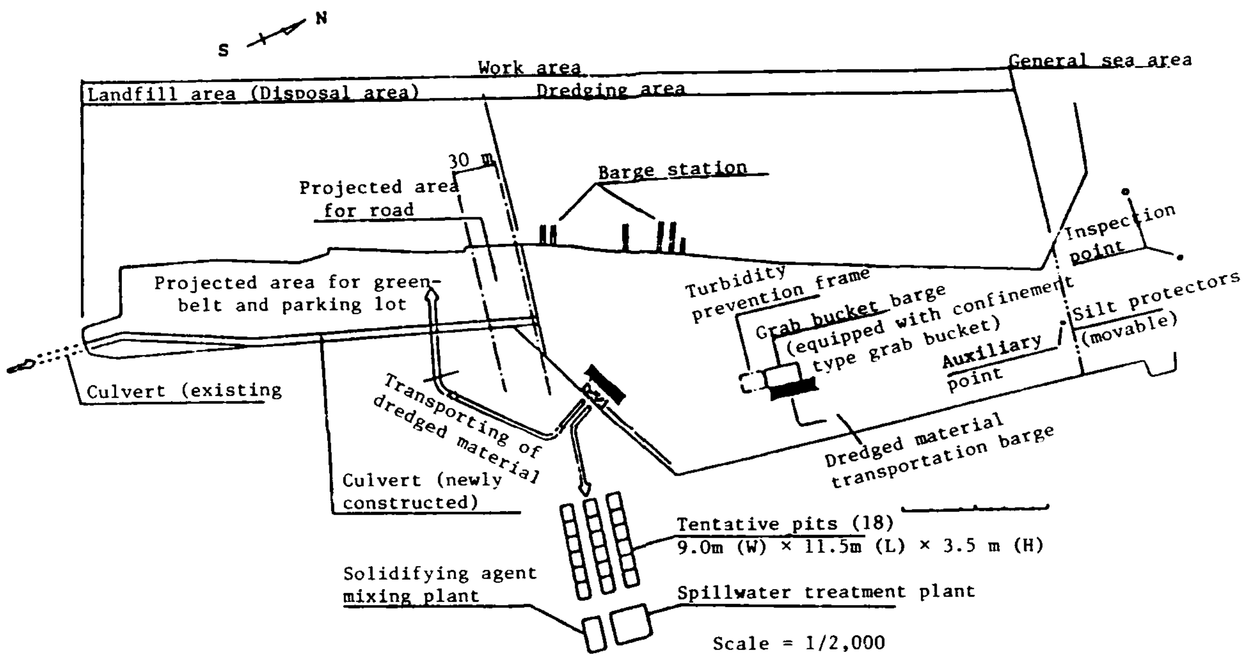


Figure 5. Plan view of Senbagawa District

Equipment

For sediment dredging, the pump dredge is normally used to minimize turbidity and to simplify the operation. However, the sediment to be dredged was not conducive to this procedure since shipbuilding yards and private houses are crowded along the river, and the sediments contained a large quantity of wires, timbers, vinyl bags, and other foreign materials. Accordingly, though problematic from the viewpoint of contaminant dispersal, the grab dredge (with 2-m^3 capacity) was employed. To prevent spillage and dispersal of contaminants, a confinement-type grab was used, and protection sheets (called "silt protectors" in Japan and "silt curtains" in the United States) were provided around the dredge (Figure 7).

During dredging, inspection and auxiliary points were provided, where PCB concentration and turbidity were measured once a week and four times a day,

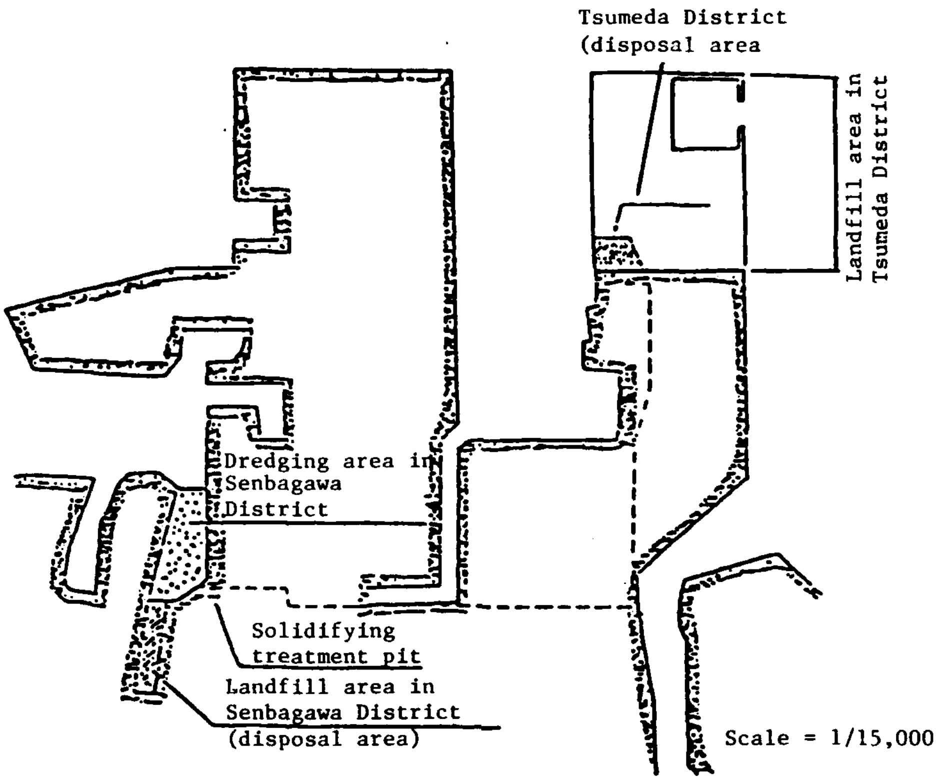
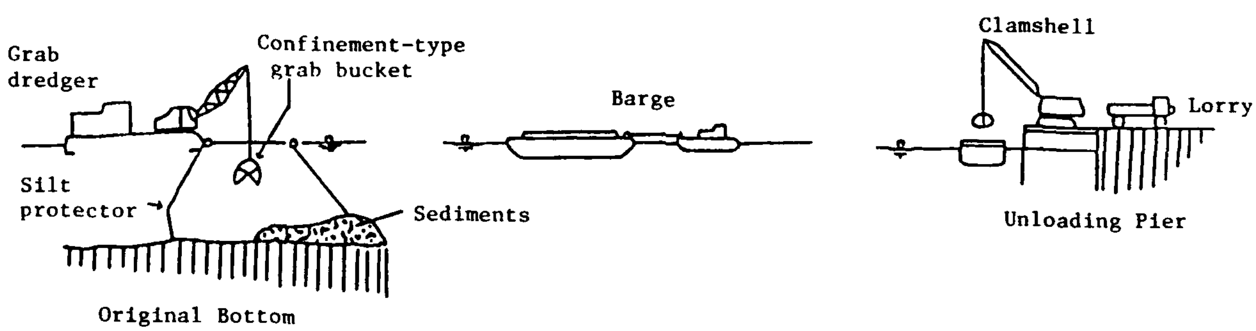
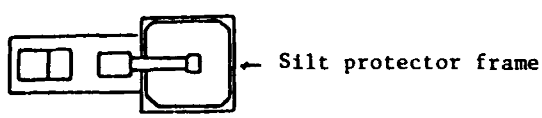


Figure 6. Location of Senbagawa and Tsumeda Districts



a. Transporting/unloading process



b. Dredging process

Figure 7. Sediment dredging procedure

respectively. Both measurement items remained below reference values during dredging. Foreign materials were removed at the time of barge loading to prevent problems during the treatment process.

Disposal

The dredged material was disposed in the contaminated area in the upper reaches of the river and in a subdivision, located 3 km from the dredged area and within a marine reclamation area (disposal area of Tsumeda District), which was convenient for the disposal.

Upper Reaches (Water-Fill), Senbagawa District

The sediment dredged by grab was loaded on a barge (with 300-m^3 capacity) and transferred to the unloading pier provided adjacent to the fill area. At the pier, the sediment was transferred by clamshell (with 2-m^3 capacity) from the barge to lorries that had been modified to prevent spillage. The sediment was dumped from the temporary decks over the fill area. Seepage water from the dredged material was fed to a spillwater treatment plant (Figure 8).

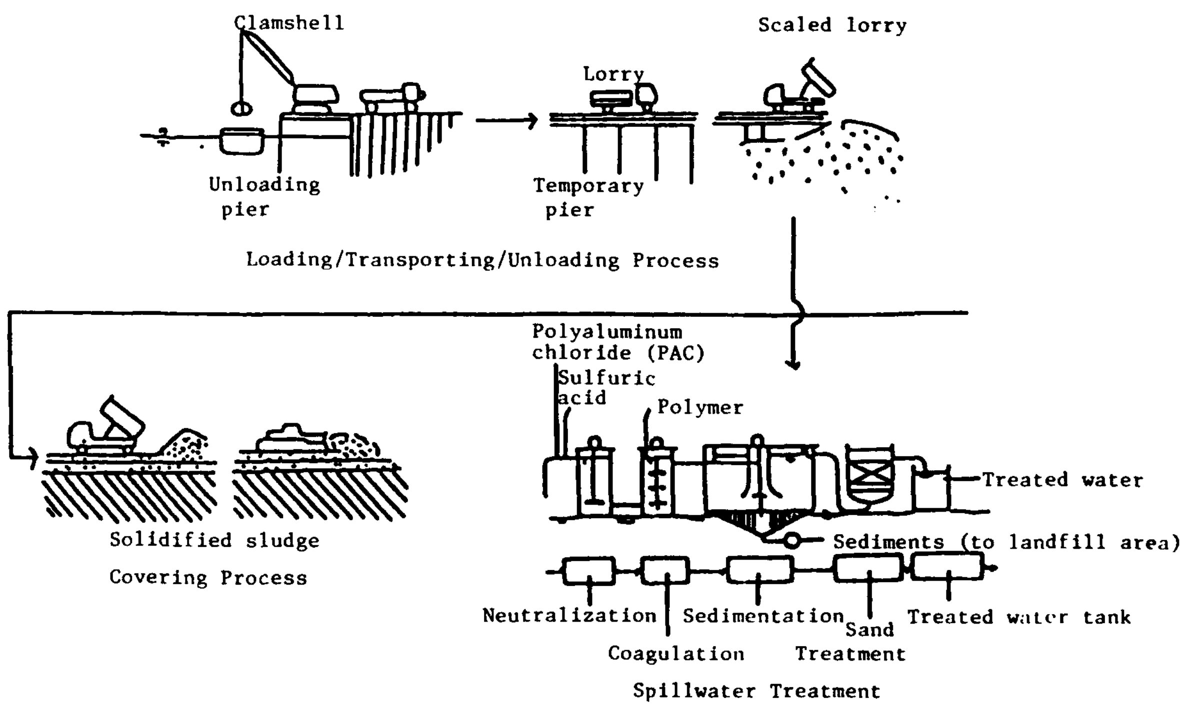


Figure 8. Water-fill of upper reaches of the Senbagawa River and spillwater treatment

Since there was a plan to reclaim the area for roads, parking lots, and greenbelt within a short period, the dredged material was treated by a special solidifying agent that was effective even on the sludge containing a large volume of organics with a high water content.

For the area transformed to road, this treatment was applied to all the layers to prevent possible subsidence. Elsewhere, the area from 1.3 to 2.8 m from the surface was treated. The target rigidities of the former and the latter were 1.0 kg/cm^2 and 0.4 kg/cm^2, respectively. The solidification treatment was conducted in such a manner that the solidifying agent was fed from the mixing plant on the shore to the dredged material by pressure pump (Figure 9) and kneaded by the vertical mixer onboard a floating boat.

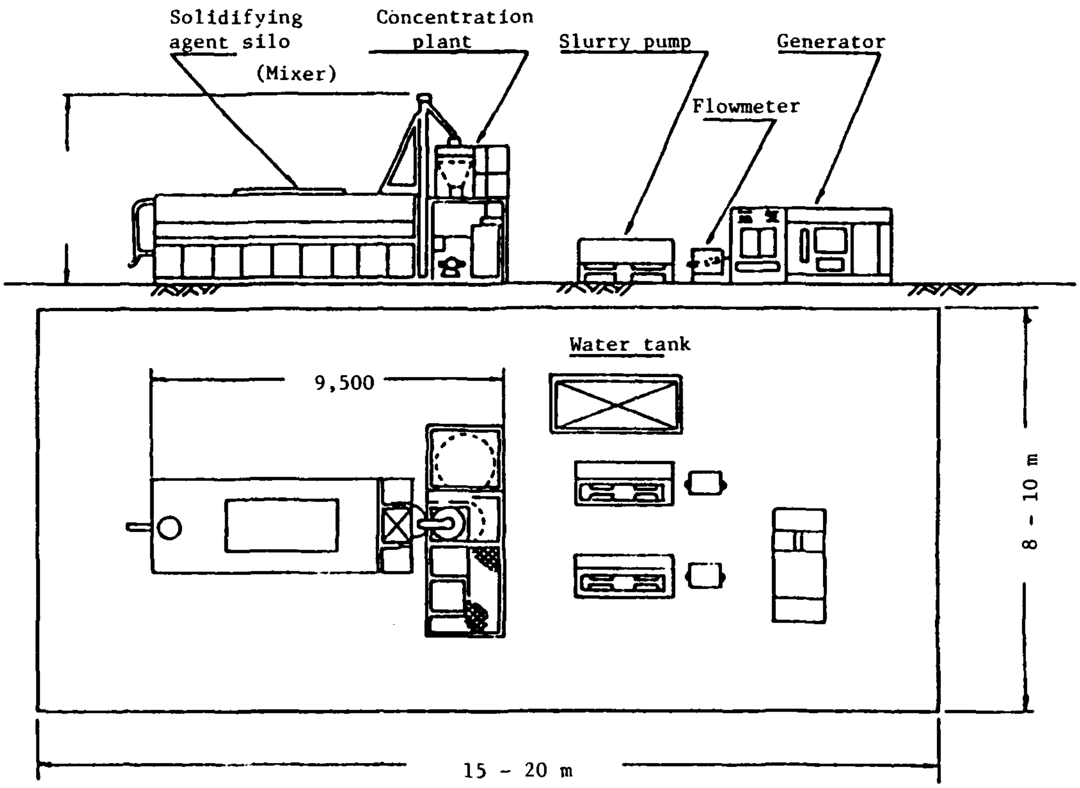


Figure 9. Mixing plant for pressurized transfer of solidifying agent

Landfill, Tsumeda District

As the dredged material would be transported across the city from the unloading pier to the fill area, safety measures for the transportation were required. Also, preventive measures against secondary contamination by the dredged material were required in the landfill area that was to be reclaimed to vegetation. Accordingly, the dredged material was treated by a special solidifying agent before transport to the fill area (Figure 10).

Temporary pits for the solidification treatment were provided in the area adjacent to the dredged area. As shown in Figure 5, 18 solidification pits were required with a unit size of 9 m(W) × 11.5 m(L) × 3.5 m(H). The schedule for solidification treatment is illustrated in Figure 11.

Kneading of the solidifying agent and the dredged material was conducted by a special mixer, rather than a bucket in a backhoe. Target rigidity of the treated material was 0.4 kg/cm^2.

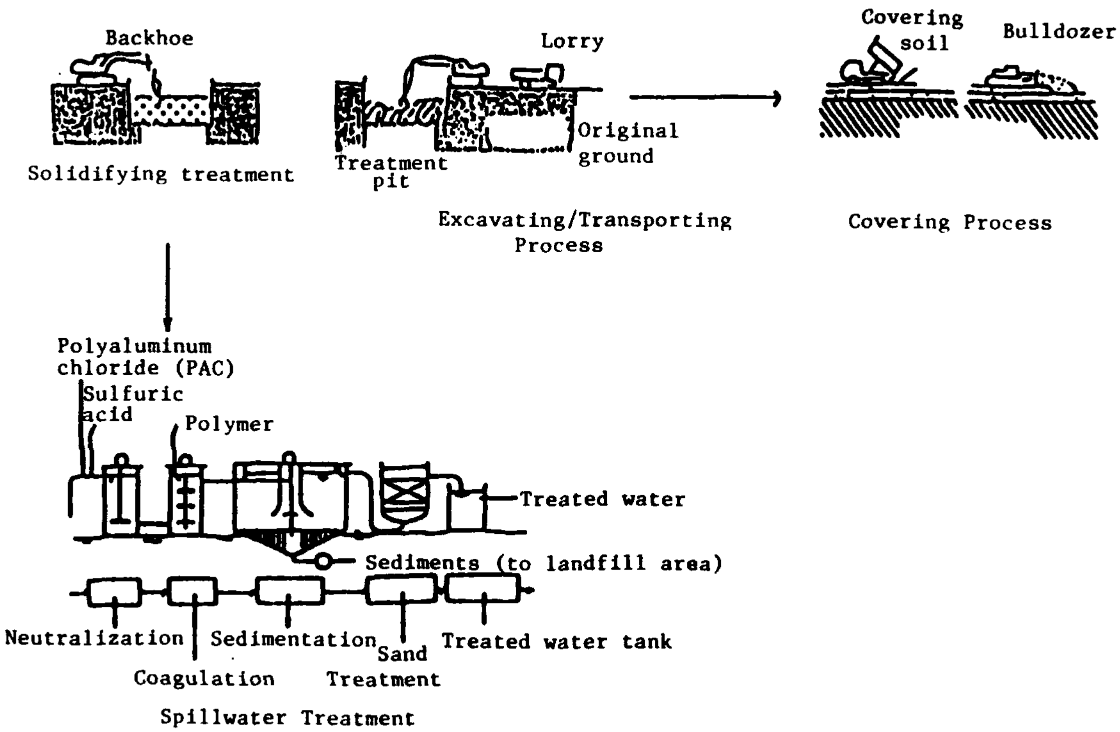


Figure 10. Solidification and spillwater treatment for landfill area of Tsumeda District

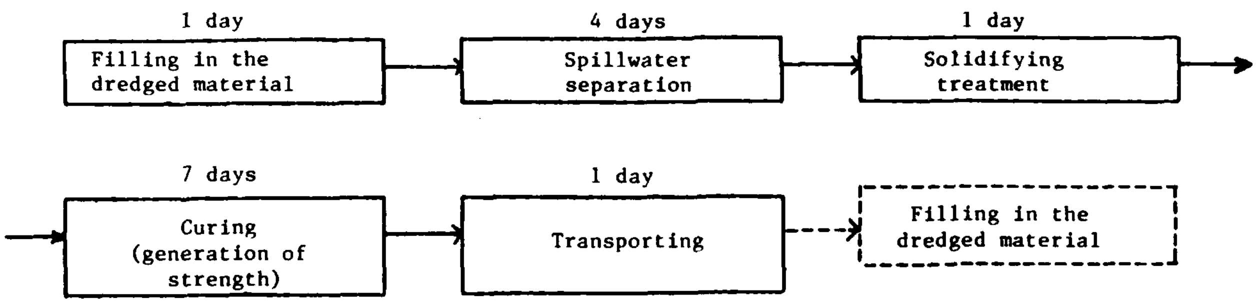


Figure 11. Operation cycle of solidfying treatment pit

The disassociated water in the pits and the rainwater were fed to a temporary spillwater treatment plant that was part of the solidification treatment system.

During this work, no complaints were raised from the public about odor, noise, or vibrations, and no problems occurred during transportation of the dredged material through the city.

Spillwater Treatment

Description

The wastewaters discharged during the rehabilitation works contain PCBs whose concentration exceeds the spillwater emission standard, so that they would cause secondary contamination if drained as they were. Therefore, proper spillwater treatment was required.

Basic tests made it clear that PCBs would easily adhere to suspended solids and would rarely transfer to water. Accordingly, if the concentration of suspended solids was limited to below 10 mg/ℓ, the PCB concentration would be reduced to the reference value and the other contaminants could also be removed simultaneously. Following the practice for such a case, a combination system of flocculation and filtration was employed in the project as the spillwater treatment method.

The spillwater in question was the discharge water from the upstream fill area and from the temporary solidification pits for the landfill. The waters were fed to the spillwater treatment systems by pump, and the treated waters were discharged to the estuaries of the Senbagawa River. A flowchart of the spillwater treatment system is shown as Figure 12.

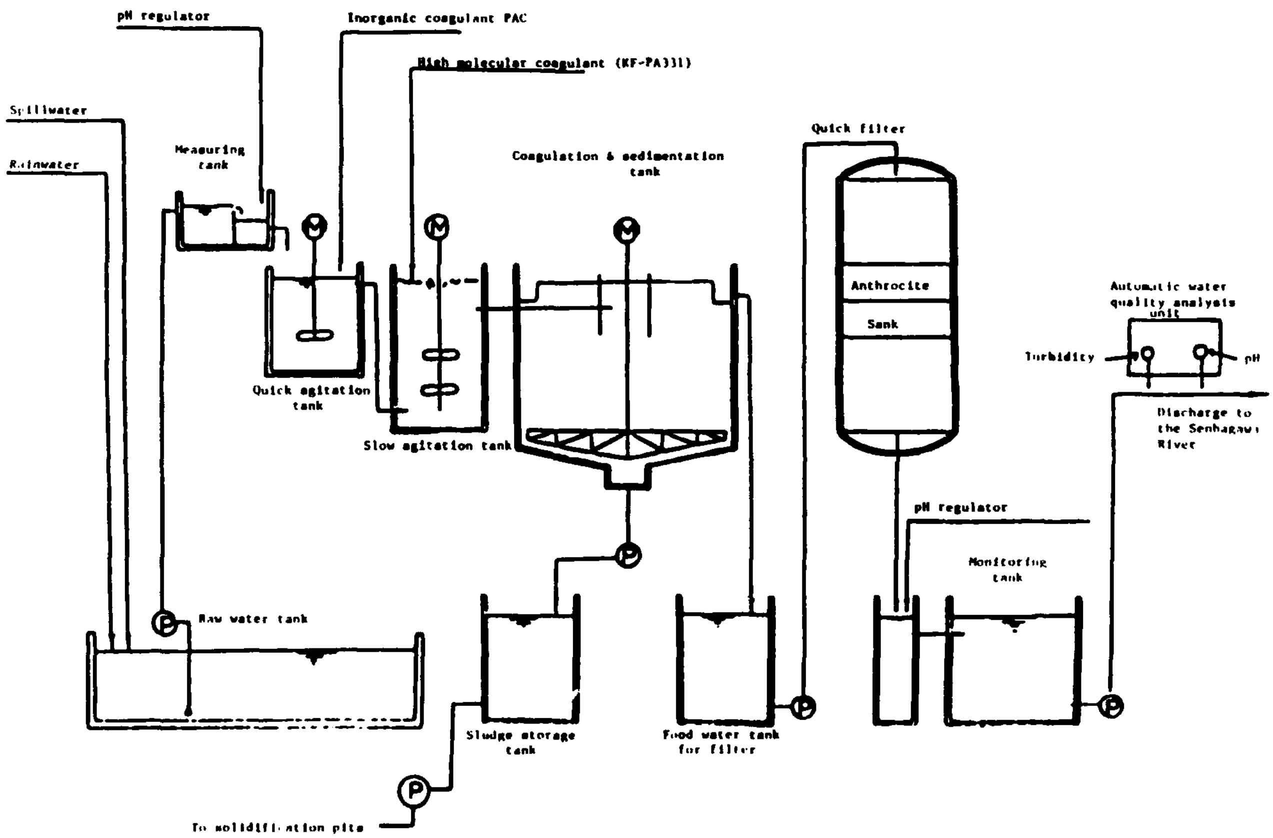


Figure 12. Spillwater treatment system

In the flocculation process, polyaluminium chloride (PAC) was injected to encourage the coagulation of fine suspended particles, and another high molecular coagulant (Polymer KF-PA331) was injected to accelerate the coagulation and the sedimentation.

However, since it was impossible to reduce the suspended solids to below 10 mg/ℓ with this process alone, a dual-media filter (with sand and anthracite) was installed at the final processing stage.

The treated water was transferred to a monitoring tank and discharged to the river after pH and turbidity were continuously measured. If the measured values were unacceptable, the water was returned to the system for retreatment.

System Operation Control

Since measurement of the PCB concentration, which is a costly process, was one of the regulation items in the emission standard, it was necessary to determine the concentration that could be easily measured. Accordingly, a widely known correlation between turbidity and suspended solids was used in this case. The results of this sediment analysis are shown in Figure 13. The emission standard for PCBs was set at ≤3 ppb, which could be satisfied by reducing the concentration of suspended solids below 10 mg/ℓ, as discussed before. Accordingly, the PCB concentration was easily predictable by the less expensive monitoring of turbidity. In addition, considering the relationship of the turbidity of spillwater, the suspended solids to be treated, and the coagulant, a pH meter and a turbidity meter with recorders were provided for continuous monitoring of the tank.

Treatment Results

Spillwater treatment was carried out from 1985 to 1987. Though the designated treatment volume was 18 m^3/hr, with the returned water from the

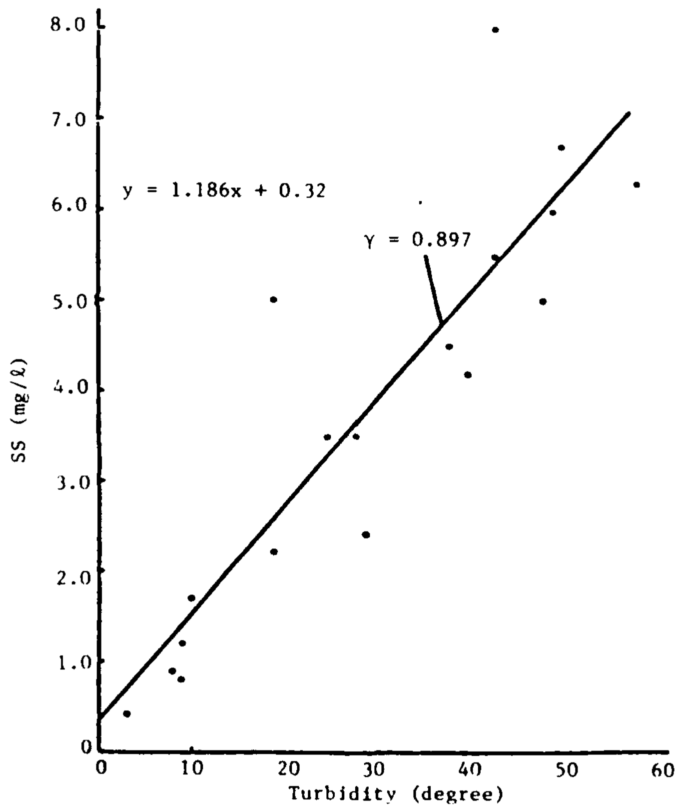


Figure 13. Correlation between turbidity and suspended solids

process and the other waters loaded upon the system, the system was actually operated at the rate of approximately 20 m^3/hr, on the condition that the water discharged from the solidification process should be treated within the day.

The qualities of the discharged spillwater (the water discharged from the monitoring tank) were as follows:

a. PCB - 0.003 mg/ℓ.

b. Suspended solids - 10 mg/ℓ.

c. Turbidity - 10 degrees or below.

During the rehabilitation project, the PCB concentration in the discharged spillwater was measured 70 times. The results showed that the average (maximum and minimum) concentrations of PCBs in the raw spillwater and the treated spillwater were 0.011 mg/ℓ (0.166 and not detected (ND)) and ND (ND, ND), respectively. The results of the suspended solids measurement by the spillwater treatment process conducted in March 1986 are shown in Figure 14.

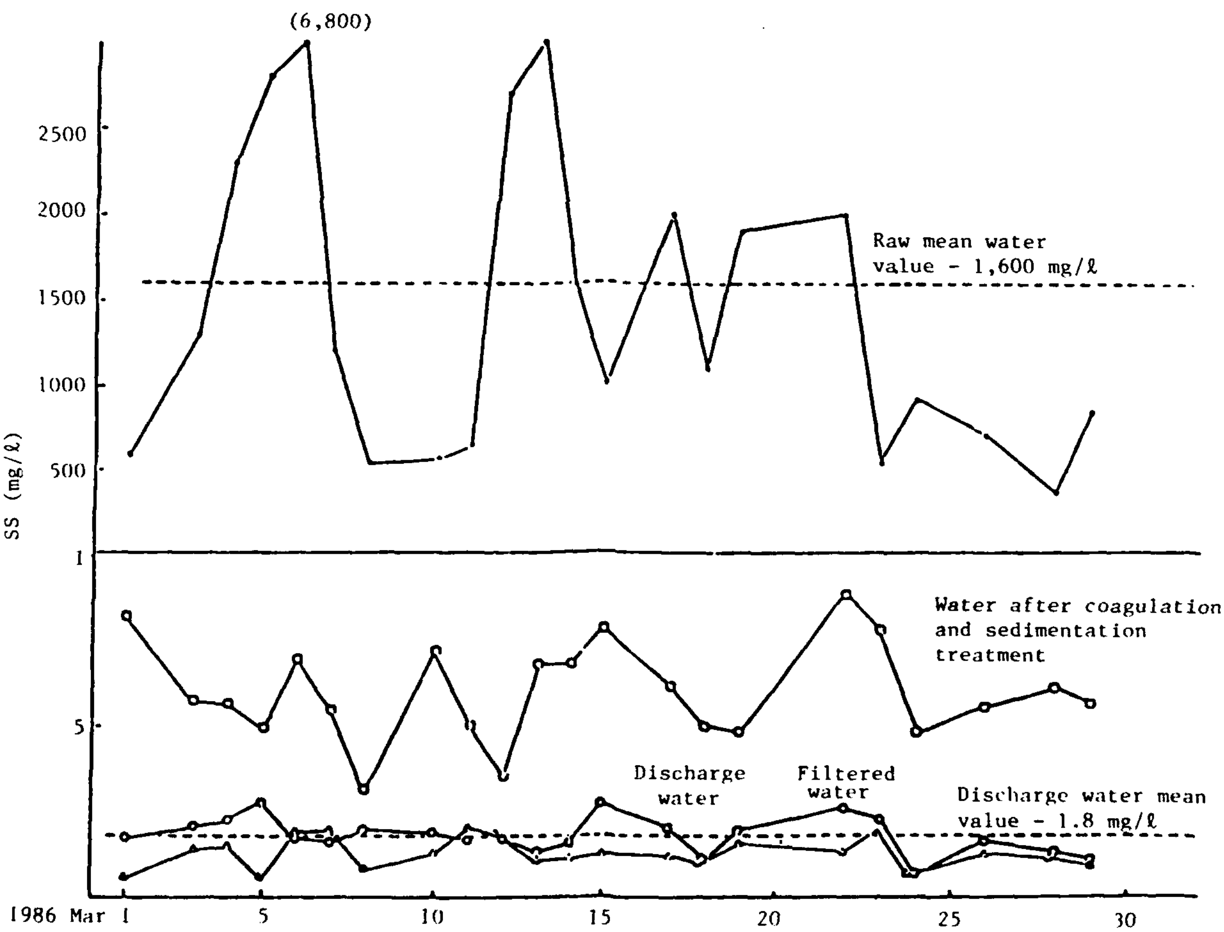


Figure 14. Time course change in water quality (suspended solids)

The suspended solids removal rates in the flocculation tank and the filtration tank were 99 and 68 percent, respectively, and that of the entire system was as high as 100 percent.

Monitoring

As required by law, inspection points and check items such as odor, vibration, and noise were set for the quality of waters (including subterranean water), as shown in Figure 15. Monitoring was conducted at a specific frequency before, during, and after dredging, for all the contingencies (Table 2).

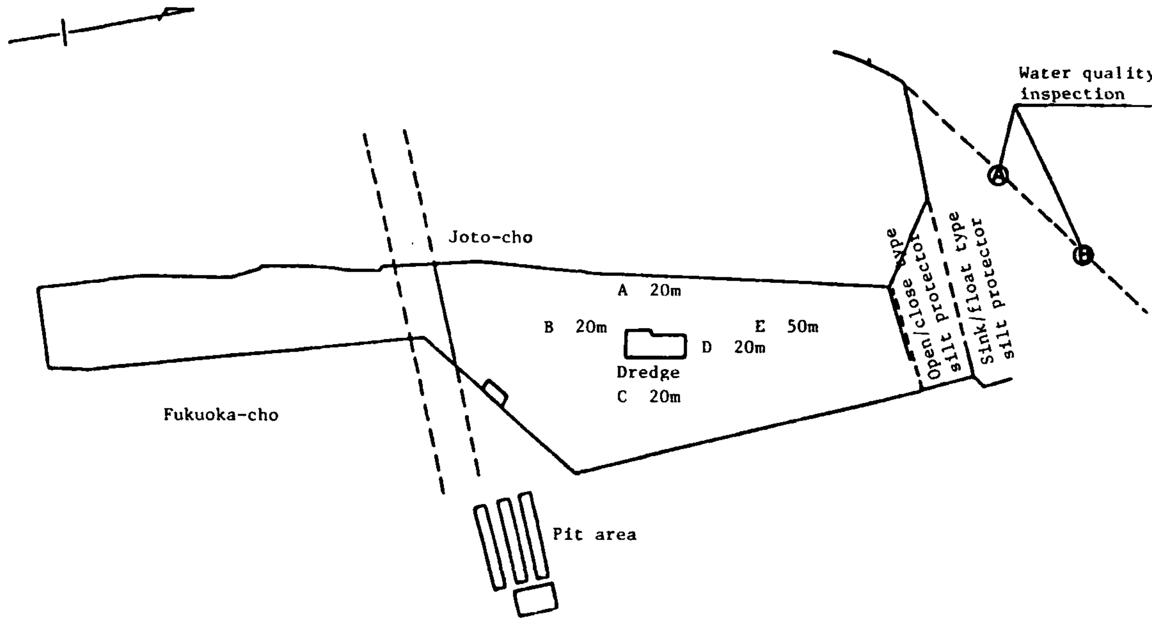


Figure 15. Inspection points for water quality, odor, vibration, and noise

The monitoring reference values and the detailed check items relating to water quality are listed in Table 3. The measurements in the Senbagawa River, especially at the estuaries, indicated no problems, and the values were 0.009 or below, except those between 0.01 and 0.02 at some observation points.

Considerable odor generation was predicted by the basic tests, but this did not become a serious problem since the work was done during winter when the temperature was low.

CONCLUSIONS

The rehabilitation project was implemented in the manner described above. Before initiation of the project, a variety of analyses, surveys, and tests had been conducted over a long period. During dredging, priority was placed on the prevention of secondary contamination and safety. Eventually, the project was completed as planned, and a natural environment was restored in the district. It is now expected that a better environment will be created along the river for the benefit of the inhabitants.

TABLE 2. WATER QUALITY INSPECTION RESULTS, SENBAGAWA DISTRICT

Location	Parameter	Reference Value	Measurement Frequency	Measured Value		Standard
				Mean	Range	
Inspection points	PCB	ND	2 points × 54 times	ND	ND	1/108 = 0.00
	pH	7.8–8.3	2 points × 49 times	8.07	7.7–8.3	1/98 = 0.01
	COD	≤4.7 mg/ℓ*	2 points × 49 times	2.30	1.0–7.0	2/98 = 0.02
	DO	≤5.0 mg/ℓ	2 points × 49 times	8.15	4.5–11.0	2/98 = 0.02
	Oil content	ND	2 points × 49 times	ND	ND	0/98 = 0.00
	Turbidity	BG + (1.7–12.5)**	2 points × 1,224 times	0.37†	0.00–0.99†	0/2.448 = 0.00
Auxiliary points	Turbidity	BG + (2.2–25.0)††	1,172 times	0.17†	0.02–0.98†	0/1.172 = 0.00
Spillwater	PCB	0.003 mg/ℓ	70	ND	ND	0/70 = 0.00
	Turbidity	10	Officially 20	2.3	0.5–5.8	0 = 0.00
Observation well	PCB	ND	2 points × 6 times	ND	ND	0/12 = 0.00

* Modified in accordance with the results of the preliminary survey before initiation of work. (Sediment.)

** The suspended solids (SS) and background (BG) values are corrected against the PCB concentration in the sediment by each dredging block.

† Indicated by the ratio of actual value/inspection reference value.

†† Decrease as far as the inspection point is considered.

TABLE 3. WATER QUALITY MONITORING CRITERIA

Location	Purpose	Check Item	Frequency	Reference Value
Inspection points	Along the boundaries between the dredged area and the remaining areas, the inspection points are provided to monitor the water quality of the remaining areas	PCB	Once a day*	ND (≤0.5 g/ℓ)
		pH	Once a week	7.8-8.3
		COD	4 times a day	3.0 mg/ℓ (on condition that the background value is ≤3.0. It if exceeds 3.0, the COD concentration should be below the background value)
		DO	4 times a day	≥5.0 mg/ℓ
		Oil	4 times a day	ND (≤0.5 mg/ℓ)
		Turbidity	4 times a day	Depending on the analysis results of PCB concentration
Auxiliary points	In order to satisfy the reference values at the inspection points, auxiliary points are provided between the dredging area and the inspection points to monitor the water quality	Turbidity	4 times a day	Depending on the analysis results of PCB concentration. The turbidity is adjusted as required, based on the relation to the analysis results at the inspection points and other locations
Spillwater inspection points	The points are provided to monitor the treated discharge water from the spillwater treatment system to prevent secondary contamination	PCB	Once a day*	3 g/ℓ or below
		Turbidity	4 times a day	Depending on the analysis results of PCB concentration
Observation well	The points are provided to monitor the subterranean water to prevent contamination by PCBs from the disposal area	PCB	Once a month	ND (0.5 g/ℓ or below)
Standard inspection points	The points are provided to monitor the background value	COD	Monitoring to be carried out if the COD concentration exceeds 3 mg/ℓ at the inspection points	
		Turbidity	4 times a day	

* If the purposes of the water quality monitoring are achieved only by measuring the turbidity on the basis of the actual correlation between PCB and turbidity, the PCB measurement frequency may be decreased to once a week.

MANAGEMENT OF DREDGED MATERIAL AT TOLEDO, OHIO

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ABSTRACT

Toledo Harbor, at the mouth of the Maumee River in northwest Ohio, is the second most active port and largest single dredging project on the Great Lakes. Over 770,000 m^3 is dredged each year. Most of this material has been confined since 1955. In 1983, over half of the harbor was declared suitable for open-water disposal. Monitoring of the open-water disposal has not shown any adverse impact on water quality. Studies of the release or bioavailability of phosphorus (P) bound to the sediments indicate that P is released from the sediments at a rate of from 10 to 30 percent per day. On an annual basis, dredging and disposal account for 0.4 to 0.6 percent of the total external loading of P to Lake Erie. High-resolution visible data from the French satellite SPOT were used to demonstrate the total extent of the dredging plume. Efforts will be made in the future to use the satellite for routine monitoring. The citizens of Toledo are strongly opposed to open-water disposal operations and are actively pursuing a long-term management strategy oriented toward reuse/upland disposal of all dredged material from Toledo Harbor.

INTRODUCTION

The purpose of this paper is to provide a brief history of the management of dredged material from the navigation channel in the Maumee River and the western basin of Lake Erie at Toledo, Ohio. The project is located in northwestern Ohio where the Maumee River (Figure 1), which drains about 16,000 km^2 of highly productive cropland, discharges into the western basin of Lake Erie.

Construction and maintenance of the commercial navigation project at Toledo have been performed by the Corps of Engineers since the initial harbor improvements were authorized by Congress in 1866. Since that time, successive Acts of Congress have increased the project to its current length of 22 km, depth of 9 m below low water datum, and width of 152 m.

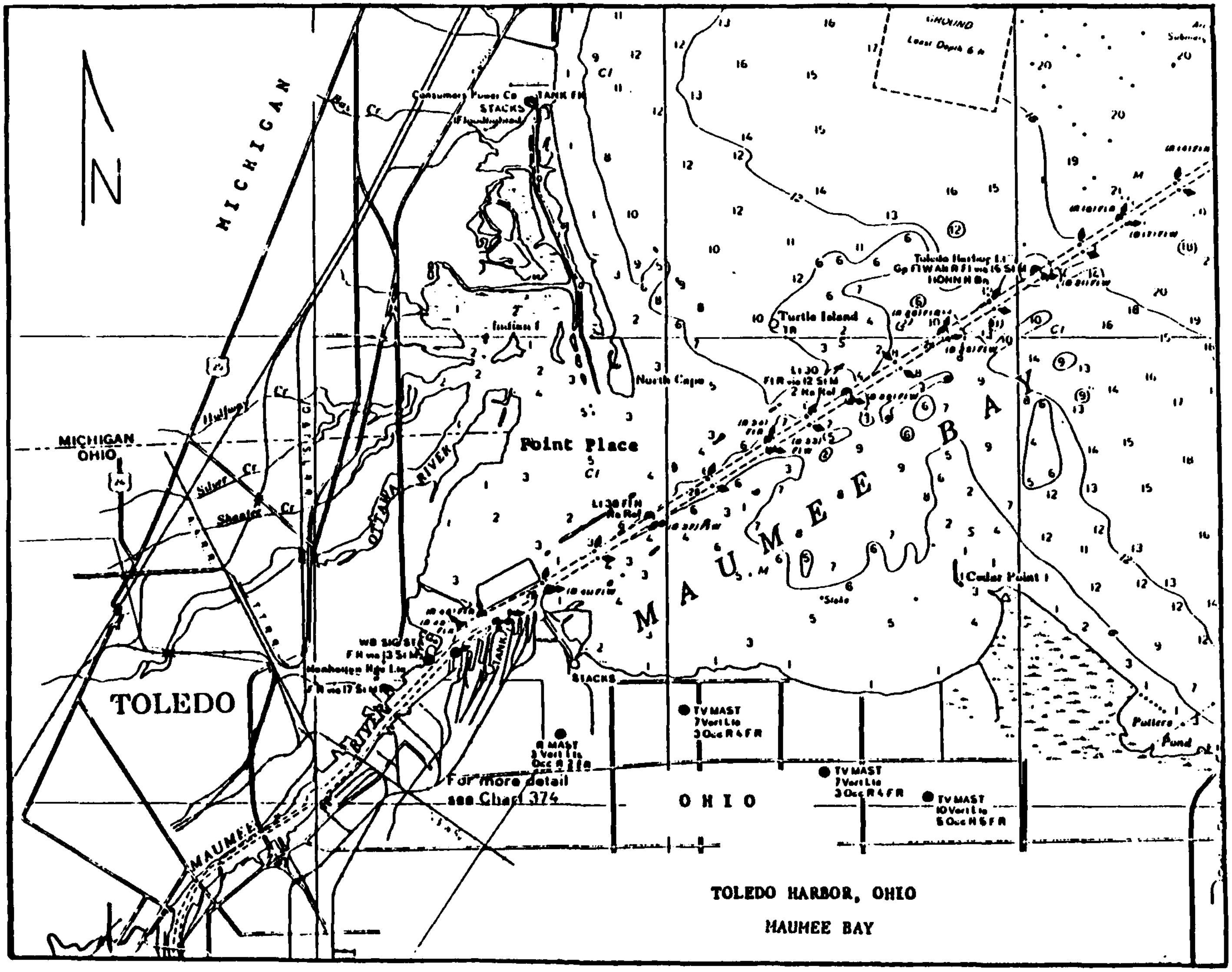


Figure 1. Toledo Harbor, Maumee Bay, and the western basin of Lake Erie

Waterborne commerce at Toledo, which is the second most active harbor on the Great Lakes, consists primarily of transshipment of agricultural and mining commodities, including wheat, soybeans, coal, and iron ore. Historical commodity movements at Toledo are given in Table 1.

The Maumee River is first among the Great Lakes harbors in volume of dredged material. The Maumee maintains a mean daily discharge of 140 m^3 sec^{-1}. This flow varies widely with frequent storm discharges over 1,000 m^3 sec^{-1} during rainfall runoff events. During these storms, the erosion of agricultural land contributes to the Maumee River's annual sediment load of approximately 1,000,000 metric tons (Mt). Nearly 25 km of the river above its mouth at Lake Erie is at lake level, and much of this sediment load is deposited in the navigation channel from which it must be removed. The annual dredging requirement at Toledo is approximately 770,000 m^3 $year^{-1}$.

Dredged Material Management (Pre-1975)

Prior to 1975, the sediments dredged from the Maumee River were disposed of strictly on the basis of economics. Dredgings were disposed simply in the least-cost manner. This may have meant either open-water or confined disposal. Between 1866 and 1955, most of the material removed from the Maumee channel was disposed at various locations in the open lake. Since 1955 much of the material has been placed in confinements along the banks of the Maumee River. These areas were less costly due to reduced transportation costs and had the added benefit of creating valuable waterfront property for both commercial and recreational use. Material from deepening projects in the lake portion of the channel was sidecast along either side of the channel. These deposits created artificial shoals that have been a benefit to sports fishing, but are a hazard to navigation during periods of low water. The first island disposal site, Grassy Island, was built in 1963 to contain mainly sediments removed from the river portion of the channel. This area was built strictly because it was less costly to build and use than it was to haul the material an additional 20 km into Lake Erie.

It was, in fact, a fortunate combination of circumstances that the cost of dike construction was lower than the cost of the long haul into the lake, which led to confinement of the most heavily contaminated Toledo Harbor sediments for almost 20 years before it was determined that open-water disposal would have been damaging to aquatic life and water quality in Lake Erie.

Dredged Material Management (Post-1975)

The era of confinement of channel dredgings because of contamination began with the completion in 1968 of a report entitled "Dredging and Water Quality Problems in the Great Lakes." This report recommended that contaminated dredged material be placed in confined disposal facilities (CDFs) and led to the inclusion in the River, Harbor and Flood Control Act of 1970 of a provision for the construction of CDFs without justification beyond the need for pollution control. Most of the very heavily contaminated material from the Maumee River had been confined since 1955. Starting with the completion of a new 100-ha CDF in 1975, virtually all material dredged from Toledo Harbor was confined.

TABLE 1. HISTORICAL COMMODITY MOVEMENTS, TOLEDO HARBOR (THOUSANDS OF TONS)

	Foreign				Domestic				
	Overseas		Canadian		Lakewise				
Year	Import	Export	Import	Export	Receipts	Shipments	Coastwise	Local	Internal
1980	292.5	1,160.2	309.3	7,137.6	3,109.5	9,986.1	12.5	0.0	0.0
1979	541.6	1,651.8	183.6	6,425.8	5,680.2	11,422.9	25.6	0.0	0.0
1978	1,039.5	2,321.1	469.7	5,941.8	5,720.8	11,779.2	0.0	299.3	0.0
1977	821.8	2,201.8	1,345.3	4,988.8	2,743.3	10,935.9	0.0	238.6	0.0
1976	499.1	1,568.4	762.6	5,832.5	4,754.9	11,329.6	0.0	227.6	9.0
1975	363.7	1,267.1	897.5	5,151.9	3,796.2	11,947.1	0.0	168.8	36.6
1974	327.5	542.3	765.9	3,900.1	5,273.4	10,520.5	0.0	194.8	32.1
1973	333.9	873.4	1,509.7	4,313.9	6,176.0	11,390.9	0.0	274.9	48.9
1972	391.7	1,751.7	1,041.2	4,339.7	5,070.2	12,343.3	0.0	279.6	31.2
1971	482.2	1,518.9	535.8	4,193.8	5,372.3	14,841.9	0.0	322.2	43.6
1970	334.5	645.4	854.2	5,349.6	5,938.9	18,417.3	0.0	345.2	47.1

Even as late as 1975, though, there were no clear-cut criteria for determining whether sediments should be confined or otherwise restricted in disposal. In 1975 the US Environmental Protection Agency (USEPA) adopted a list of contaminants, including volatile solids, total nitrogen, chemical oxygen demand, total phosphorus, oil and grease, mercury, lead, and zinc, and maximum permissible concentrations for open-water disposal. In 1977 the USEPA Region V developed a more extensive list of criteria that have become known as the "Great Lakes Sediment Criteria." These criteria used the longer list of contaminants shown in Table 2 and the new classes of unpolluted, moderately polluted, and heavily polluted. These classes were based on the variation in sediment contamination in Great Lakes harbors. Moderately polluted meant that the harbor was about average. The elutriate test was also included in the criteria, but no numerical standards were proposed for it. Other tests, including bioaccumulation and bioassay, have been used in evaluating sediment quality but have never been promulgated in a regulatory manner. The decision to approve or disapprove open-water disposal has always been made through negotiation and subjective evaluation of the results of all testing performed.

In 1981 the Buffalo District signed a memorandum of agreement with the USEPA Region V that set forth the terms under which the testing and evaluation of all harbor dredged material would be performed. In addition to the evaluation procedure, the Buffalo District agreed to resample each of the District's major harbors for a full evaluation of the continuing validity of the current dredged material management methods every 5 years.

SEDIMENT SAMPLING

Table 2 shows the 3 levels of classification and the 18 bulk chemistry parameters that were established by USEPA in 1976 to evaluate the suitability of harbor sediments for open-water disposal, confinement in an in-water CDF such as the one built in the Maumee Bay, or some other more restrictive means of disposal. With regard to the Great Lakes Sediment Criteria, the decision on the classification of a harbor is based on the most common (or mode) of the 20 parameters.

Historically, the bottom sediments of the Maumee River have never been grossly polluted. Table 3 gives the results of a chemical analysis in the Maumee River in 1983. Of the parameters that indicate heavy contamination, the level of arsenic is actually not untypical of any agricultural soil. The level of cyanide was probably set too low in the Criteria, as over 90 percent of all the samples fell into the heavily polluted range. The levels of iron and phosphorus are also typical of Maumee River Basin soils.

The testing performed in 1982 was inconclusive. Although the bulk and elutriate chemistry indicated that many areas and parameters were unpolluted or moderately polluted, the data were spotty, and all parties agreed that confinement of all materials should continue. The area was retested in 1983 and showed a significant reduction in the number and extent of heavily polluted areas. Based on these and additional bioassay tests, it was determined that sediments lakeward of lake mile 2 could be open-lake disposed. The area upstream of lake mile 2 is still heavily contaminated and will continue to be confined. The open-lake disposal of 434,000 m^3 of sediment dredged from the lake portion of the channel during 1985 was the first such operation at Toledo in 10 years.

TABLE 2. GREAT LAKES SEDIMENT CRITERIA

Parameter	Unpolluted	Moderately Polluted	Heavily Polluted
Volatile solids	<5%	5-8%	>8%
Chemical oxygen demand	<40,000	40,000-80,000	>40,000
Total Kjeldahl N	<1,000	1,000-2,000	>2,000
Oil and grease	<1,000	1,000-2,000	>2,000
Lead	<40	40-50	>60
Zinc	<90	90-200	>200
Mercury	<1.0	Not applicable	>1.0
Ammonia	<75	75-200	>200
Cyanide	<0.10	0.10-0.25	>0.25
Phosphorus	<420	420-650	>650
Iron	<17,000	17,000-25,000	>25,000
Nickel	<20	20-50	>50
Manganese	<300	300-500	>500
Arsenic	<3	3-8	>8
Cadmium	*	*	>6
Chromium	<25	25-75	>75
Barium	<20	20-60	>60
Copper	<25	25-50	>50

Note: All ranges in milligrams per kilogram unless otherwise noted.
* Lower limits not established.

TABLE 3. POLLUTIONAL CLASSIFICATION OF TOLEDO HARBOR SEDIMENTS, 1983

Parameter	Lake Mile 7	Lake Mile 6	Lake Mile 5	Lake Mile 4	Lake Mile 3	Lake Mile 2	Lake Mile 1	Mile 0	River Mile 1	River Mile 2	River Mile 3	River Mile 4	River Mile 5	River Mile 6	River Mile 7
Total volatile solids	U	M	U	U	U	U	M	M	M	M	M	M	M	M	M
Cyanide	H	H	H	H	U	H	H	H	H	H	H	H	H	H	H
Arsenic	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Cadmium	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
Chromium	U	M	U	U	M	U	M	M	M	M	M	M	M	M	M
Copper	M	M	M	M	M	M	M	H	H	H	M	H	M	M	M
Lead	U	U	U	U	U	U	U	U	H	M	M	U	M	U	U
Mercury	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
Nickel	M	M	M	M	M	M	H	H	H	H	H	H	M	H	M
Zinc	M	M	H	M	M	M	M	H	H	H	M	M	M	M	M
Iron	M	H	H	M	H	M	H	H	H	H	H	H	M	H	H
Manganese	M	H	M	M	H	M	H	H	M	M	M	M	M	H	M
Chemical oxygen demand	M	H	M	M	H	M	H	H	H	H	M	M	M	M	M
Ammonia-N	M	H	M	M	M	M	H	H	H	H	M	M	M	M	M
Total Kjeldahl nitrogen	H	M	M	M	H	M	H	H	M	U	M	M	M	M	U
Total phosphorus	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
No. of unpolluted ratings	8	7	8	8	7	5	3	3	2	2	2	3	2	3	4
No. of moderately polluted ratings	7	5	7	8	6	8	4	2	4	4	9	6	11	7	9
No. of heavily polluted ratings	4	7	4	3	6	3	9	11	10	10	4	7	3	6	3
Mode	U	U	U	U	U	M	H	H	H	H	M	H	M	M	M

Note: U = unpolluted, M = moderately polluted, H = heavily polluted.

MONITORING OF OPEN-WATER DISPOSAL

The Corps and the local community were justifiably concerned over the reinitiation of open-water disposal of even marginally contaminated material. As a stipulation of the Ohio Environmental Protection Agency's (EPA) water quality certification of the disposal operation, the Corps was required to conduct monitoring of the disposal for violations of State water quality standards.

In the 3 years since the resumption of open-water disposal, the Corps has performed water quality monitoring projects to study the impacts of the operation.

In 1985 the program consisted of weekly monitoring. The design of this program (Figure 2) involved measurements of water quality in the plume of sediment immediately following its release from the dredge. The sampling boat moved into the disposal zone to make a series of measurements near the location at which the dredge would make its next disposal. Field measurements included dissolved oxygen at 20, 50, and 80 percent of depth, pH near the surface, and secchi depth. At this time, a sample was also taken for laboratory analysis. After the initial set of measurements, the transect was repeated at the same stations. After the dredge had made its disposal and moved out of the area, the sampling boat returned to the center of the disposal area and began another sequence of field measurements along the same transect. The same transect was then repeated at intervals of 1 and 2 hr after the disposal event. At the conclusion of the final transect and before the dredge returned for another disposal, the boat returned to the center of the area and took another sample for laboratory analysis. Sampling took place on 10 dates during the almost 2 months of dredging operations. During this period, no violations of Ohio water quality standards were observed to result from the disposal operations.

Phosphorus Bioavailability

Probably more important than the immediate impacts of the disposal operation itself and possible transient water quality standard violations is the potential for the sediment to release phosphorus. The sediments dredged from the Maumee River are much cleaner than they were 10 years ago. Toxic substances, once present in high concentrations, have been greatly reduced. However, there has been little or no change in the pollution of the sediment by phosphorus. Considering the emphasis that has been placed on the reduction of phosphorus transport to Lake Erie, it is reasonable that we should be concerned over the possibility that the open-lake disposal operation might be adding a significant additional load of phosphorus to the lake.

In order to assess this question, studies were conducted of the time rate of availability of the phosphorus associated with the sediments for algal growth. It is known that some portion of the phosphorus adsorbed to the sediments can be released to the water. The important question that remains is: How much phosphorus can be released before a sediment particle is again situated on the bottom in relatively the same position as before it was picked up.

Sediment samples were taken from 12 locations in the Maumee River, Bay, and the western basin of Lake Erie. For data analysis the stations were

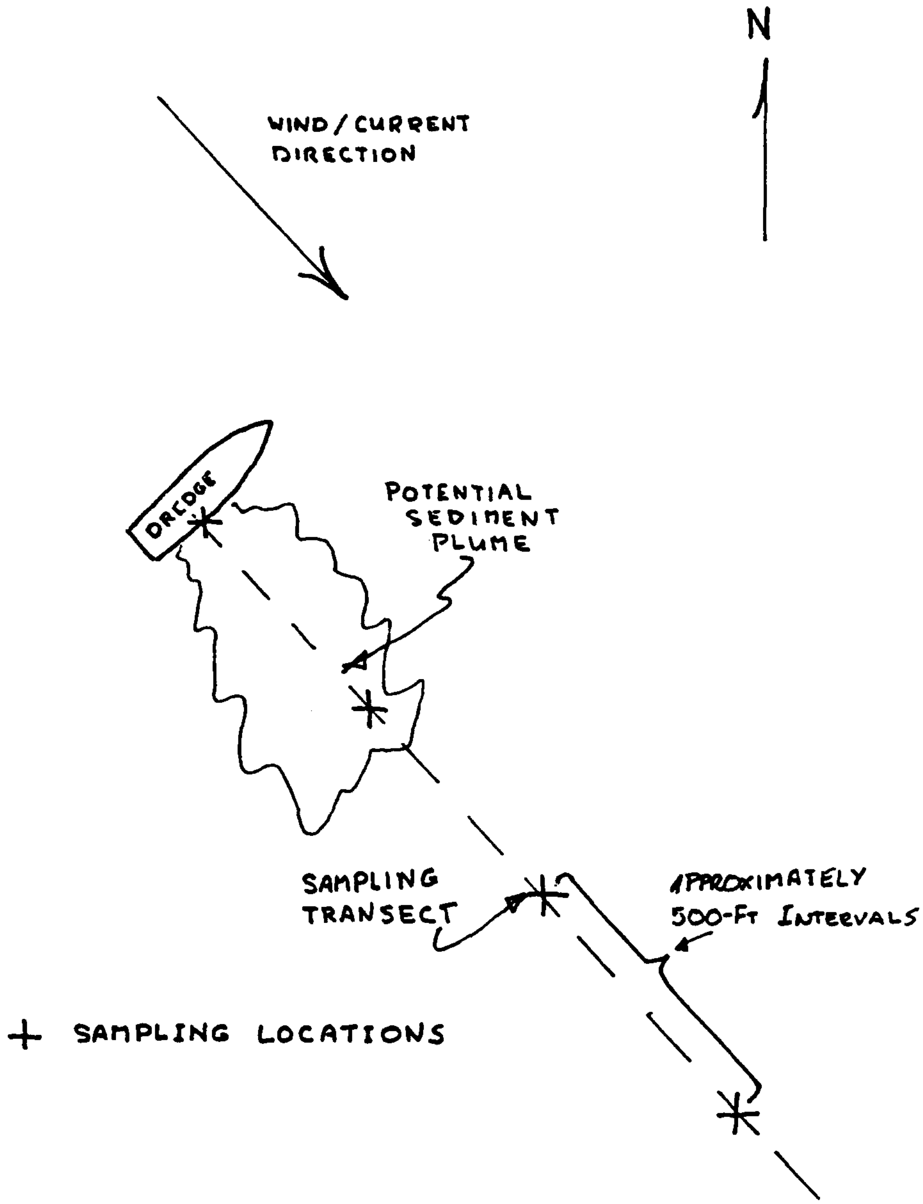


Figure 2. Sampling plan for water quality monitoring in 1985

grouped by: (a) the polluted area of the river channel, (b) the area of the river and bay from which the sediments that are open-water disposed come, (c) undisturbed areas of the open waters of Lake Erie, (d) the areas in the lake that are used for disposal, and (e) two stations in Maumee Bay.

The phosphorus fractions that were measured in this study are listed below. The R-NaOH-P, or reactive NaOH extractable phosphorus, is readily available and can be extracted from the sediment particle while it remains in the water column at a rate of between 10 and 30 percent per day.

a. R-NaOH-P - reactive sodium hydroxide extractable phosphorus. 100-percent available over time.

b. T-NaOH-P - more severe extraction. Available very slowly.

c. CDB-P - citrate-dithionate-bicarbonate extractable phosphorus. Only partially available. Requires anoxia to become available.

d. HCl-P - hydrochloric acid extractable phosphorus. Apatite mineral phosphorus. Not available.

e. TR-P - perchloric acid digestion. Not available.

Table 4 shows the results of these measurements on the 12 samples. The river channel samples were taken from a part of the river that is still considered polluted. The reactive NaOH-P represents about 42 percent of the particulate phosphorus. The lake channel, open lake, disposal areas, and depositional area of Maumee Bay are all very similar and contain an average of 21 percent of the readily extractable phosphorus.

It is important that the phosphorus in the lake channel sediments is not significantly different from the undisturbed areas of the lake, as that is part of the criteria upon which the decision to confine or permit unrestricted disposal is made. Once removed from the channel and placed on the bottom at the disposal area, the sediment will not alter the bottom from existing conditions.

The studies of the time rate of release of phosphorus involved placement of the sediment in a device called a dual culture diffusion apparatus. The sediment is placed in a darkened vessel across a semipermeable membrane from a culture of phosphorus-starved algae in natural light. Phosphorus that is released from the sediment can pass through the membrane where it is consumed by the algae. The algae culture is removed periodically to determine the amount of phosphorus that has been released from the sediment.

The results of these studies indicated that the phosphorus release rate of these sediments was about 26 percent per day. Assuming that sediments in these tests behave as they do in the environment, 1 year's disposal operation would contribute from 20 to 30 Mt of available phosphorus to the lake. This represents only 0.4 to 0.6 percent of the available phosphorus load to Lake Erie from all other external sources.

Water Quality Monitoring

Since the 1985 monitoring program had failed to reveal any serious water quality problems, the Ohio EPA directed the Corps to change the design of the monitoring program. In 1986, monitoring was performed over a much broader area, and on transects radiating from the center of the disposal site (Figure 3). Sampling cruises were planned without regard to the timing or placement of dredging. Many more samples were taken for laboratory analysis. In-situ measurements were made at each of the 36 stations on the transects as before with the addition of an additional set at 1 ft off the bottom. The program was carefully designed so that statistical methods could be used to detect trends and subtle changes in water quality. A reference station was

TABLE 4. RESULTS OF PHOSPHORUS EXTRACTIONS FOR TOLEDO HARBOR BOTTOM SEDIMENTS

Site	Total-P	Total Dissolved-P	Percent	Total Particulate-P	R-NaOH-P	Percent	T-NaOH-P	Percent	CDB-P	Percent	HCl-P	Percent	Residual-P	Percent
1	1.850	0.089	4.81	1.760	0.774	43.98	0.936	53.18	0.448	25.45	0.090	5.11	0.128	7.27
2	0.891	0.037	4.15	0.854	0.313	36.65	0.460	53.86	0.236	27.63	0.152	17.80	0.120	14.05
3	0.662	0.037	5.59	0.625	0.143	22.88	0.247	39.52	0.152	24.32	0.198	31.68	0.082	13.12
4	0.051	0.002	3.92	0.049	0.001	2.04	0.007	14.29	0.010	20.41	0.007	14.29	0.001	2.04
5	0.795	0.017	2.14	0.778	0.147	18.89	0.229	29.43	0.122	15.72	0.075	9.64	0.077	9.90
6	0.835	0.033	3.95	0.802	0.128	15.96	0.213	26.56	0.163	20.32	0.194	24.19	0.055	6.86
7	0.547	0.017	3.11	0.530	0.083	15.66	0.148	27.92	0.128	24.15	0.136	25.66	0.051	9.62
8	1.010	0.034	3.37	0.976	0.271	27.77	0.394	40.37	0.229	23.46	0.292	29.92	0.108	11.07
9	0.882	0.028	3.17	0.794	0.140	17.63	0.245	30.86	0.228	28.72	0.242	30.48	0.109	13.73
10	0.560	0.025	4.46	0.535	0.052	9.72	0.101	18.88	0.104	19.44	0.118	22.06	0.041	7.66
11	0.715	0.056	7.83	0.659	0.092	13.96	0.187	28.38	0.183	27.77	0.184	27.92	0.068	10.32
12	0.351	0.012	3.42	0.339	0.028	8.26	0.066	19.47	0.075	22.12	0.063	18.58	0.023	6.78

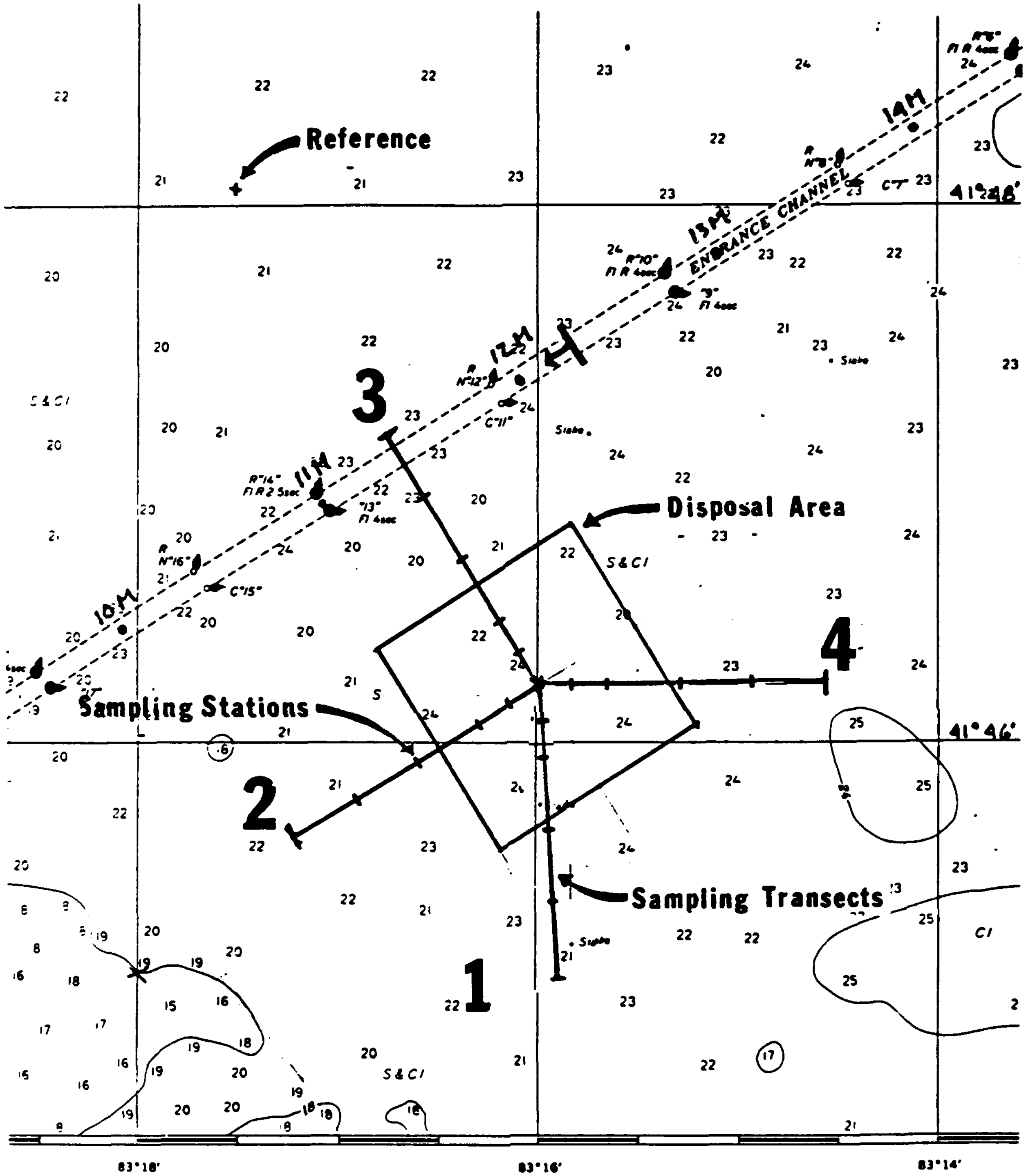


Figure 3. Sampling plan for water quality monitoring in 1986

also added so that comparisons with an unimpacted area could be made. One of the transects extended from the disposal area directly toward the city of Toledo water intake, one was parallel to the navigation channel, one was perpendicular to it, and a fourth extended due east into the open waters of Lake Erie. Sampling was performed on two dates before dredging began, on six dates during operations, and on two dates after dredging ceased.

The careful design and execution of this survey enabled the conclusion that no significant impacts resulted from the disposal operations. Two very small changes in water quality, slightly reduced pH and dissolved oxygen, were documented along transects that extended across the disposal zone. Figure 4 shows the variation in copper concentration over the period of sampling. Only copper is shown because it was the only metal that frequently exceeded the water quality criteria. However, even though the criteria are exceeded on many occasions within the disposal zone, they are also exceeded at the reference site far removed from the operation. The copper criteria were also exceeded on one of the predredging sampling cruises. The increases in copper concentration were probably due to wind-induced resuspension of bottom sediments throughout the western basin.

Figure 5 documents the fact that the operations had little effect on the Toledo drinking water intake. The solid line (Figure 5a) is a plot of the daily measurements of turbidity at the intake. The squares and diamonds along the bottom of the graph plot the turbidity of water in the disposal area and reference site, respectively. It can be seen that the water intake is almost always more turbid than the disposal area. When this plot is overlain with a graph of the Maumee River discharge (Figure 5b), it can be seen that the river plays a great role in the variation of water quality at the intake. The remaining increases in turbidity at the intake, which is in only 4 m of water, are due to wind-induced resuspension of bottom sediments.

Remote Sensing

An additional project was included in the 1986 monitoring program. The French satellite SPOT obtained an excellent image of the western basin on 4 June 1986. A sampling cruise was planned to coincide with the overpass so that water quality data would be available for calibration of the satellite data. Figure 6a shows the unprocessed satellite image with an overlay of the navigation channel and disposal zone. When the data are classified to enhance levels of suspended solids in the water (Figure 6b), a plume of sediment can be seen extending to the west from the disposal zone. Suspended solids measurements confirm that the plume had very little mass. This project showed that very small differences in suspended solids concentrations can be measured with satellite imagery.

DREDGED MATERIAL REUSE

As was mentioned earlier, the local community is strongly opposed to open-water disposal of dredged material in Toledo Harbor. They are also not inclined toward the construction of additional confinements. This leaves only the productive reuse of dredged material as a long-term management strategy for Toledo.

While the Corps has done much research into the possibilities of reuse and continues to provide technical assistance to the community, current Federal law places the financial burden for the additional costs of reuse on

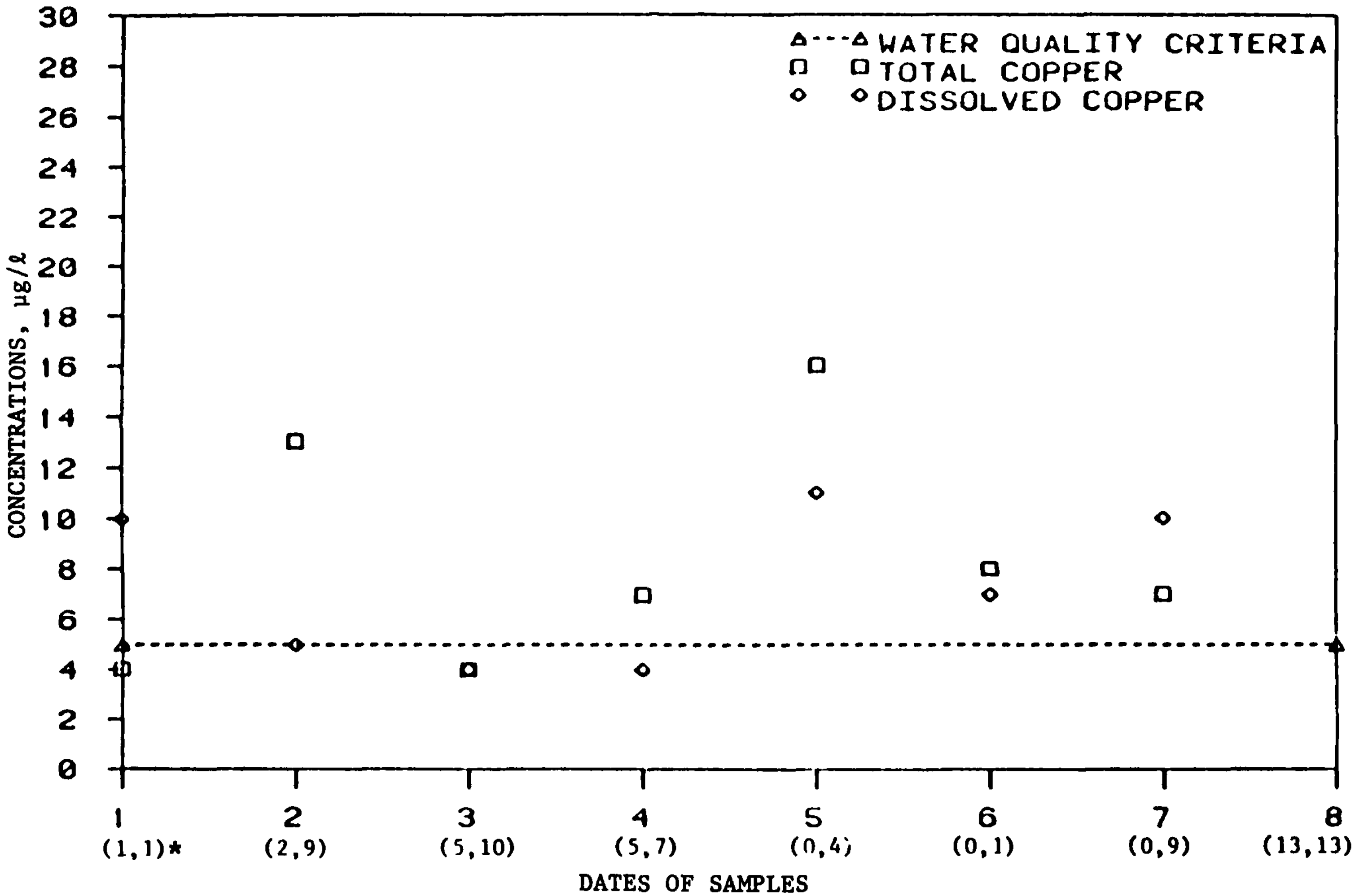
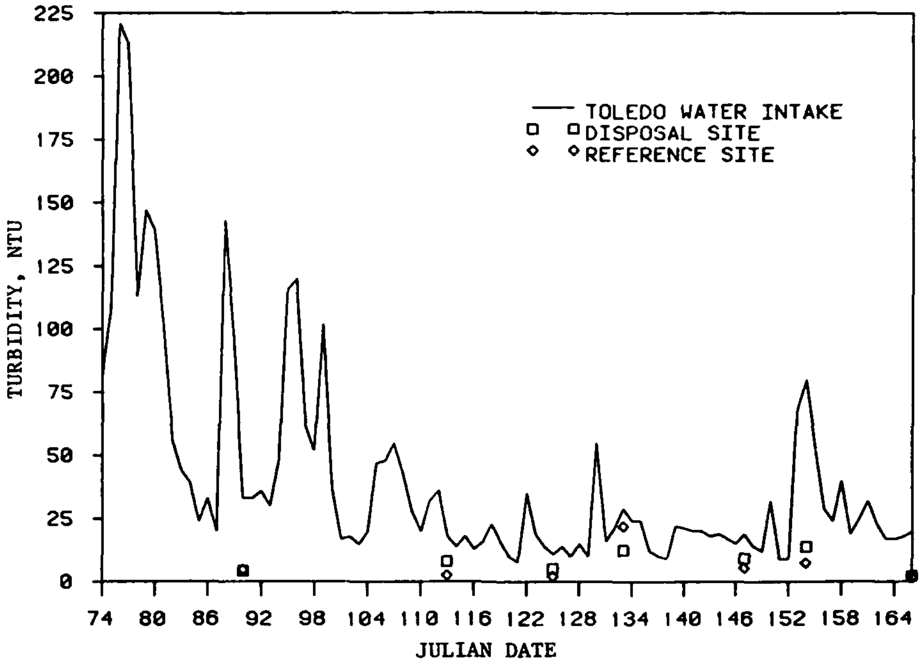
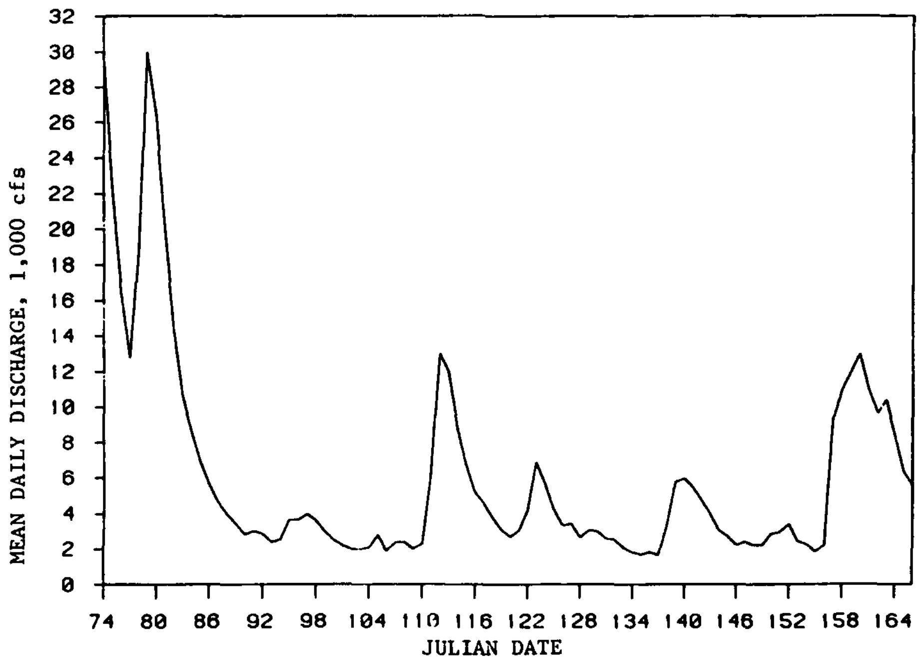


Figure 4. Concentration of copper in the open-water disposal area during 1986 (*Copper not detected in water below detection limit of 4 PBB (Total, dissolved).)

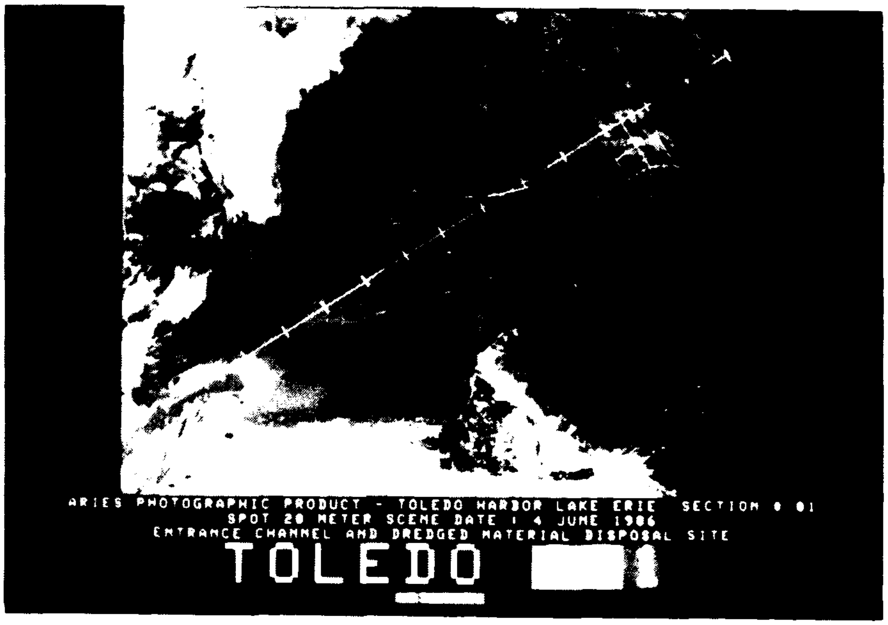


a. Turbidity measurements

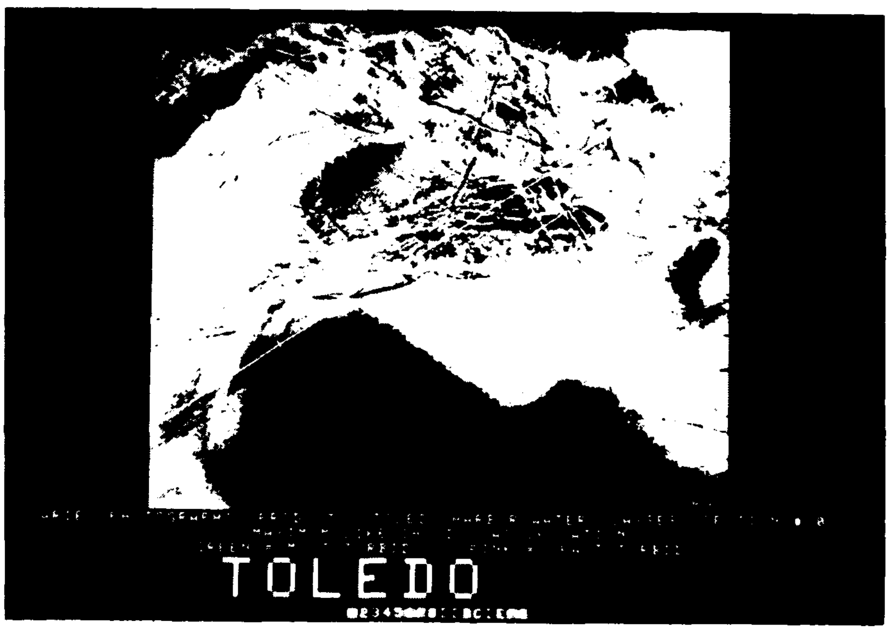


b. Mean daily discharge at Waterville

Figure 5. Comparison of turbidity in the disposal area and at the Toledo water intake with streamflow in the Maumee River, 15 March-15 June 1986



a. Unprocessed image (superimposed lines show the navigation channel, disposal area, and sampling transects)



b. Enlarged view showing the data classified to enhance variation in sediment concentration

Figure 6. Satellite images of western basin of Lake Erie

the local cooperator. It is for this reason that much of the emphasis on reuse in the Toledo area has focused on schemes that are designed to be profitable.

At this time the Port Authority of Toledo is actively pursuing an arrangement with a local fertilizer supplier. Dredged material is combined with leaf litter collected from city streets, sewage sludge, and/or sludge from drinking water treatment to produce soil that can be used for landscaping. Pilot tests with this material have been very successful, but it is still unknown whether a market can be found for the volume of material involved.

Other reuse alternatives that have been studied include: topsoil and fill for a golf course to be built on very flat terrain, daily cover for sanitary landfills, agricultural land spreading, stripmine land reclamation, shoreline protection, construction fill, and ski hills.

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THE BIOFILTER SYSTEM--USE OF AQUATIC PLANTS FOR WATER PURIFICATION

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ABSTRACT

This paper describes a mechanical system for cultivating aquatic plants (waterhyacinth, watercress) in rivers and lakes that are severely polluted, for the purpose of water purification. The system also addresses the recovery of overgrown aquatic plants and reutilization as fertilizer, feed, solid fuel, or methane gas.

Through laboratory and field tests and use of a simulation model, the water purification effectiveness of various cultivation, growth, and removal scenarios can be estimated.

A plan for recovery, disposal, and reutilization of aquatic plants is described. Experiments with test plants in Doho Pond (3.4 ha) in Ibaraki Prefecture demonstrated effective removal of nutritive salts, with less energy, low cost, and no waste generation.

INTRODUCTION

Because of the increase in wastewater from homes and factories, as well as eutrophication resulting from overfertilization of fields, the quality of water in lakes, marshes, and ponds (hereafter called the "water area") has worsened, limiting use as service water and for industry, agriculture, fisheries, tourism, etc. To minimize eutrophication of the water area, water quality control for sewerage along the water area and for wastewater has been executed, but the improvement is not always satisfactory. It is well known that the removal of accumulated sludges would be most effective for water quality improvement, but is not considered the best approach from the viewpoint of economy. To prevent eutrophication, it is necessary to remove nitrogen and phosphorus in water as well as the sludge. To meet these needs, the water purification method using the nutritive salt absorption ability of aquatic plants has been widely used. However, since almost all of the interest has been focused on the purification ability of aquatic plants, many of the tests have proven unsuccessful because of the difficulty in removing the plants.

The biofilter system, a water purification system using aquatic plants, is a total system for water purification in conjunction with reuse of the plants collected (Figure 1). It is based on laboratory and field tests conducted over several years.

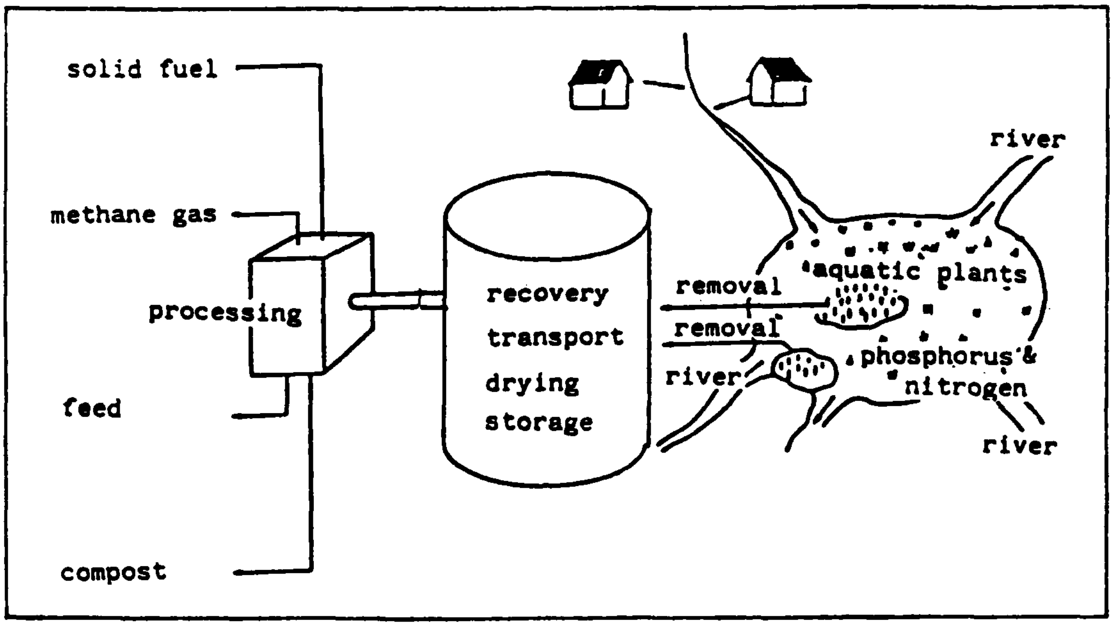


Figure 1. Biofilter system

The biofilter system also promotes developed of the local area, by recognizing the harmony of nature and society.

BIOFILTER SYSTEM

Description

The biofilter system consists of four subsystems: cultivation, recovery, processing, and reutilization (Figure 2).

The cultivation subsystem is for the purpose of promoting the absorption of nutritive salts by the proliferation and growth of aquatic plants. The

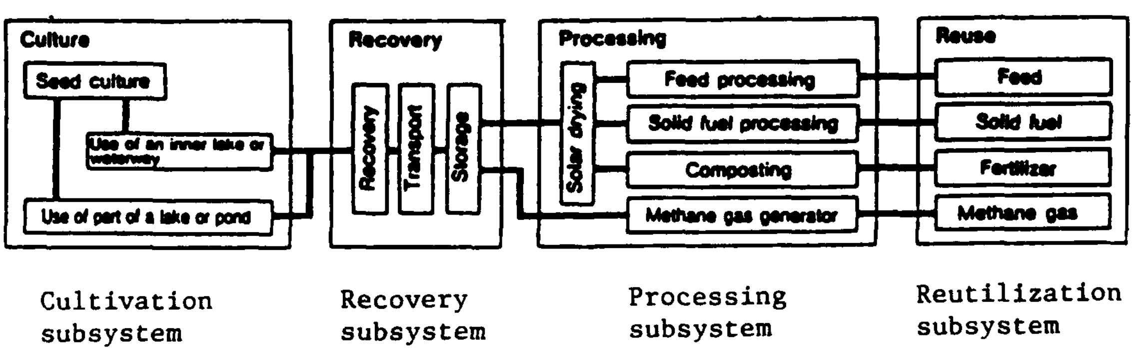


Figure 2. Subsystems of biofilter system

recovery subsystem addresses the collection, conveyance, and storage of the aquatic plants. The processing subsystem involves the processing of the collected plants to produce feed, solid fuel, fertilizer, and methane gas. The reutilization subsystem produces finished products from raw materials procured through the processing and recovery subsystems.

The biofilter system has the following advantages: resource reutilization, energy savings and low cost, ease of maintenance, and creation of intimacy with water and open-air area.

Suitable Aquatic Plants

The aquatic plants suitable for this system are those that easily absorb nutritive salts, are easily removed from the water, and can be reutilized. Of the various aquatic plants, 13 kinds were selected for comparison (Table 1). Based on this comparison, waterhyacinth, which grows well in water temperatures over 15° C, and watercress, which grows quickly even in low temperatures, were selected, so that alternative cultivation of these two plants could be made, depending on the seasons.

Waterhyacinth

This plant, of Brazilian origin, is an annual and flowers from July to October. It grows in the temperate and subtropical zones in the Southeast Asian countries and Japan and, because it sometimes interferes with navigation due to overgrowth, is considered a nuisance plant. It withers in low temperatures but is rated highly in the comparison of system requirements. Accordingly, this plant was selected for cultivation during the period April/May and October/November.

Watercress

This is a perennial plant of the rape family, is of European origin, and was introduced to Japan around 1870. Having vigorous propagating ability, it grows thick in a clear stream, with mustachelike roots. It is therefore most suitable as an alternative for waterhyacinth, for cultivation from late autumn to early spring, during the time waterhyacinth is withering.

Cultivation Subsystem

This subsystem establishes a cultivation environment that allows for propagation and growth of the plants, collection of overgrown plants from the waterway, and absorption of nitrogen and phosphorus in the water area (Table 2). Consequently, the removal of aquatic plants contributes to water purification. There are two methods in the cultivation system: inner-lake and waterway (Figure 3).

A number of advanced technologies have been employed: the technique of aeration and agitation of water to supply nutritive salts continuously to the roots of aquatic plants to promote propagation, the technique of flow-type catalytic oxidation for the removal of organic matter in water, and the technique of "greenhouses" to maintain environmental conditions (Figure 4) suitable for plant growth.

TABLE 1. COMPARISON OF AQUATIC PLANTS*

Biofilter System Requirements	Importance**	Aquatic Plant Type												
		Immersed			Floating Leaf			Submersed				Floating		Other
		Reed	Water-oat	Cattail	Water chestnut	*Nymphoides indica*	Water fringe	*Hydrilla verticillata*	Water caltrop	Brazilian elodea	Florida elodea	Duckweed	Waterhyacinth	Watercress
Vigorous absorption ability for nutritive salts														
Vigorous propagation	V	0	0	0	Δ	Δ	×	Δ	×	Δ	Δ	×	0	Δ
High nitrogen and phosphorus content in plant	V	Δ	Δ	Δ	0	0	0	0	0	0	0	0	0	0
Short turn and short overtime	V	×	×	×	×	×	×	×	×	×	×	0	Δ	0
Ease of cultivation														
Rather small subterranean stem	I	×	×	×	Δ	Δ	Δ	Δ	Δ	Δ	Δ	0	0	0
Cold-proof	V	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	0
Ease of recovery - shallow water depth in habitat	I	Δ	Δ	Δ	×	×	×	×	×	×	×	0	0	0
Ease of transport - low water content	I	0	Δ	Δ	Δ	×	×	×	×	×	×	×	×	×
Ease of reutilization - reusable as food, feed, compost, and fuel	V	0	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	0	0	0

* Applicability ranking is as follows: 0 > Δ > × .
** Very important (V); important (I).

TABLE 2. NUTRITIVE SALT ABSORPTION ABILITY OF AQUATIC PLANTS

Aquatic Plant	Absorption Ability, $g/m^2/day$ Nitrogen	Phosphorus	Concentration in Cultivating Water, ppm T-N	T-P
Reed	20-40	2.0-4.5	0.8-2.0	0.04-1.0
Duckweed	0.17	0.018	2.0	0.5
Waterhyacinth	0.18-0.75	0.021-0.081	0.8-2.0	0.04-1.0
Watercress	0.34	0.076	4.6-6.0	2.4-3.0

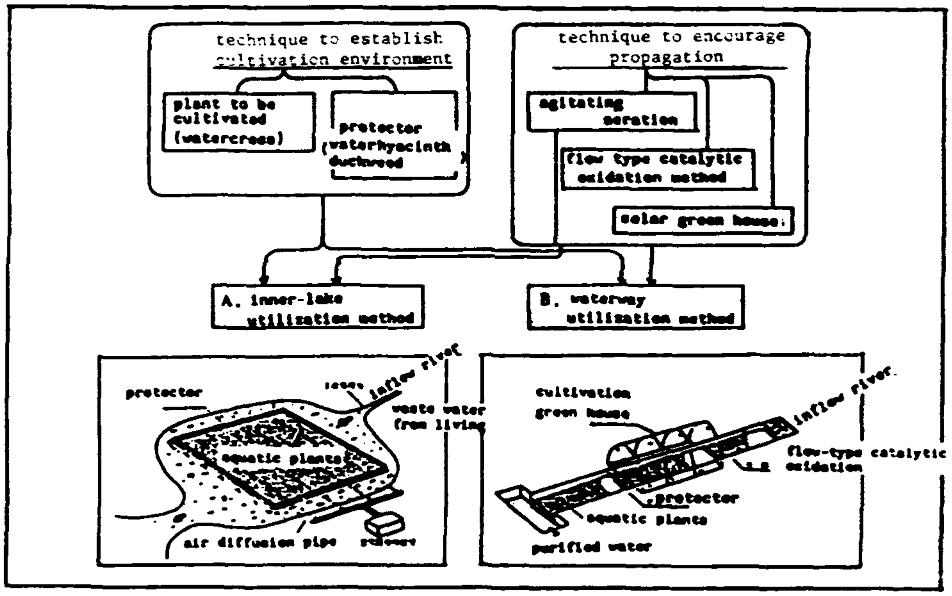
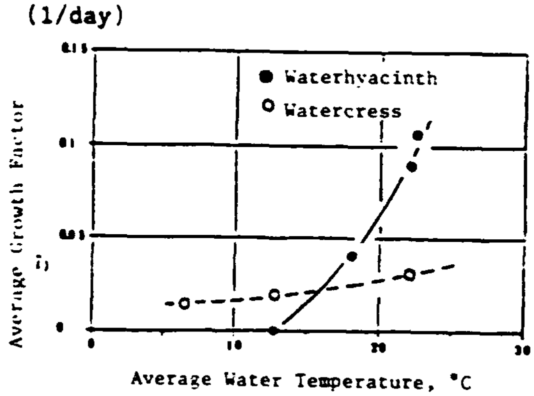


Figure 3. Cultivation subsystem

Figure 4. Water temperature and growth factor of aquatic plants



Recovery Subsystem

This subsystem collects, forwards, and stores grown aquatic plants without diffusion and conveys them to the processing subsystem (Figure 5).

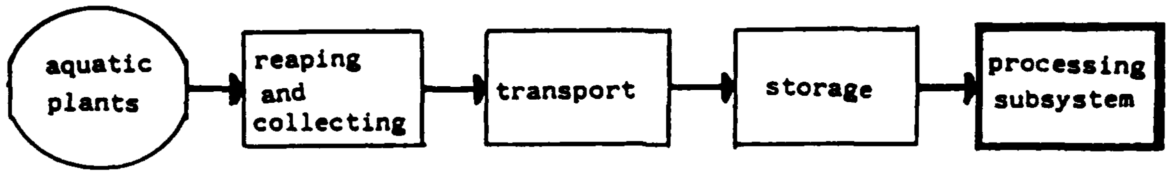


Figure 5. Recovery subsystem

Processing Subsystem

This system processes the aquatic plants reaped and conveyed for conversion into raw materials required for the reutilization subsystem. Drying is the most important process of this subsystem (Figure 6).

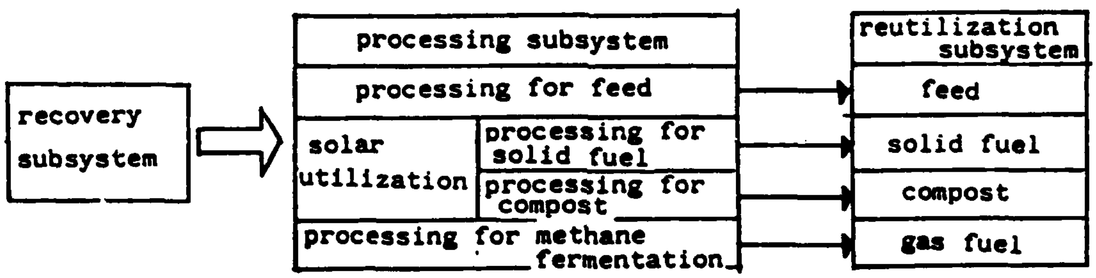


Figure 6. Processing subsystem

Reutilization Subsystem

This system processes the treated materials for making any valued products such as fertilizer, feed, solid fuel, or gas fuel (Figure 7).

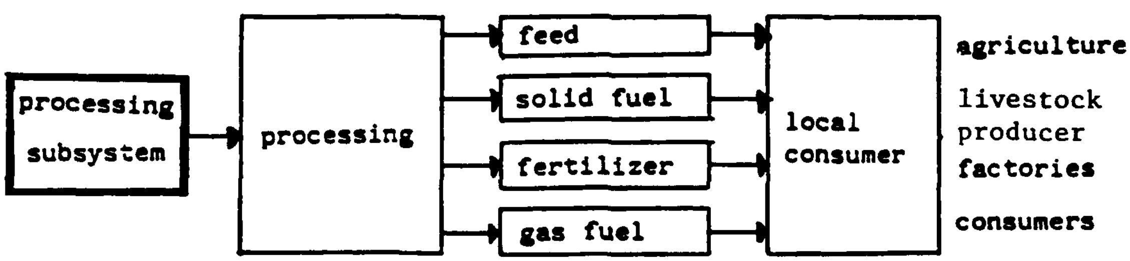


Figure 7. Reutilization subsystem

System Design

Design of the biofilter system involved the following phases.

Site Investigation

The water volume, water quality, bottom material, biological conditions, topography, and water depth of the lakes, marshes, and rivers are investigated to determine the present conditions.

Coordination with Policies

An investigation is made to determine if the function of lakes, marshes, and rivers is satisfactory (in terms of river conservancv, water utilization, etc.) or if it is coordinated with any other policies.

Conceptual Plan

To make the best use of the water area, a conceptual land utilization plan is developed, including consideration of the construction of resort, educational, and cultural installations as well as the creation of intimacy with water and open space.

Basic Plan

On the basis of this conceptual plan, the condition for the water area purification is estimated and the basic plan is developed (Figure 8). It is anticipated that a simulation model for water purification will be used (Figure 9), and this is the most distinct feature of the system.

Plan Execution

After obtaining funding and selecting contractors, the design plan is implemented.

Simulation Model for Water Purification

The simulation model for water purification is a power scientific model to simulate the water quality index for biological oxygen demand (BOD), dissolved oxygen (DO), etc., as well as variation characteristics for the production process of plant plankton, animal plankton, and aquatic plants to be cultivated on the basis of the simulation model by DiToro et al. (1975) (Figure 10).

By this simulation model, the wastewater load, scale, and initial amount of cultivation of aquatic plants are established, and the amount of purified water, water quality, and weight of aquatic plants to be collected are estimated considering the natural environmental conditions in the area.

The water area is partitioned into sections on the supposition that the water is completely blended, and each section is the primary model based on the ecological model.

To express the growth of plants, it is considered best to use the logistic curve. According to it, if any limiting factors, such as nutritive

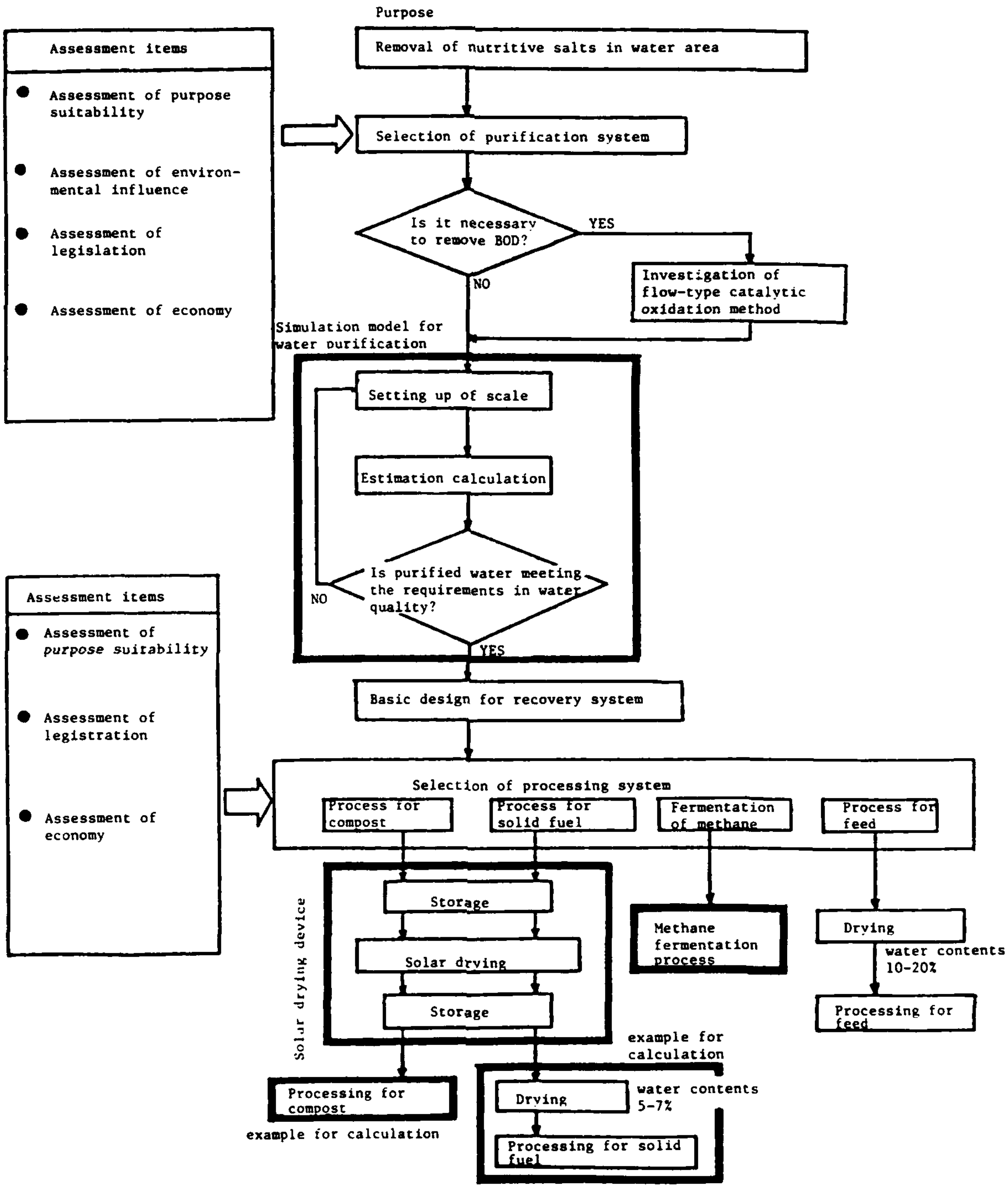


Figure 8. Flowchart of basic design, biofilter system

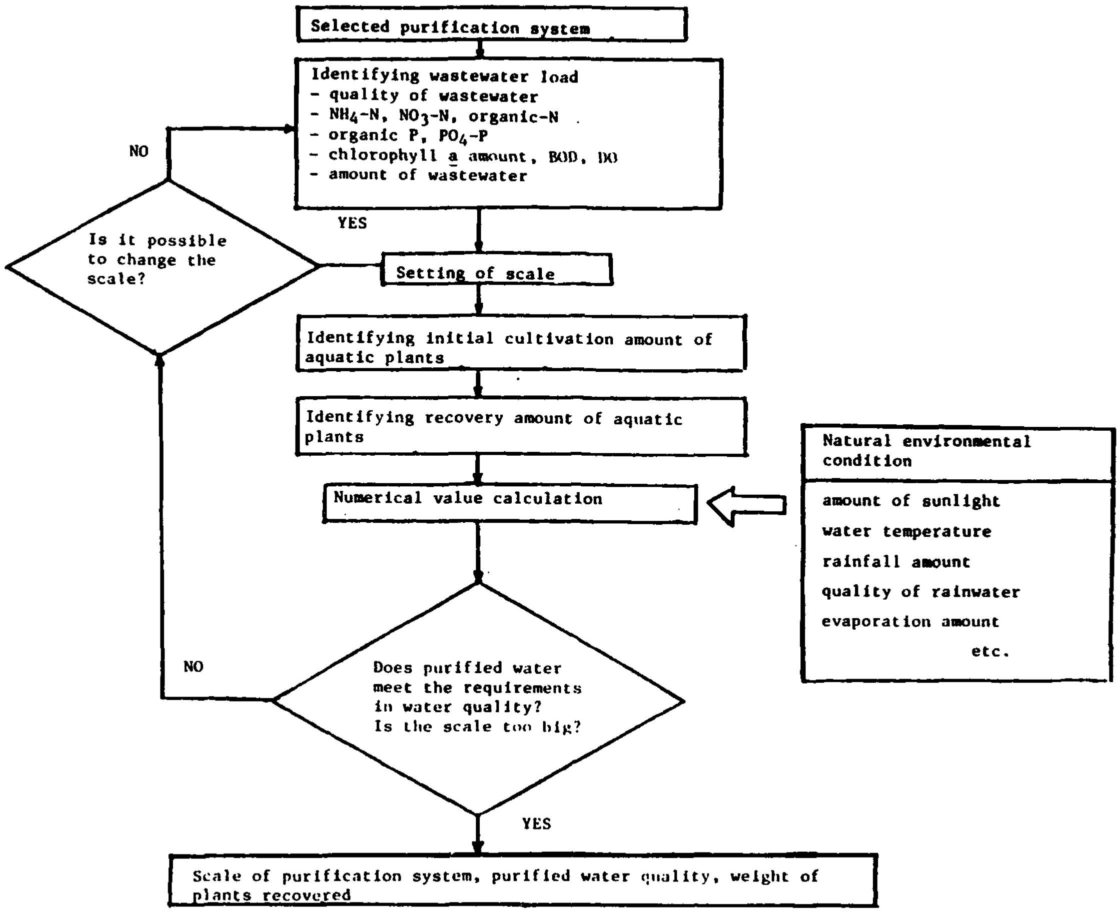


Figure 9. Flowchart for calculation model

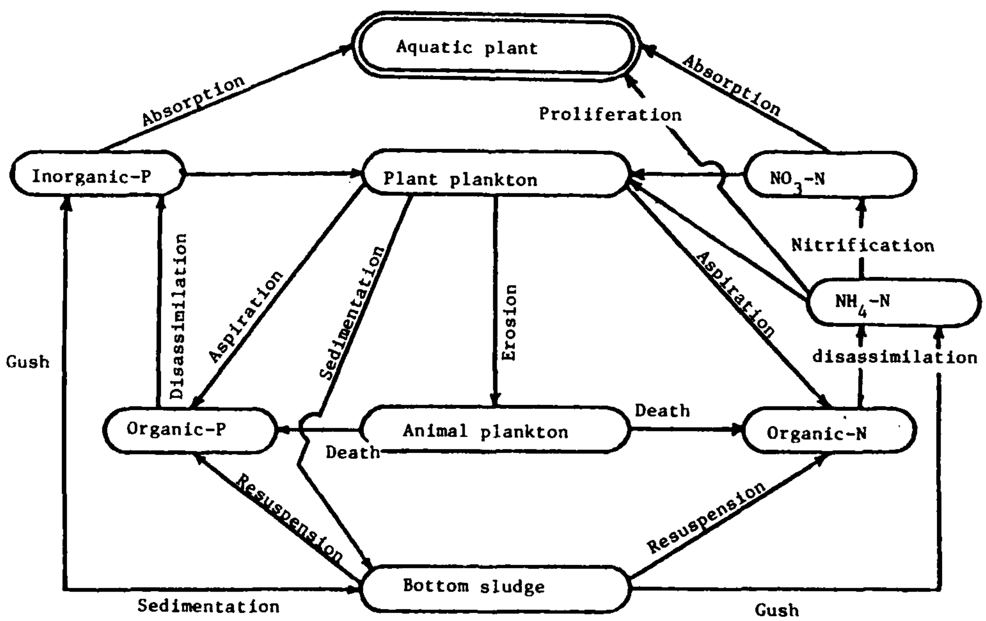


Figure 10. Organism model

salts, unsuitable growing spaces, and so forth, are found, then the growth of plants is hindered and the growth amount shows the saturated amount. In this case, the growth curve is represented by the logistic curve.

$$\frac{dWt}{dt} = \lambda Wt\left(1 - \frac{Wt}{K}\right)$$

where

Wt = present amount after the elapse of t hours

λ = growth factor (1/day)

K = upper limit of value of Wt

Results of the simulation for cultivation experiments performed four times for 4 years using waterhyacinth are shown in Figures 11-15. The calculated figures by means of the simulation model clearly show the variation patterns for each item and indicate that the model would be practical.

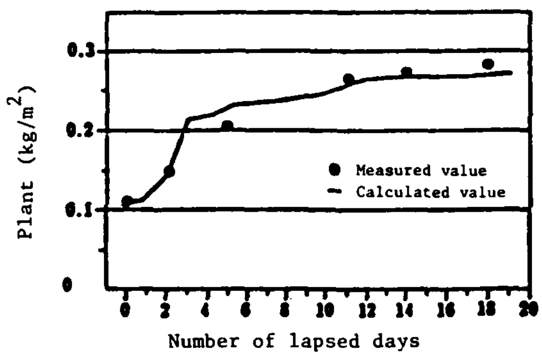


Figure 11. Growth of waterhyacinth

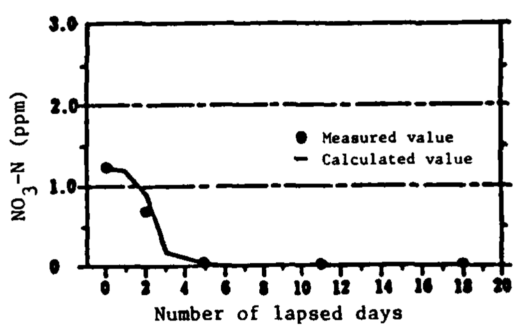


Figure 12. Concentration of NO_3-N

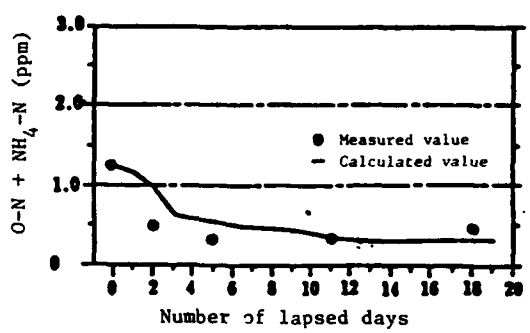


Figure 13. Concentration of organic N+NH_4-N

Solar Drying Device

The solar drying device available for the system consists of the warehouse for incoming cargo, the drying unit, and the warehouse for outgoing cargo. The drying unit functions by a two-step process (Figure 16). The

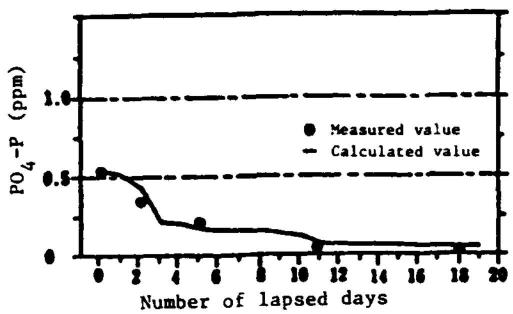


Figure 14. Concentration of PO_4-P

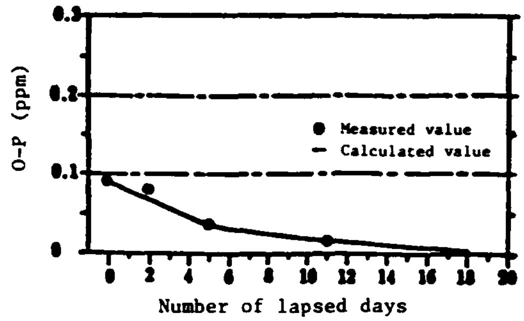
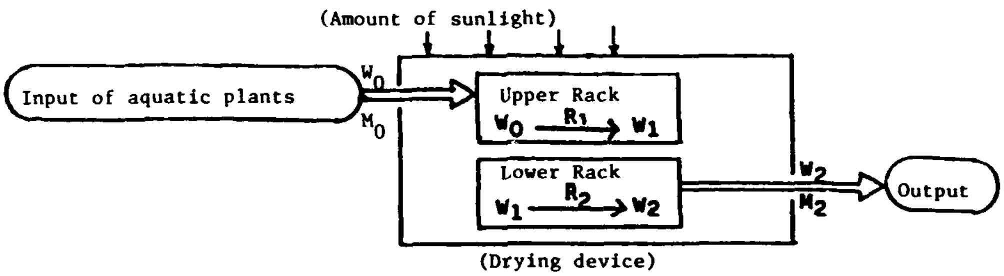


Figure 15. Concentration of organic-P



W_0 = Initial water content

W_1 = Optional water content

W_2 = Objective water content for drying

M_0 = Input volume

M_2 = Output volume

R_1 = Required drying days of $W_0 - W_1$

R_2 = Required drying days of $W_1 - W_2$

Figure 16. Solar drying two-step process

dry data can be calculated by means of the relative formula (index regressive formula) on the basis of the water contents and the accumulated sunlight, obtained from the model experiments. The flowchart (Figure 17) shows the basic design for the solar drying device.

DEMONSTRATION TEST

Demonstration Test Plant

In 1984, a demonstration test plant (Figures 18 and 19) was constructed in Doho Pond (3.4 ha) located in the southwestern area of Tsukuba Science City, Ibaraki Prefecture, Japan. One section of the water area of the pond, the northwestern part, was designated for the cultivation of aquatic plants, while polluted (raw) water was pumped into the plant cultivating area by a submerged pipeline. The outline of each facility is as follows.

a. Scale of the installation - Doho Pond, 3.4 ha; circulating water volume, 300 to 800 m^3/day.

b. Main facilities.

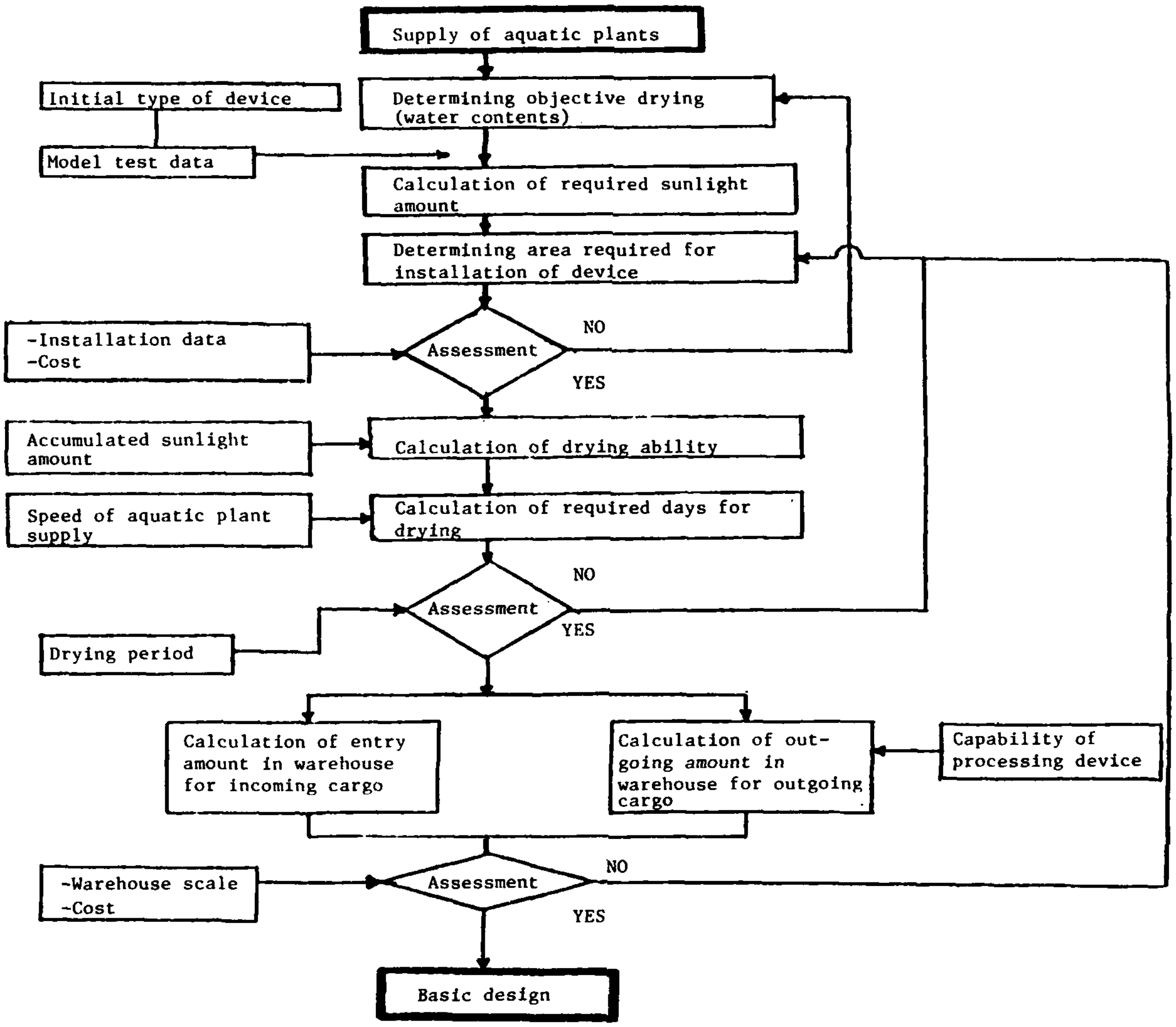


Figure 17. Flowchart for solar drying device

(1) Cultivation facilities.

Upper Pond: 1,800 m^2 in total area and 0.9 m water depth (waterhyacinth and watercress).

Lower Pond: 160 m^2 in total area and 0.1 m water depth (watercress).

Flow-type catalytic oxidation waterway: 42.5 m in length and 48.3 m^3 in volume, animal shield filter.

Agitating aeration: air dispersion pipe, 200 m in length.

(2) Recovery system - raker (absorption type), capacity of 130 m^3/hr (amount of plant absorption: 30 percent of the total absorption volume).

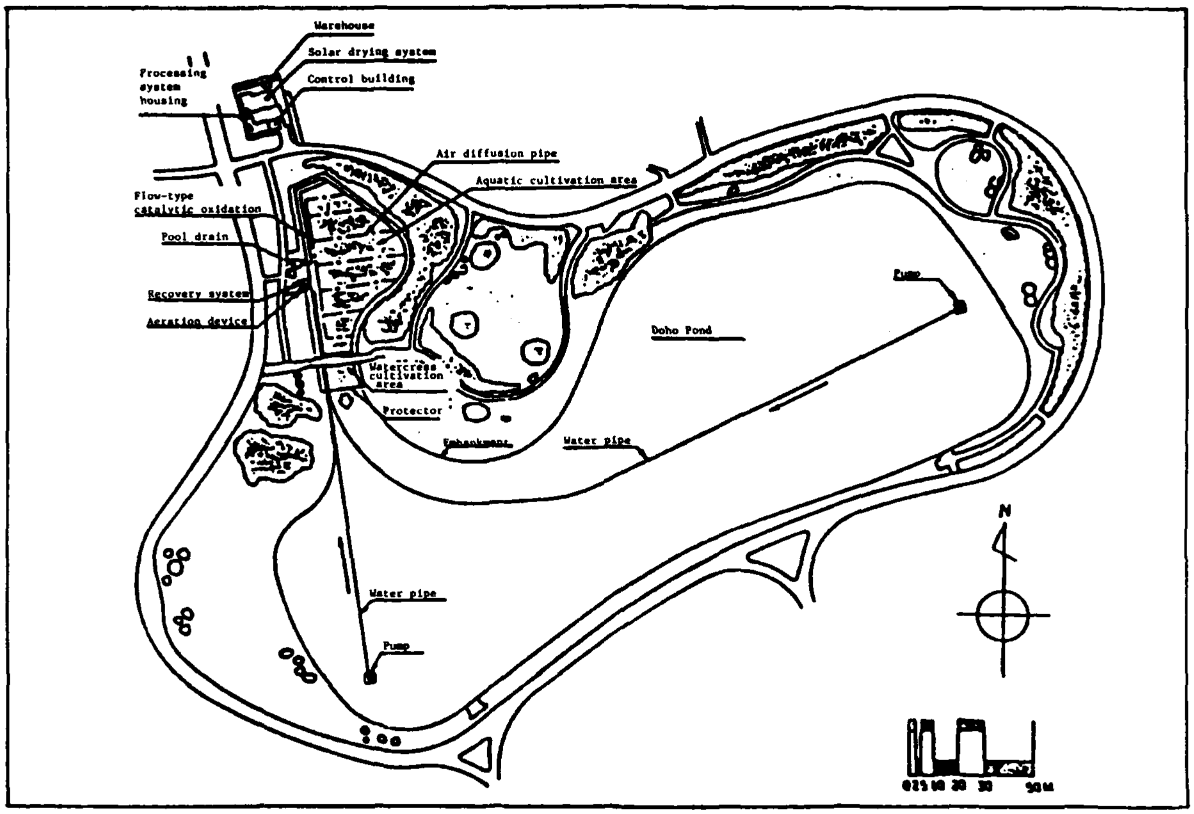


Figure 18. Schematic of basic plan

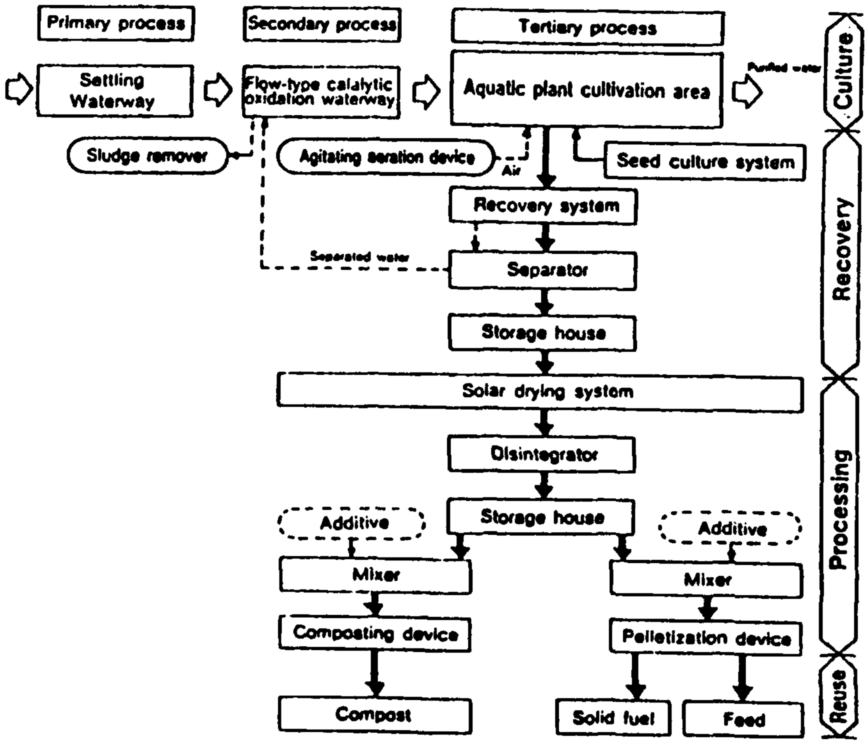


Figure 19. Test plant flowchart

(3) Solar drying device.

Size: 6 m wide, 14 m long, 6 m high
Solar collector, 4 × 10 m; lifter; drying racks (two-step conveyor type).

(4) Composting device - fermentation tank, effective volume of 4 m^3; blender and plant feeder; delivery conveyor.

(5) Pelletizing device - ring pelletizer in 450-mm diam for pellet diameter of 6.5 mm; screw conveyor; blender.

Cultivation Facilities

Plant cultivation is performed in the upper and lower ponds as shown on Figures 20 and 21. Waterhyacinth is cultivated in the upper pond from June to November, and watercress in the lower pond year-round. The primary facilities are described below.

Figure 20. Upper pond (waterhyacinth)

Figure 21. Lower pond (watercress)

Pond Water Circulation Device

This device pumps pond water by means of a submerged pump for conveyance through a water pipe to the aquatic plant cultivation area located on the other side of the pond (Figure 18). Two submerged pumps were installed: one at the east area and the other at the west area of the pond.

Agitating Aeration Device

Duckweed, like waterhyacinth, grows by absorbing the nutritive salts of the surface water; therefore, it may be possible that the nutritive salts of the surface water will be lacking at times. This device promotes the vertical blending of the water mass so that nutritive salts in the bottom can be carried to the surface.

Flow-Type Catalytic Oxidation Waterway

The roots of aquatic plants adhere to microbes; therefore, the plants must have the capacity to remove organic matter. However, in the case of flowing water, the absorption function for nitrogen and phosphorus from the roots must be hindered. Consequently, the flow-type catalytic oxidation waterway, with no power drive but with filter-type shields for the removal of organic matter, was installed (Figure 22).

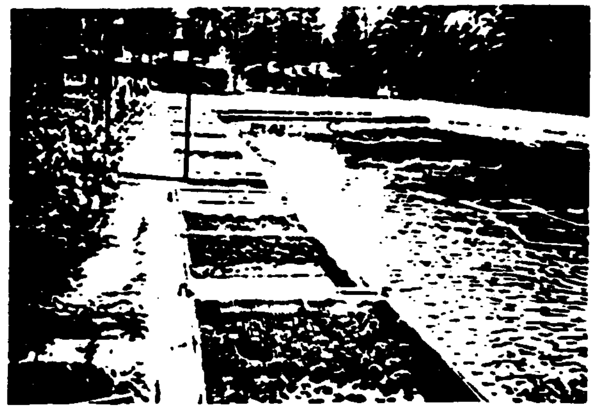


Figure 22. Flow-type catalytic oxidation waterway

Recovery System

This system consists of a raker, main unit, and separator (Figure 23). The raker collects aquatic plants to the intake port of the main unit, and the vacuum crusher condenses the plants with water for transport. The crushed aquatic plants are then separated with water in the separation bath (Figure 24).

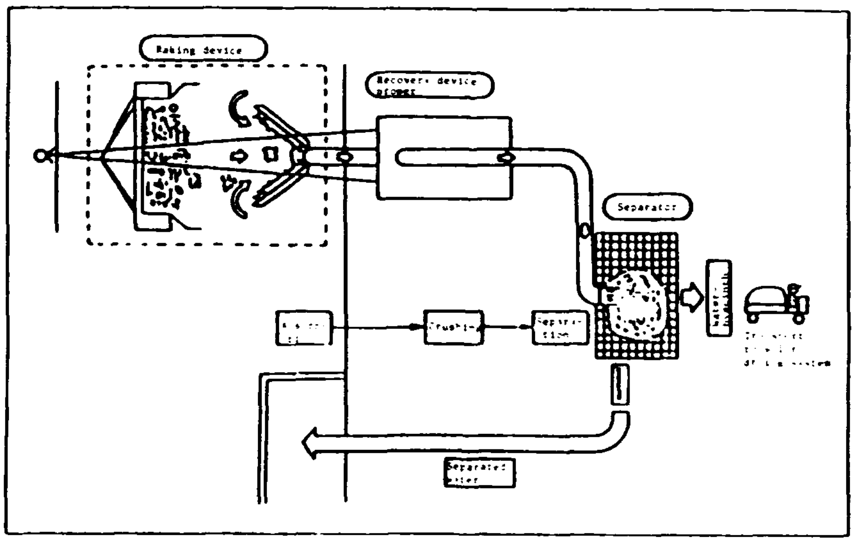


Figure 23. Recovery system flowchart

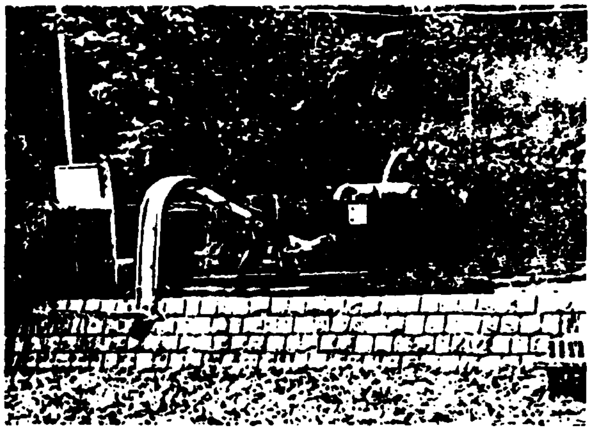


Figure 24. Recovery system

Solar Drying System

Since the water content of recovered aquatic plants is high, a drying system is indispensable for processing the plants into feed, solid fuel, and compost. For drying, a solar air dryer is employed, as shown in Figure 25. Air is heated in a solar collector and is then blown onto the aquatic plants placed on the drying racks. The aquatic plants are put on a pallet and moved by either a carrier or a vertical feeder for continuous drying (Figure 26).

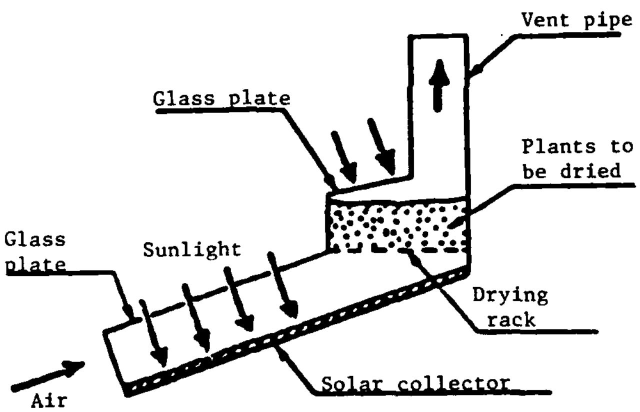


Figure 25. Solar air dryer

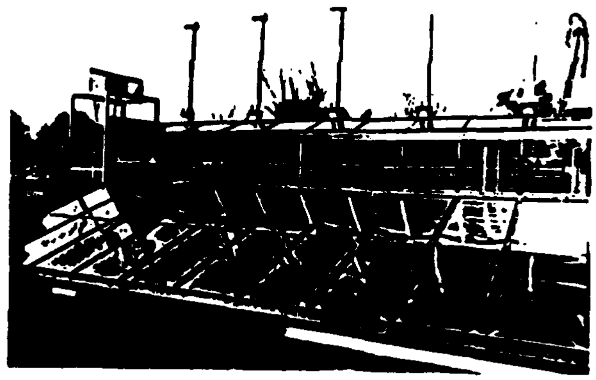


Figure 26. Solar drying device

Compost Device

This device produces compost by means of effective fermentation of aquatic plants. The dried and crushed aquatic plants are mixed with additives and are subjected to aerobic fermentation for about 4 weeks in a holding tank to produce compost (fertilizer) (see Figures 27 and 28).

Pelletization Device

This device converts aquatic plants into pellets of feed or solid fuel. The solid fuel is produced by adding a polymer binder as additive to the dried aquatic plants; the feed is produced by adding fish powder or molasses as an additive to the dried plants (Figure 29).

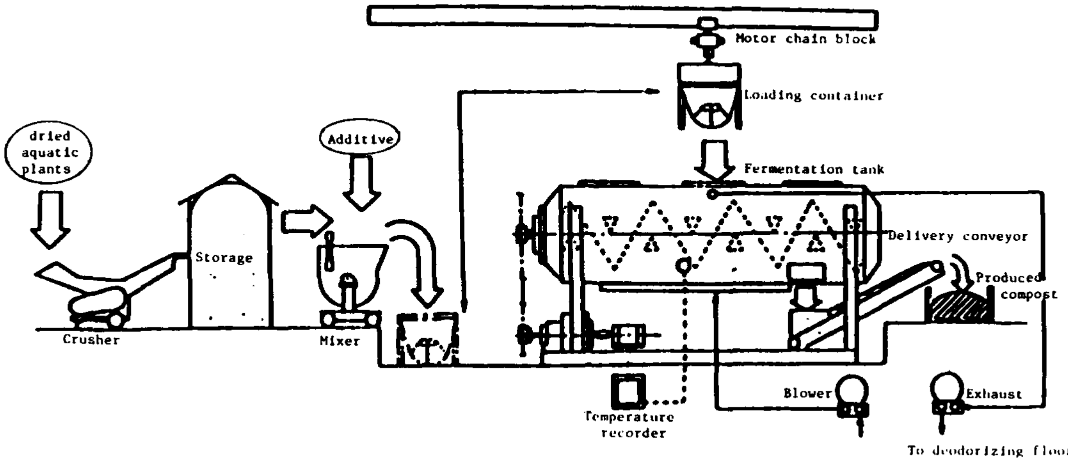


Figure 27. Flowchart for composting device

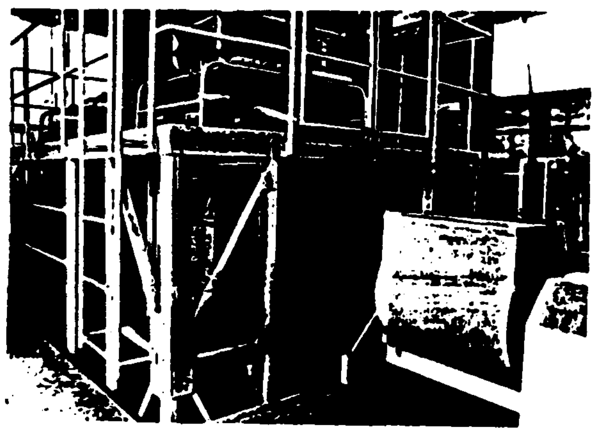


Figure 28. Composting device

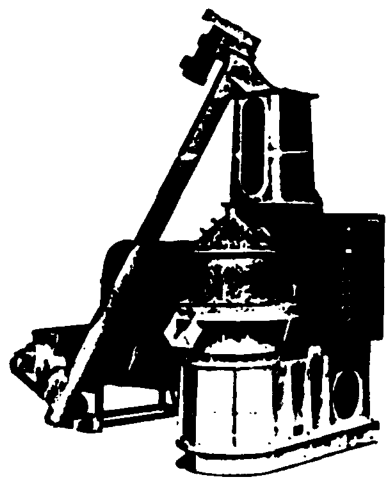


Figure 29. Pelletization device

TEST RESULTS

The water quality simulation results for the test plant are shown in Figures 30 and 31.

According to the test results, the average removal of nitrogen and phosphorus was about 60 percent. The removal effect estimated by the water purification simulation was nearly the same as that demonstrated by the test (Figure 32). For phosphorus, the concentration for inflow water was greater than the estimated value, so that the purified water quality was worse than the estimated value (Figure 33). The chemical oxygen demand removal rate in the flow-type catalytic oxidation waterway (retaining time, 0.9 to 1.6 hr) averaged 32 percent, and the suspended solids removal rate was 53 percent. These percentages are nearly the same as those used by the gravel pebble catalytic oxidation system performed by The Ministry of Construction and by others.

The recovered waterhyacinth (approximately 40 tons) was dried and processed into compost, solid fuel, and feed. The compost produced (3 tons) was

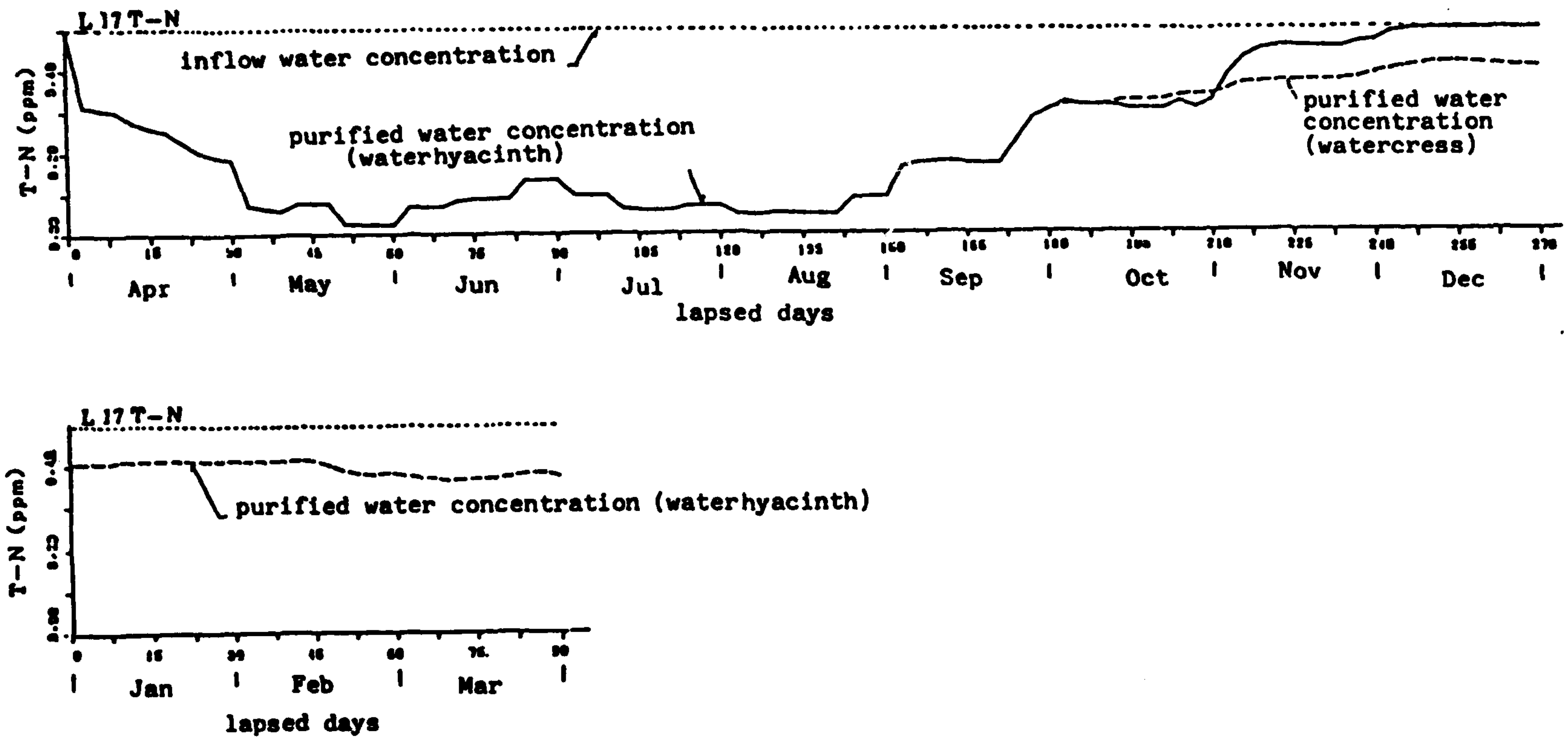


Figure 30. Calculation results for total nitrogen

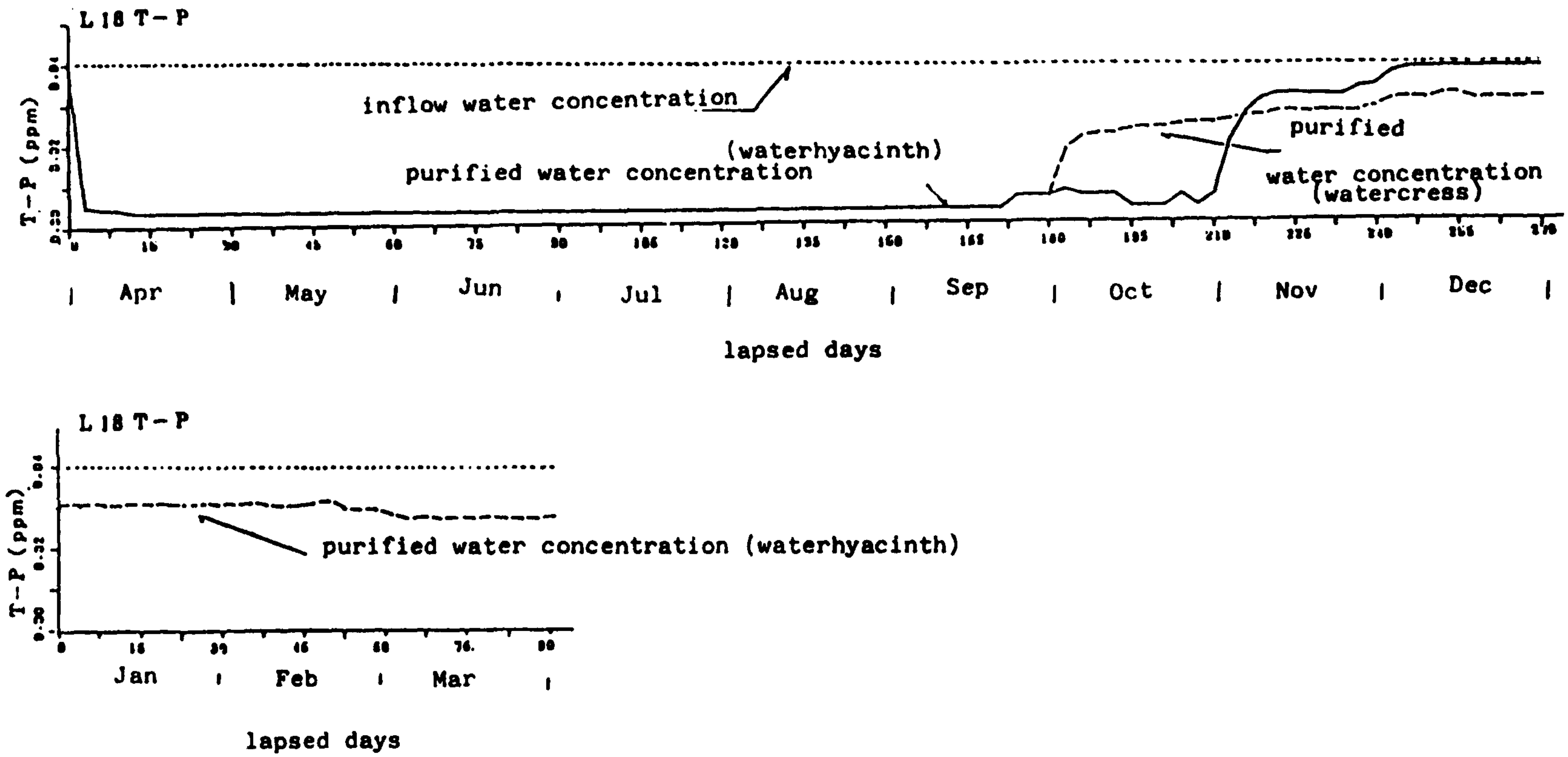


Figure 31. Calculation results for total phosphorus

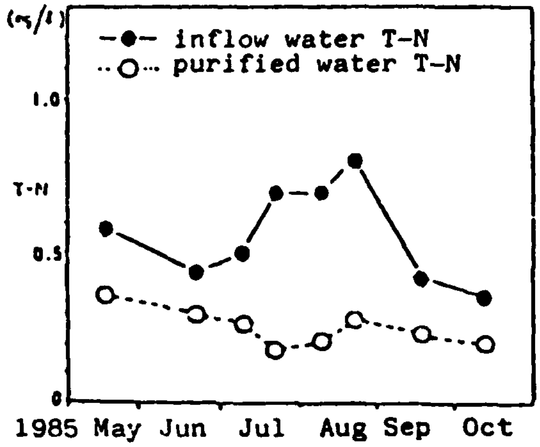


Figure 32. Water quality variation (T-N)

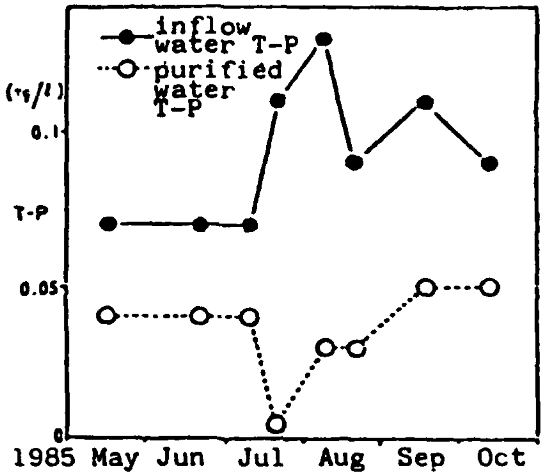


Figure 33. Water quality variation (T-P)

supplied to the neighboring farmhouses, to their satisfaction. The feed produced (0.3 ton) was supplied to the Stockbreeding Faculty of Tsukuba University for test use. The solid fuel (0.5 ton), having a heating value of 4,500 Kcal/kg, was used as fuel made available to the laboratory at Doho Pond. Composition of the compost (shown in Figure 34) is detailed in Table 3. Figure 35 shows the pelletized solid fuel, and Figure 36 shows the stove used exclusively for pelletized solid fuel production.

Figure 34. Compost

TABLE 3. COMPOSITION OF COMPOST

Element	Percentage
Total nitrogen	3.1
Total phosphoric acid	2.0
Total potassium	2.1
Total carbon	21.3
C/N	7.0 (value converted as dried)

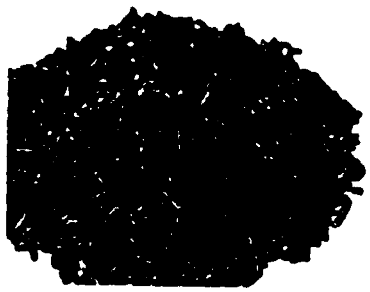


Figure 35. Pelletized solid fuel

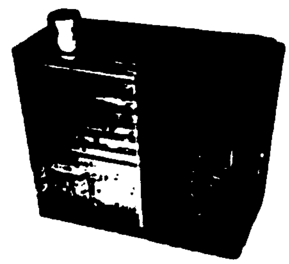


Figure 36. Stove for solid fuel pellet production

The operational cost of the biofilter system was Yen 14.7 per 1 m^3 of treated water in 1985, which is considered lower than the expenses required for other wastewater treatment installations on similar scales. By this test, the biofilter system was proven to be most effective in terms of water purification, production of by-products, and operational cost.

Azuchi Town Project

As part of the municipal wastewater purification activity promoted by the Shiga Local Government, pollution prevention work was initiated by Azuchi Town, Shiga Prefecture, in 1983 on the inflow of the Tohichi River. This waterway receives wastewater from the city and runs into the Nishino-ko (285 ha), an inner lake of Lake Biwa. The work utilized aquatic plants under the direct river purification method.

Description of Work

The facilities are described below and shown in Figure 37.

a. Treatment system - by catalytic oxidation and aquatic plant cultivation.

b. Main facilities.

   (1) Waterway, 2.5 m wide, 100 m long (total 250 m^2).

   (2) Catalytic oxidation pond, 19 m^2.

   (3) Aquatic plant cultivation pond, 200 m^2.

   (4) Warehouse for storing recovered aquatic plants, 45 m^2.

c. Cultivation plant.

   (1) Waterhyacinth (from April to October)

   (2) Watercress (from November to March of the next year)

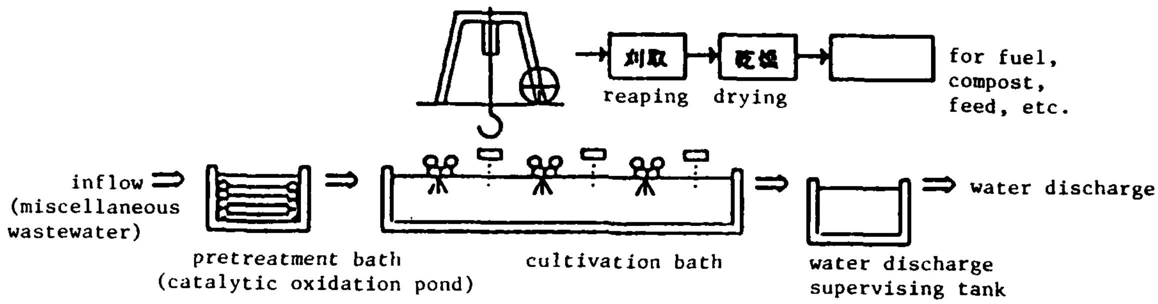


Figure 37. Diagram of system performance, Azuchi Town

d. Devices available.

(1) Reaper for aquatic plants (self-driving system on rail).

(2) Hand cart.

(3) Circulating pump.

e. Scale - 50 m^3/day, average; retaining period, 2 to 2.5 days

Test Results

The tests were initiated in May 1983 by planting the aquatic plants, and the plant recovery work was performed once a week after the plants reached full growth in the cultivation area. The water quality investigation results were as follows:

Parameter	Raw Water ppm	Treated Water ppm	Removal Rate %
BOD	9.0	3.0	67
COD	11.3	5.2	54
T-N	3.36	1.66	50.6
T-P	0.34	0.25	26

The above-mentioned work has been proved to result in the reduction of contamination as well as environmental improvements such as decreased accumulation of sludge and waste and reduced generation of mosquitos and odors. Furthermore, it has proved to contribute to the elevation of regional inhabitants' environmental consciousness, by their voluntary participation in the aquatic plant removal and drying work (Figures 38 and 39).

Ancient Castle Fair, Hikone City

In the World Ancient Castle Fair held in Hikone City, Shiga Prefecture, Japan, from March to May 1987, wastewater coming from the restaurants and all other facilities of the fairground had been induced to the moat where water-hyacinth was cultivated for water purification, and then discharged to Lake Biwa. In consideration of the surrounding environment, cultivation fences were installed to enhance the aesthetics of the landscape, having water, greenery, and stone wall in harmony (Figure 40).

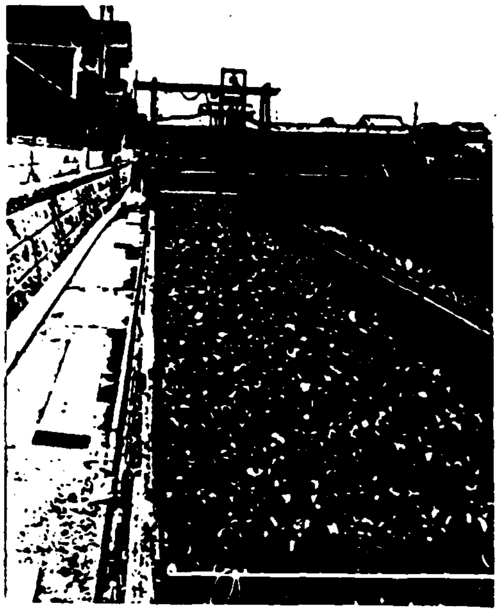


Figure 38. Cultivation of aquatic plants in Juhichi River (Azuchi Town)

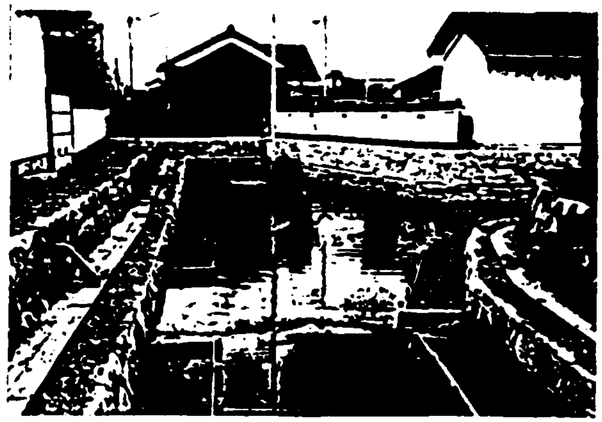
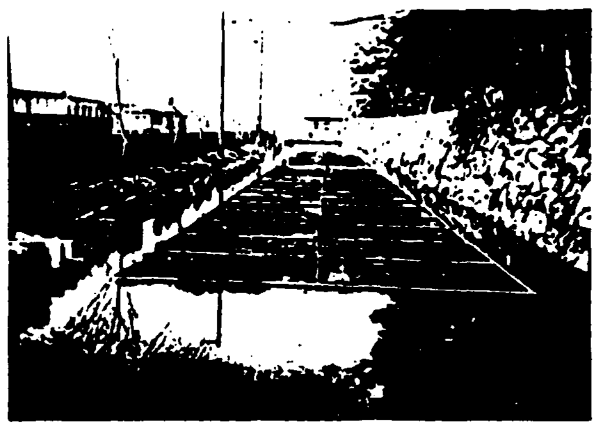


Figure 39. Landscaping for environmental improvement (at Jonohama of Azuchi Town)

Figure 40. Watercress cultivated in fairground moat for water purification



CONCLUSIONS

Research on the water area purification system utilizing aquatic plants (biofilter system) commenced in 1980 and continued to 1984. During the first 3 years (1980 to 1982), the selection of aquatic plants suitable for the system, framing of the structure of each subsystem, confirmation of the practical use of the system through various tests, planning of the calculation model for various basic designs suitable for each application, and other fundamental investigations were accomplished. In 1983 the demonstration test was planned for execution in Doho Pond of Tsukuba Science City in Ibaraki Prefecture, Japan, to verify the practical use of this system. From 1983 to 1984, the cultivation facilities, recovery devices, solar drying devices, compost devices, pelletization devices, and other related facilities were developed for the system and the operational test was performed in Doho Pond.

As the result of the test, the following features of this system have been confirmed:

a. It is possible to employ the quantitative nutritive salt absorption ability of aquatic plants and to absorb and remove the low-concentration nutritive salt diffused in the water area.

b. It is possible to make use of aquatic plants effectively as compost, solid fuel, methane gas, and feed.

c. The system is saving energy because of the use of the solar drying system.

d. The system is easy to maintain, energy effective, and operable at low cost.

e. It is easy to create appropriate landscape on the water side using aquatic plants.

The biofilter system is not only a water purification technology effective for the eutrophied water area but also a biotechnology by which the recovered aquatic plants can be converted to valued by-products and by which the surrounding environment can be improved.

This system is available for application to any water areas where water purification is a serious issue. Further, this system promotes local participation.

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SUMMARY OF THE CE/EPA FIELD VERIFICATION PROGRAM

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ABSTRACT

The Field Verification Program, jointly sponsored by the US Army Corps of Engineers (CE) and the US Environmental Protection Agency (EPA), was a 6-year comparative study of three methods of dredged material disposal. The $7.2-million effort evaluated test methods for predicting and assessing environmental impacts of upland disposal, wetland creation, and aquatic disposal as techniques for disposing of dredged material. The objectives of the program were to determine (a) the reproducibility of test methods in the laboratory, (b) the ability of laboratory test methods to predict effects in the field, and (c) the comparative effects of the same dredged material in upland, wetland, and aquatic environments.

The program demonstrated that methods of predicting effluent and surface water quality are useful for evaluating whether a particular dredged material is suitable for disposal in an upland site. Methods that test the toxicity and bioaccumulation in wetland plants showed fair ability to predict the suitability of the material for use in creation of wetlands, but the usefulness of the upland and wetland animal bioassays for this purpose cannot be fully judged until the reproducibility of laboratory test results is confirmed. Methods with good utility for evaluating dredged material proposed for aquatic disposal include toxicity, bioaccumulation, intrinsic rate of population growth, and scope for growth.

In general, upland disposal produced the greatest and most persistent impacts. Wetland creation produced considerably less impact, and aquatic disposal resulted in relatively minor and nonpersistent impacts. This is in keeping with the physicochemical behavior of dredged material in these different environments. A similar ranking of effects would be expected in the disposal of other contaminated estuarine dredged material.

INTRODUCTION

Program Objectives

In January 1982, the US Army Corps of Engineers (CE) and the US Environmental Protection Agency (EPA) initiated the 6-year, $7.2-million Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives (referred to as the Field Verification Program or FVP). The FVP was designed to meet both agencies' needs to (a) document the effects of placement of the same contaminated dredged material in upland, wetland, and aquatic environments, (b) verify the accuracy of techniques now in use to predict the suitability of the material for disposal by a particular method, and (c) provide a basis for determining the degree to which biological response is correlated with bioaccumulation of key contaminants in the species under study.

To accomplish the program objectives, evaluation techniques developed by the CE, EPA, and others were applied to dredged material from a single maintenance dredging operation in Black Rock Harbor (BRH), Bridgeport, Conn. A portion of the dredged material was placed in a typical upland disposal site, a second portion was placed in a typical aquatic site, and a third was used for wetland creation. This provided the technical opportunity both to verify predictive evaluation procedures and directly compare the environmental consequences of the same material under three frequently used disposal conditions. The BRH dredging project was chosen for the program because the material to be dredged was in an industrial area and known to contain a variety of contaminants. Although the material was not considered to pose an unacceptable potential for adverse environmental effects, it was considered sufficiently contaminated to rigorously test the evaluation methods and to allow comparison of effects in upland, wetland, and aquatic environments.

Studies of each of the three major disposal environments included both laboratory documentation of the applicability and reproducibility of the technique(s) and verification of the accuracy of the laboratory tests in predicting environmental consequences in the field. Evaluations of aquatic disposal were conducted by the EPA Environmental Research Laboratory at Narragansett, R. I. Upland disposal and wetland creation studies were conducted by the US Army Engineer Waterways Experiment Station (WES) at Vicksburg, Miss.

Terminology

The terms upland disposal, wetland creation, and aquatic disposal were carefully chosen for use in the FVP to convey the essential physicochemical characteristics that create potentials for different impacts of disposal in the three disposal environments. The physicochemical characteristics of dredged material in various disposal environments are the major factors controlling the potential for contaminant-related environmental impacts of dredged material (Saucier et al. 1978, Francingues et al. 1985).

The term upland disposal refers to placement of dredged material in conditions such that the material will dry over time and take on characteristics typical of upland soils. The drying and oxidizing of the dredged material that occur over time can often result in a substantial increase in acidity, increasing the environmental mobility and potential release of metals in the dredged material. The biological availability of organic contaminants can also be altered by volatilization or oxidation of the humic materials with which they are associated. Major subjects of environmental concern with upland disposal include effluent quality, surface runoff quality, leachate quality, and lethal and sublethal effects on colonizing plants and animals (Francingues et al. 1985).

Aquatic disposal refers to placement of dredged material within a body of water so that it is always covered with water and remains saturated, anoxic beneath the sediment surface layer, and near neutral in pH. Thus, the factors contributing to the release of metals and organic contaminants remain relatively unchanged from the predredging situation. The organisms that colonize aquatic dredged material disposal sites are typical aquatic organisms. Major topics of environmental concern with aquatic disposal include water column impacts during and shortly after disposal, lethal and sublethal effects on colonizing animals, and bioaccumulation (Francingues et al. 1985).

Wetland creation with dredged material refers to placement of material under conditions such that, after consolidation, the surface is alternately covered and uncovered with water, but is never exposed long enough to dry and take on typical upland soil characteristics. Physicochemically, dredged material used in wetland creation remains saturated with water, anoxic below the surface layer, and close to neutral in pH. Wetland creation sites tend to be colonized by aquatic organisms adapted to an intertidal existence and by typical wetland plants. Major topics of environmental concern with wetland creation include effluent quality, surface runoff quality, leachate quality, and effects, including toxicity and bioaccumulation, on colonizing plants and animals.

SEDIMENT COLLECTION AND MIXING

Before dredging of the BRH channel began, sediment samples were collected along the channel and placed in a refrigerated truck at 4° C for transportation to the WES. Upon arrival at the WES, the samples were composited into one homogeneous sample (Folsom and Lee 1982), which was then subdivided among the researchers so that upland, wetland, and aquatic laboratory studies were performed with the same dredged material. The composited dredged material samples were maintained at 4° C in sealed containers until used in laboratory studies.

SITE CONSTRUCTION

Site Selection and Design

Site Selection

The upland disposal and wetland creation sites were located at Tongue Point, Conn., about 4.5 nautical miles from the BRH channel (Figure 1). The Central Long Island Sound (CLIS) disposal site (Figure 1) was selected for the aquatic studies.

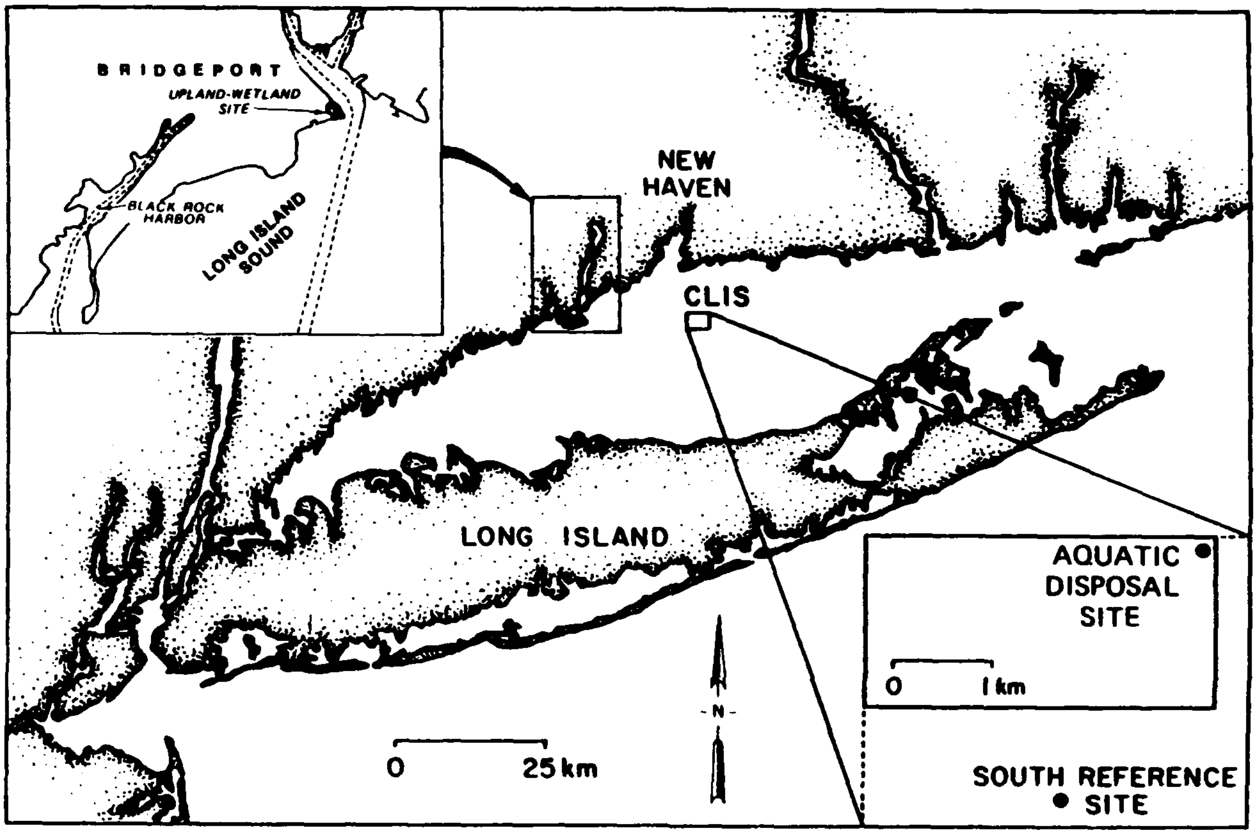

Figure 1. Long Island Sound area showing the location of Black Rock Harbor, the upland and wetland study sites at Bridgeport, and the aquatic study site at the Central Long Island Sound disposal area

Site Design

The available surface areas for the upland and wetland sites were limited; therefore, the major objective of the site design was to match a maximum allowable filling rate to the available volume for temporary holding or ponding of water within the site to allow settling of suspended solids before the water was discharged. Procedures found in Palermo, Montgomery, and Poindexter (1978) and Palermo (1985) were followed for the designs of the upland and wetland sites. Approximately 2,294 m^3 of in situ channel material was placed in the upland site to achieve the desired final substrate elevation. Total surface area of the upland site was approximately 2,583 m^2. Approximately 765 m^3 of dredged material was required to construct the wetland. Final total surface area of the wetland was approximately 706 m^2. Approximately 55,000 m^3 of dredged material was disposed at the CLIS aquatic disposal study site.

Dredging and Disposal

Because the available sites for upland, wetland, and aquatic studies were located away from the BRH channel, transportation and off-loading of the material from barges were required. Material for the FVP aquatic studies was removed by clamshell dredge from a strip along the entire length of the study reach, loaded on barges, and point-dumped at a disposal buoy marking the center of the selected aquatic disposal site. The remaining undredged strip of the channel was later used for acquiring the upland/wetland material, meeting the requirement that the same sediment be used for upland, wetland, and aquatic sites.

EVALUATION OF PREDICTIVE TECHNIQUES

The results of each evaluative technique were expressed in terms of quantitative data, but the relative comparisons of the techniques were expressed by qualitative ratings of good, fair, and poor. A rating of good indicates that a technique showed sufficient correspondence between tests and between the laboratory and field for most parameters to be reliably applied in routine evaluations. If the correspondence was not so good or was not consistently good for most parameters, the technique was rated fair. Poor ratings indicate little or no correspondence between tests or between laboratory and field data, so that the technique cannot at present be relied upon for routine applications.

In the context of this report, the evaluation of the utility of a technique refers to the predictive reliability of the technique as demonstrated in the FVP. This evaluation of utility does not consider the need for the evaluation in a particular case (cost, time requirements, etc.). Therefore, a rating of good utility for a particular technique cannot be taken as a suggestion that it be routinely used in all dredged material evaluations.

Techniques for Predicting Upland Disposal Effects

Upland Site Design

The settling and consolidation tests used to determine the filling rates, weir lengths, and initial storage volumes required to achieve the desired final surface elevations in the upland site proved successful. The field verification of the laboratory predictive tests was good, in that the construction based on the test results produced the desired final surface elevations in the upland site.

Effluent Quality

The quality of the effluent during the filling of the upland and wetland sites was predicted from the combined results of modified elutriate tests (Palermo 1985) and column settling tests (Palermo, Montgomery, and Poindexter 1978). The reproducibility of the predictive method in the laboratory and the field verification of the predictions of effluent quality were good (Folsom et al. 1988). The effluent quality prediction technique was good for predisposal evaluations of potential contaminant effects on effluent quality from upland and wetland creation sites.

Surface Runoff Quality

The mean concentrations of most contaminants predicted in surface runoff by laboratory tests (Lee and Skogerboe 1984) were in fair agreement with the values observed in surface runoff tests conducted on the upland site after it was filled and had dried to typical upland conditions (Folsom et al. 1988). The procedure for evaluating surface runoff water quality showed fair utility for predisposal evaluations of proposed upland disposal of dredged material. Although not evaluated in the FVP, the surface runoff procedure could be useful for postdisposal monitoring applications, in which the purpose would be to quantify existing surface runoff quality and the predictive ability of the method would be of little concern.

Upland Plant Toxicity

The reproducibility of the upland plant toxicity method (Folsom and Lee 1981) was limited because survival of plants in the upland site was almost nonexistent (Folsom et al. 1988). Laboratory predictions and field observations of plant survival agreed well. Even so, the utility of the technique for predisposal evaluation of toxicity to plants under upland disposal conditions was considered fair, because the reproducibility and the exposure-response relationship were not clear. Vegetation was successfully established only on plots amended with lime plus horse manure, and lime plus sand plus gravel plus horse manure. Establishment of even salt-tolerant plant species on these plots was sparse and occurred primarily in cracks where the soil amendments were concentrated. All other plots were completely void of vegetation.

Bioaccumulation in Upland Plants

Reproducibility of the plant bioaccumulation test (Folsom and Lee 1981) in the laboratory was limited because survival of plants in the upland site was almost nonexistent. The agreement between laboratory predictions of metals bioaccumulation and the bioaccumulation observed in the field was poor (Folsom et al. 1988). At the present time the variability in these predictions limits the utility of the upland plant bioaccumulation technique for predisposal evaluations. The method would be useful for monitoring plant tissues after disposal; the purpose of such monitoring would be to quantitate the actual bioaccumulation taking place on the site, and the predictive ability of the method would be of little concern.

Upland Animal Toxicity

Effects on earthworms of BRH dredged material under upland conditions were so great that the toxicity test procedure could not be satisfactorily evaluated. The laboratory test predicted high and rapid mortality, which was observed in the field. However, the high salinity of the dried soil was almost certainly a major contributor and interfered with evaluation of the technique's ability to identify contaminant-related toxicity (Folsom et al. 1988). Therefore, the utility of the upland animal toxicity test for predisposal evaluation of proposed upland disposal of contaminated dredged material remains unknown, and research is necessary for further development of the technique.

Bioaccumulation in Upland Animals

Because of the poor survival of earthworms under upland conditions, techniques for predicting bioaccumulation could not be evaluated (Folsom et al. 1988), and their utility remains unknown.

Techniques for Predicting Effects of Wetland Creation

Wetland Site Design

The settling and consolidation tests (Palermo, Montgomery, and Poindexter 1978) used to determine the filling rates, weir lengths, and initial storage volumes required to achieve the desired final surface elevations in the wetland site proved successful. These tests have been used extensively elsewhere, and their reproducibility was not evaluated in the FVP. The field verification of the laboratory predictive tests was good, in that the construction based on the test results produced the desired final surface elevations in the wetland site (Simmers et al., in preparation).

Wetland Plant Toxicity

The plant toxicity test (Folsom and Lee 1981) in the wetland environment was not evaluated for its reproducibility or ability to indicate changes in toxicity related to changes in exposure to contaminants. The laboratory predictions of survival of *Spartina* were confirmed in the field, but laboratory predictions that *Sporobolus* would survive were contradicted in the field. The method should have good utility for predisposal evaluations of *Spartina* survival in wetlands created with dredged material, but not for evaluations of *Sporobolus* survival (Simmers et al., in preparation). It appears the overall utility of the technique depends upon the species to which it is applied; incomplete information on reproducibility also limits the utility of the method. Further research is necessary if this technique is to be developed for routine use.

Bioaccumulation in Wetland Plants

Reproducibility of response and the ability to detect changing bioaccumulation in response to different contaminant exposures were not evaluated. The correspondence between laboratory predictions (Lee, Folsom, and Bates 1983) and metals bioaccumulation in *Spartina* and the metals concentrations observed in plants in the field was fair (Simmers et al., in preparation). Because of the inconsistency and the lack of information on reproducibility, the wetland plant bioaccumulation technique can be considered to have fair utility for preconstruction evaluation of wetland creation with dredged material. However, for monitoring purposes, the technique seems useful, because the predictive ability of the method would not be of concern in such applications.

Wetland Animal Toxicity

The reproducibility of the method for testing the toxicity of dredged material to sandworms *Nereis virens* and *Neanthes succinea*, mussels *Modiolus demissus*, and snails *Nassarius obsoletus* was not evaluated. A relationship between toxicity and exposure to contaminants was indicated by the absence of survival in static laboratory tests with pure BRH dredged material, but good survival in BRH dredged material mixed 1:3 with clean sand (Simmers et al., in preparation). However, an exposure-response relationship was not clearly defined. The animals survived in recirculating laboratory tests, and the same species survived in the field, indicating fair field verification of the technique. The utility of the wetland animal toxicity test for predisposal evaluation is fair.

Bioaccumulation in Wetland Animals

The reproducibility of the test method and the ability of the method to detect changing bioaccumulation associated with different contaminant exposures were not evaluated. Laboratory predictions of metals bioaccumulation from the predredging BRH samples were field verified for four metals by comparing laboratory data on *N. virens* with field data on *N. succinea*, which naturally recolonized the wetland site (Simmers et al., in preparation). Field verification of the technique is considered poor. Although this indicates poor utility of the technique for preconstruction evaluations, the technique might be useful for monitoring where predictive ability is not of concern. Field verification of bioaccumulation of organics was considered fair. The utility of the wetland animal technique for preconstruction evaluations of bioaccumulation of organics is considered fair.

Techniques for Predicting Effects of Aquatic Disposal

Aquatic Site Design

The sampling methods and calculations used to determine dredged material volume destined for the aquatic disposal site proved reliable. The point-dumping techniques were successful, in that they resulted in a discrete, well-defined mound at the disposal point (Gentile et al. 1988).

Toxicity

Tests of toxicity (Rogerson, Schimmel, and Hoffman 1985) were reproducible in the laboratory in that repeated tests showed good survival of all 11 test species of annelids, molluscs, arthropods, and fishes except the infaunal amphipod *Ampelisca abdita*, which was consistently affected. Mortality of *A. abdita* was directly related to the proportion of BRH dredged material in the sediment to which the animals were exposed. Mortality was also directly related to the concentration of suspensions of BRH sediment. Field verification of the toxicity tests was indirect for the most part, because few of the laboratory test species would have been expected to colonize the field site. However, the survival of many species in the laboratory was paralleled by the occurrence of a wide range of species at the disposal site as time progressed (Gentile et al. 1988). Laboratory toxicity tests simulating field exposure conditions have good utility for predisposal evaluations of dredged material proposed for aquatic disposal.

Scope for Growth (SFG) and Bioenergetics

Scope for growth in blue mussels *Mytilus edulis* (Nelson et al. 1987) was reproducible and directly related to exposure to suspensions of BRH dredged material. There was good correspondence between laboratory and field SFG values in *M. edulis* when data collected under similar exposure conditions were compared. Scope for growth in *M. edulis* has good utility for predisposal evaluations for dredged material proposed for aquatic disposal. The technique also has good utility for postdisposal monitoring purposes.

The bioenergetics measurements made on the polychaete *Nephtys incisa* (Johns, Gutjahr-Gobell, and Schauer 1985) were also reproducible and correlated with exposure to BRH dredged material. At present, techniques for measuring bioenergetics in the field are limited to excretion and respiration, so only these aspects of bioenergetics could be field verified. The utility of the technique for predisposal evaluation is considered fair because only two aspects of bioenergetics could be field verified. These two measurements showed good correspondence between laboratory and field data. The utility of bioenergetics techniques for predisposal evaluations or postdisposal monitoring is fair.

Adenylate Energy Charge (AEC)

Measurements of AEC in mussels *M. edulis* and polychaetes *N. incisa* (Zaroogian et al. 1985) in the laboratory were inconsistent and not clearly related to exposure to BRH dredged material. There was a semblance of comparability between laboratory and field results in that field responses were also erratic and minor. However, the utility of AEC for either predisposal evaluations or postdisposal monitoring of aquatic dredged material disposal is poor.

Sister Chromatid Exchange (SCE)

Measurements of SCE in polychaetes *N. incisa* (Pesch et al. 1987) in the laboratory were not reproducible, although there was some relationship to exposure to BRH dredged material. Because of the inconsistency of response, field verification was poor, and the utility of the procedure for predisposal or postdisposal evaluation is poor.

Histopathology

There was not a reproducible relationship in the laboratory between exposure to BRH dredged material and histopathological response in mussels *M. edulis*, polychaetes *N. incisa*, amphipods *A. abdita*, or bivalves *Yoldia limatula* (Yevich et al. 1986). Field verification was fair in that minor, sporadic responses were seen in the laboratory, and occasional scattered incidences of minor abnormalities were seen in the field. In the FVP, histopathology showed poor utility in predisposal evaluation of dredged material proposed for aquatic disposal. In concept, histopathology could be very useful for long-term monitoring where the duration of exposure would allow for the possible induction and manifestation of histologic changes.

Population Growth Rates

Growth, reproduction, and intrinsic rate of population growth in arthropods *Mysidopsis bahia* or *A. abdita* (Gentile et al. 1985) were reproducible and related to exposure to BRH dredged material in the laboratory. They were not field verified because the technique is not amenable to application in the field. However, on the basis of the consistency of response in the laboratory, the ability to detect effects at low-exposure conditions typical of the field, and the environmental importance of the parameters measured, the techniques are considered to have good utility for predisposal evaluations of dredged material proposed for aquatic disposal.

Bioaccumulation

Bioaccumulation (Lake, Hoffman, and Schimmel 1985) of metals and organics in mussels *M. edulis* and the polychaetes *N. virens* and *N. incisa* in the laboratory was very reproducible and was directly correlated with exposure to BRH dredged material. When bioaccumulation data collected under the same exposure conditions in the laboratory and field are compared, field verification of the technique is good. The utility of bioaccumulation for both predisposal evaluations and postdisposal monitoring of dredged material in the aquatic environment is good.

COMPARISON OF EFFECTS OF DREDGED MATERIAL PLACEMENT IN UPLAND, WETLAND, AND AQUATIC ENVIRONMENTS

Detailed quantitative comparison of effects of dredged material disposal in upland, wetland, and aquatic environments is not possible in as comprehensive a study as the FVP because of the lack of commonality among the ecologies of the different disposal environments. However, qualitative findings of the FVP in terms of effects in different disposal environments can be summarized in a few general observations (Peddicord 1988).

a. Effects tended to be more severe in the upland environment than in the wetland or aquatic environments. This is particularly true when the almost total mortality of some upland species is compared with the generally low incidence of sublethal responses of animals in the aquatic environment under actual exposure conditions.

b. At the end of the 6-year program, some plant and animal species still were not established on the upland and wetland sites. Community studies at the aquatic site showed rapid recolonization by a variety of species to a benthic community typical of Central Long Island Sound with few indications of serious long-term impacts.

c. The proportion of the species examined that showed substantial effects was much greater in the upland environment than in the wetland and aquatic environments. The detrimental effects of upland disposal were certainly influenced by the presence of environmental contaminants as well as by the very high salinity typical of estuarine sediments dried in upland environments.

d. Prior to the FVP, techniques for evaluating dredged material disposal in the aquatic environment had received more developmental effort for a longer time than techniques for evaluating upland disposal or wetland creation. Therefore, more techniques are available for aquatic disposal evaluation than for evaluation of upland disposal or wetland creation. The techniques available for evaluating upland and wetland effects on plants and animals emphasize mortality and bioaccumulation. Because aquatic techniques have a longer developmental history, aquatic techniques tend to emphasize chronic, sublethal effects in addition to mortality and bioaccumulation. Therefore, in the FVP, more sublethal effects were measured in the aquatic environment than in the upland or wetland environments.

e. Techniques for managing upland disposal sites to establish vegetative cover proved successful. Laboratory and field data indicated that the use of salt-tolerant plant species and extensive efforts to control soil texture, acidity, and free metals using sand, lime, and manure would be required, and these proved effective in the field.

f. The techniques for evaluating water quality effects at upland and wetland sites during site filling (effluent evaluations) and site operation (surface runoff evaluation) were useful predictive tools.

g. In general, BRH dredged material had a greater and more persistent impact in the upland environment than in the wetland environment, and impacts in the aquatic environment were the least severe and least persistent. Because the underlying physicochemical characteristics that distinguish upland, wetland, and aquatic dredged material sites are consistent wherever such sites occur, there is no reason to expect the three environments to rank differently in overall degree of impact resulting from the dredged material. However, specific effects could differ with different dredged material.

CONCLUSIONS

The Field Verification Program has demonstrated that the environmental effects of disposal of contaminated dredged material are greatly influenced by the biogeochemical environment in which the material is placed. Aquatic disposal, which results in the fewest biogeochemical changes, produced the least severe and least persistent impacts, whereas upland disposal results in the most biogeochemical changes and produced the greatest and most persistent impacts. Wetland creation usually resembles aquatic disposal more than upland disposal from a geochemical perspective and consequently resulted in fewer impacts than upland disposal but more impacts than aquatic disposal.

Techniques for predicting effluent quality and plant toxicity associated with upland disposal were verified by field studies. The effluent quality evaluation technique was also shown to have good utility for predisposal evaluation of dredged material disposal in the upland environment. Wetland plant and animal toxicity tests showed good predictive ability. Although plant bioassay tests have their optimum utility for preconstruction evaluation of wetland creation, the animal bioassay tests await confirmation of their reproducibility and ability to detect different responses to different contaminant exposures. Both scope for growth and bioaccumulation showed good field verification of laboratory results in the aquatic environment and have good utility for predisposal evaluation of dredged material proposed for aquatic disposal. Laboratory toxicity results are hard to verify in the field, but the low laboratory toxicity was consistent with the generally good survival and recolonization seen in the field. The same is true for laboratory measurements of intrinsic rate of population increase. Both these techniques have good utility for predisposal evaluations of proposed aquatic disposal of dredged material. Several other techniques appropriate to each of the disposal environments have promise and are being refined to enhance their utility.

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RELATIONSHIP BETWEEN THE ENVIRONMENT AND KASAI MARINE PARK

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INTRODUCTION

The Port of Tokyo, once called "Edo-Minato," is located in the inner part of the Bay of Tokyo and has a history of 500 years. The Port has been developed both to handle navigation traffic and to serve as a fishing area for the residents of Tokyo and adjacent cities. Since the Meiji age, the Port has played an important role as the main entrance to the city for commercial traffic.

Environmental pollution of the bay, especially of the water quality, has been accelerated by industrial development and overcrowding (since 1955). Fishing activities were discontinued in 1962, marking the direct influence of pollution on the life of people around the bay.

These circumstances prompted the design of the Tokyo Metropolitan Marine Park Project in December 1970, with the main objective of restoring the former conditions of the bay. Construction of the project began in 1972. The aim of the Kasai Marine Park is to function not only as a bathing resort and to stabilize the beach physically, but also to recover and maintain the natural environment around the park and to provide a recreation area for nearby residents by using refined techniques to construct an artificial beach.

The Kasai Marine Park has been established between the mouth of the Arakawa and Edogawa Rivers near the boundary of Chiba Prefecture, located on the eastern side of the Bay of Tokyo (Figure 1). A natural tidal flat called Sanmaizu lies in the offshore area in front of the park, with adequate water quality and sediment. Figure 2 illustrates the process for construction of the park.

The tidal flats in the Kasai region were extended to the mouth of the Sakongawa River before construction of the park began in 1972. About a third of the tidal flats have disappeared due to reclamation of the background area for the Kasai Marine Park, which occurred from 1973 to 1976. Most of these tidal flats, however, were in the area where pollution of the benthic environment had been the worst.

Coincident with the reclamation, preliminary experiments on constructing permeable banks have been conducted since 1974 with H-shaped steel and soft

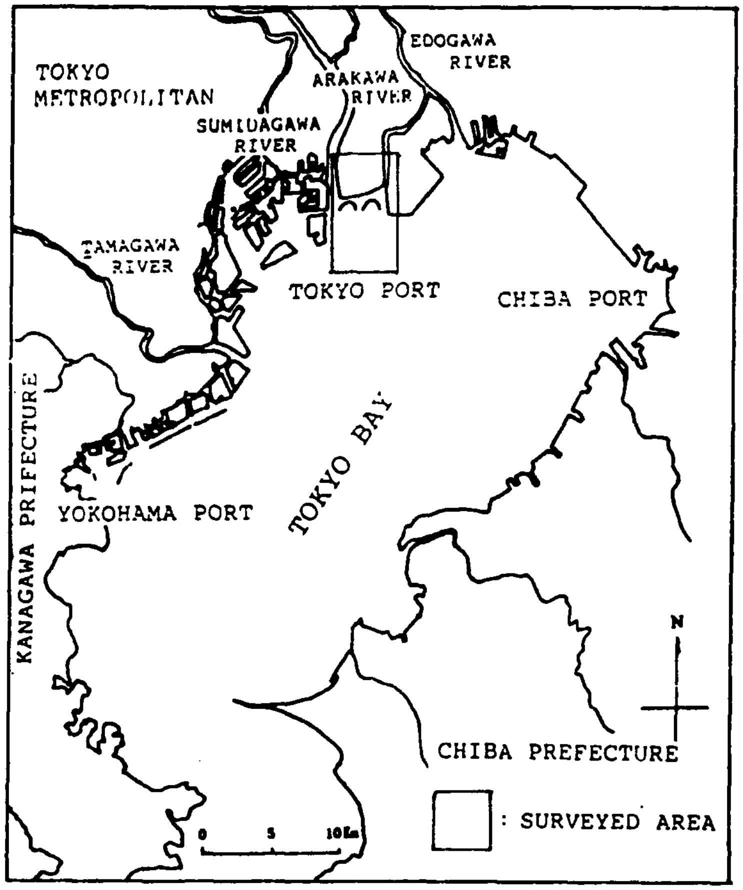


Figure 1. Project area in the Bay of Tokyo

sandy rocks. In these experiments, the artificial beach was raised from the offshore side of the banks, using surrounding sand and an additional 160,000 m^3 transported from Kashima, Ibaraki Prefecture, for a total of 200,000 m^3 over the 1,400-m length and 120-m width. The experimental beach was completed in 1975.

Since 1981, the artificial beach has been raised based on the results of the preliminary experiments described above. Two banks that were brought to completion in 1985, which are 1,500 m long on both the eastern and western sides, form the base of the artificial beach.

Except for a portion of the western side, creation of the artificial beach has been completed, using pumps to move sand from behind the banks.

This report presents the results of the experimental construction of the artificial beach to support benthic organisms and the results of environmental surveys in the park area, including a natural tidal flat (Sanmaizu), to allow more effective use of the park and adjacent area.

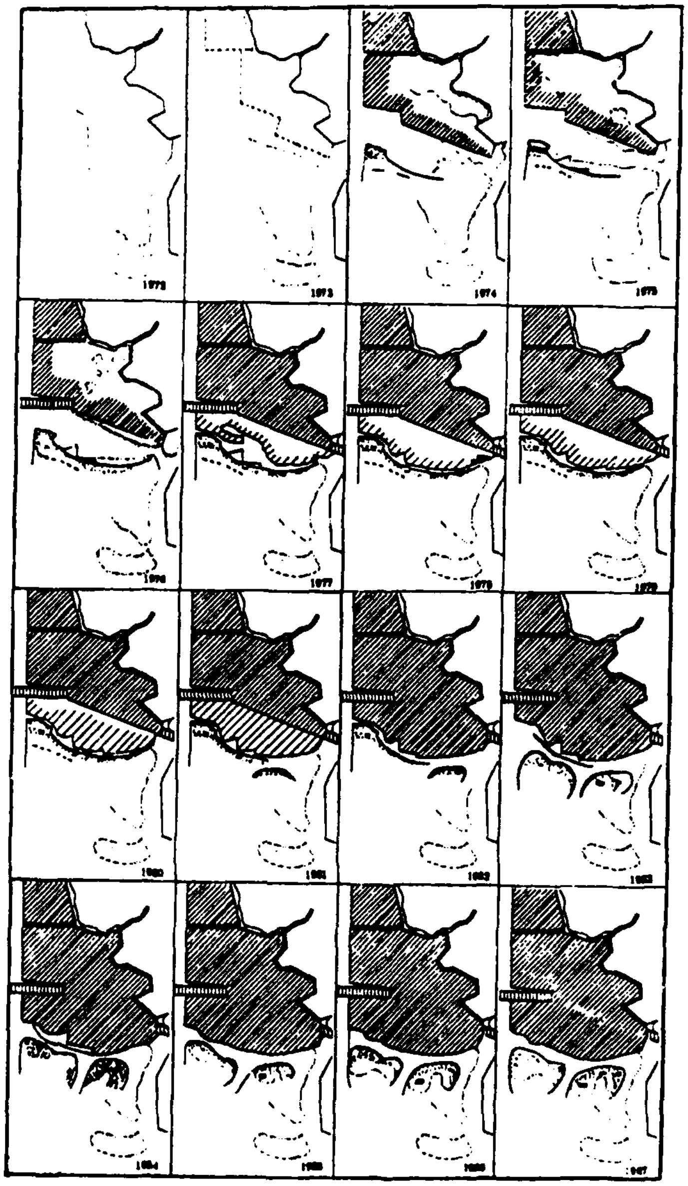


Figure 2. Construction process for Kasai Marine Park

EXPERIMENTAL CONSTRUCTION OF THE ARTIFICIAL BEACH

The objectives of the project to establish Kasai Marine Park were to create the artificial beach, preserve the surrounding natural environment, and promote recreational use. Construction of the park has been carried out simultaneously with environmental surveys because a park of this scale has not been attempted in Japan before.

Construction of artificial beach shown in Figures 3 and 4 was accomplished to examine the preservation or recovery of the natural environment, since we were unable to simulate these processes with an experimental model.

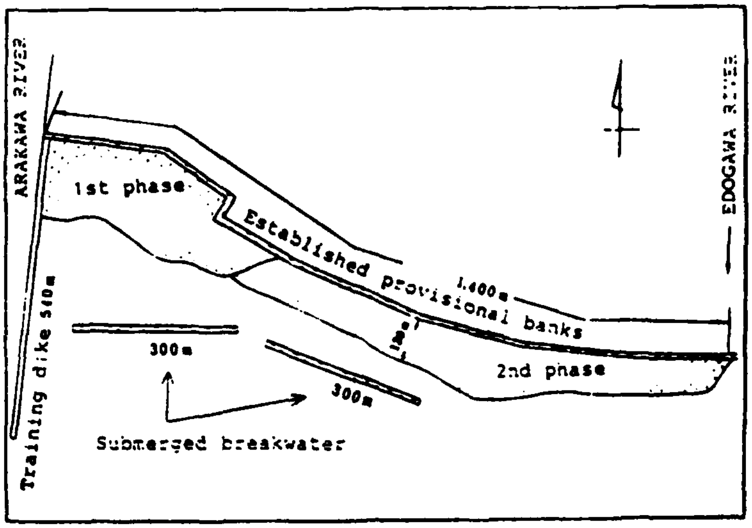


Figure 3. Artificial beach in the Kasai area

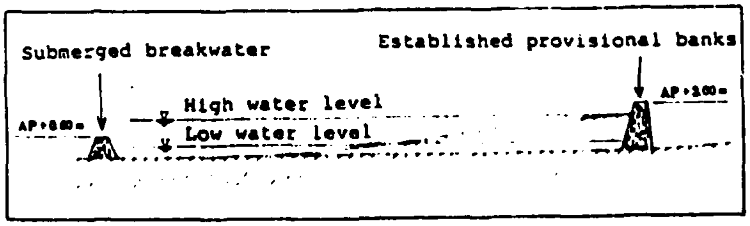


Figure 4. Section profile of the artificial beach

The raised area of the artificial beach has 50 to 80 percent mud composition with 0.0625-mm mean grain size diameter (Akiyama et al. 1974). The beach was created with an inclination of 1/100, covered with fine sand (mean diameter 0.25 mm). As a result, the bank provided attachment for barnacles and mussels, as discussed in Hiyama (1976), Akiyama (1974, 1975, 1976, 1977), and Hiwatashi (1977). Benthic organisms appeared in the beach 3 months after beach creation.

Figure 5 shows the changes in benthic organisms 2 years after the transport of sand to the beach. Gammaridae (Amphipoda, Crustacea) and Polychaetae were distributed before the beach creation (Akiyama 1976), in contrast with the later settlement of sand dwellers such as *Scopimera globosa* (Brachyura, Decapoda, Crustacea), *Solen strictus*, and *Mactra chinensis* (Heterodontina, Lamellibranchia, Pelecypoda, Mollusca). *Pseudopolydora* sp., *Neanthes* spp., (Spiomorpha, Sedentaria, Polychaetae), and *Cyathura muromiensis* (Anthuroidea isopodae, Crustacea) showed significant increases not correlated with beach establishment. As for the polychaetae *Pseudopolydora* sp., the population almost disappeared 15 months after beach creation, in spite of the normal early-spring peak in abundance, which is considered to be based on the seasonal or annual fluctuation.

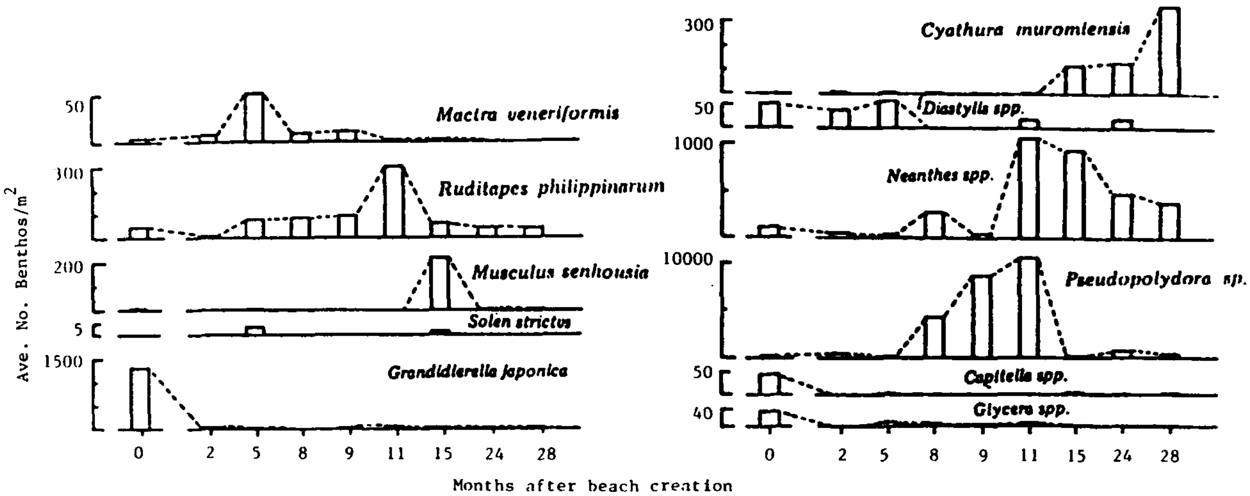


Figure 5. Changes in benthos distribution after creation of artificial beach at the Kasai area

As a result of the beach creation described above, it was noted that the benthic fauna was dominated by sand dwellers that had recently settled in the surveyed area. However, no effort was made to quantify the changes in the population structure of the organisms.

SURVEYS CONDUCTED

Benthic Biota Survey

The purpose of the survey was to investigate the current distribution and characteristics of the benthic biota around the park.

Methods

Triplicate bottom samples were collected at 12 stations (shown in Figure 6) using the Ekman-Berge sampler with a mouth of 0.12 m^2. Samples retained after sieving with 1-mm mesh were identified and counted. Samples were taken four times: in August 1985 and in March, April, and August 1986.

Results

The number of identified species ranged between 32 and 65, with a maximum density of approximately 5,000/m^2 in March 1986. The biomass ranged between 30 and 40 g, dominated in both numbers and species by polychaetes during the sampling period (Figure 7). Major species identified were: *Paraprionospio pinnata*, *Prionospio japonicus*, *Polydora* sp., *Pseudopolydora* sp., *Rhynchospio* sp., *Armandia* sp., *Musculus senhousia*, *Ruditapes philippinarum*, and *Grandidierella japonicus*. Three species, *Pseudopolydors* sp., *Rhynchospio* sp.,

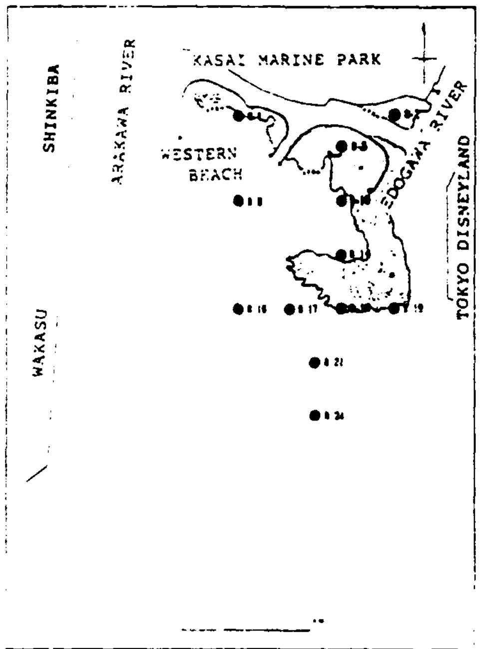


Figure 6. Sampling stations for benthic organisms

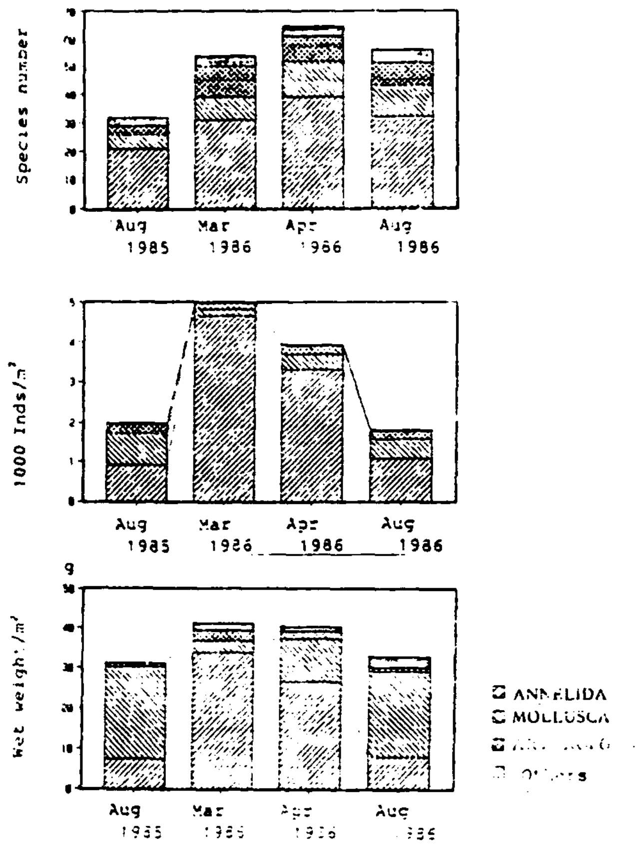


Figure 7. Seasonal fluctuations of benthic organisms

and *Armandia* sp., were the major inhabitants of the tidal flats. In all cases, their abundance peaked in the spring, as shown in Figure 8, which illustrates the distribution of *Armandia* sp.

In contrast, *Paraprinospio pinnata* and *Musculus senhousia*, known as index species of organic pollution, were found at the station situated in deep sites. *Ruditapes philippinarium* was found throughout, from the shallow to the deep sites.

The sampling area was characterized by the domination of both *Pseudopolydora* sp. and *Rhynchospio* sp., especially at tidal flats in the spring; a lower abundance of these species in the summer, along with the increase of *R. philippinarum*; the appearance of *P. pinnata* throughout the year, and the abundance of *G. japonicus* in the summer at deeper sites.

Some differences were considered to be related to location (eastern and western side of the beach) and also to the effect of the river discharge, based on surveys made on the contours of the tidal flats, supplemented by mud sampler stations. Benthic organisms found in the park area were dominated

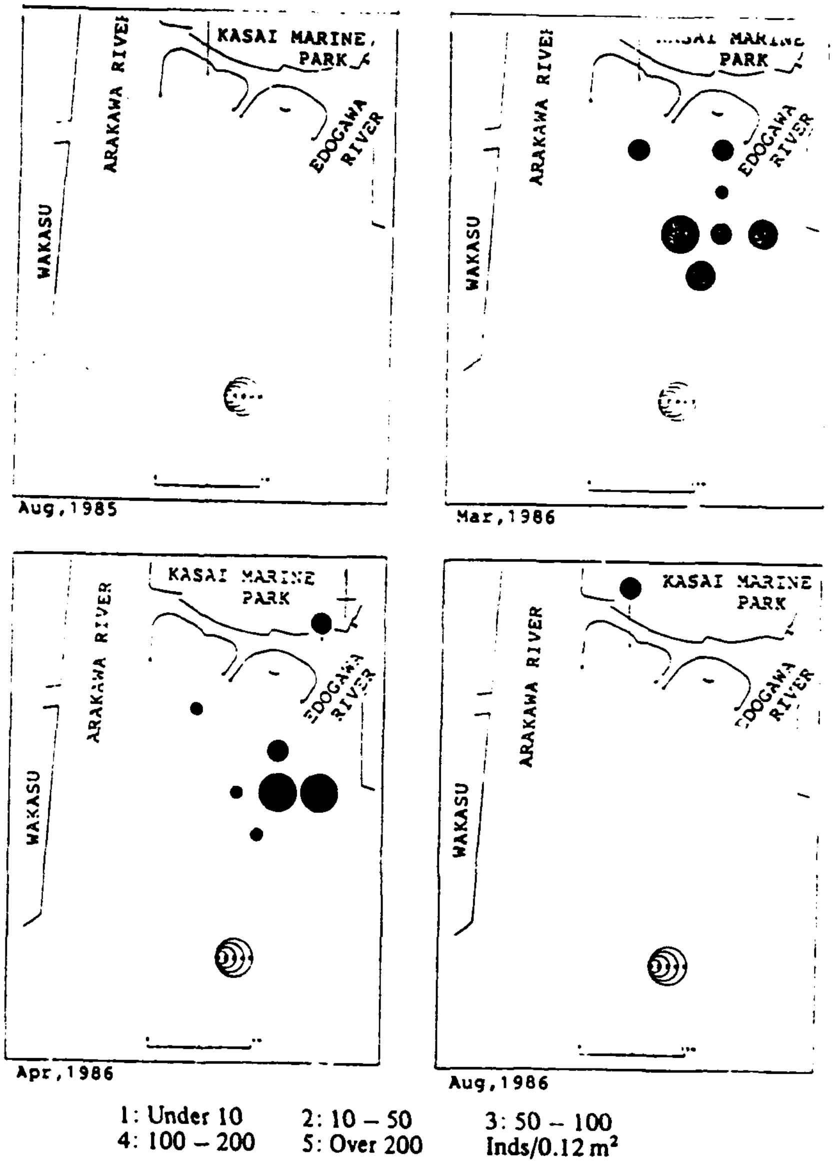


Figure 8. Distribution of *Armandia* sp. on the tidal flats of the Kasai area

by the polychaetes *Neanthes japonica*, *Neanthes succinea*, and *Diopatra sugokai* and the bibalve *Mactra veneriformis*, which were less abundant on the western beach than on the eastern beach.

It might be that the western beach has a smaller area of tidal flat and steeper slopes than the eastern beach and that the southward waves occurred mainly in summer, which directly affected the stability, consequently disturbing the habitat of benthic organisms in the area.

It is worthy of note that some effects on benthic organisms in the eastern beach would be expected from waters of Edogawa River, as the survey shows the increase of individuals of *Corbicula japonica*, *P. japonicus*, and *Macrophthalmus japonicus* and the decrease of *R. philippinarum*.

To summarize, the tidal flat, including the artificial beach in the park area, might maintain its function as a beach, in spite of the pollution around the park.

As for the artificial beach, it is important for the preservation of the tidal flat to first solve the Edogawa River drainage problems on the eastern beach and the stability problem of the western beach.

Survey of Seawater Temperature and Salinity

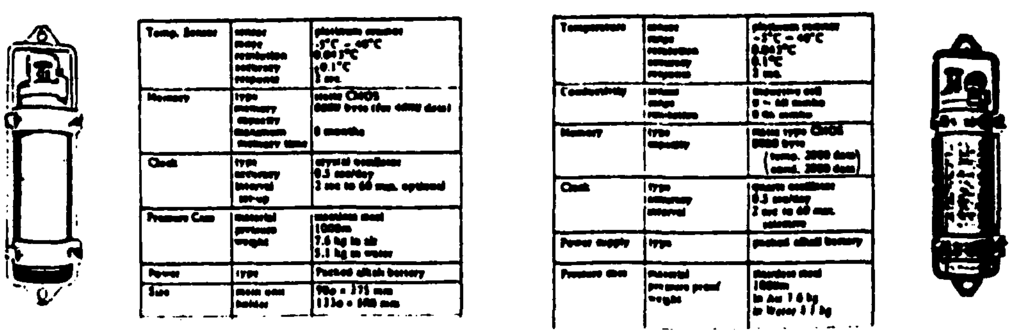
Since the park is located between the mouths of the Arakawa and Edogawa Rivers, the fluctuation of environmental conditions, especially seawater temperature and salinity, might affect the growth and distribution of the organisms inhabiting the tidal flats around the park.

It is very difficult, however, to determine the fluctuation of the abiotic environmental factors in tidal flats because of their complex topographical characteristics and the rapid temporal changes.

The automatic salino-thermometer with memory function was used in the survey, rather than ordinary water samplers or the electrical salinometer, to determine the fluctuation of temperature and salinity at the representative sampling station.

Methods

Salino-thermometers (Figure 9) were located in the bottom sediment and exposed to seawater (Figure 10) to determine the water quality nearest the benthic organisms at the sampling stations shown in Figure 11. At two of the three stations, the apparatus was placed at 5 and 10 cm beneath the bottom surface to expose their sensors.



T-4000 CT-2000

Figure 9. Salino-thermometers with memory function

Five surveys were conducted between May and September 1986 (each with 10-min intervals).

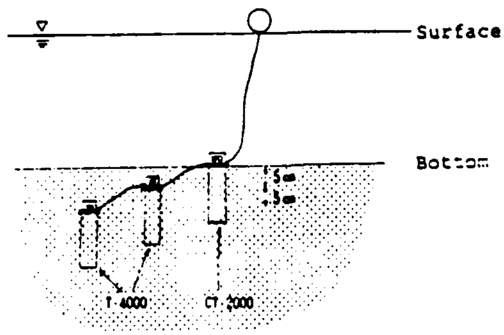


Figure 10. Placement of the salino-thermometer

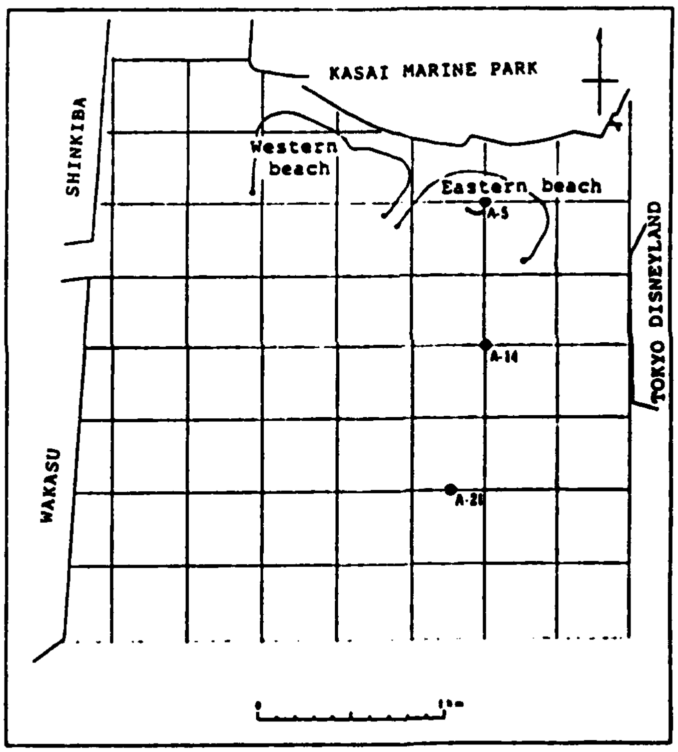


Figure 11. Sampling stations for survey of seawater temperature and salinity, Kasai area

Results

Figures 12 and 13 show the fluctuations of seawater temperature and salinity at each station. Both temperature and salinity fluctuated less farther from the mouth of the rivers. The temperature 10 cm from the bottom did not change as sharply as that at the bottom (Figure 14).

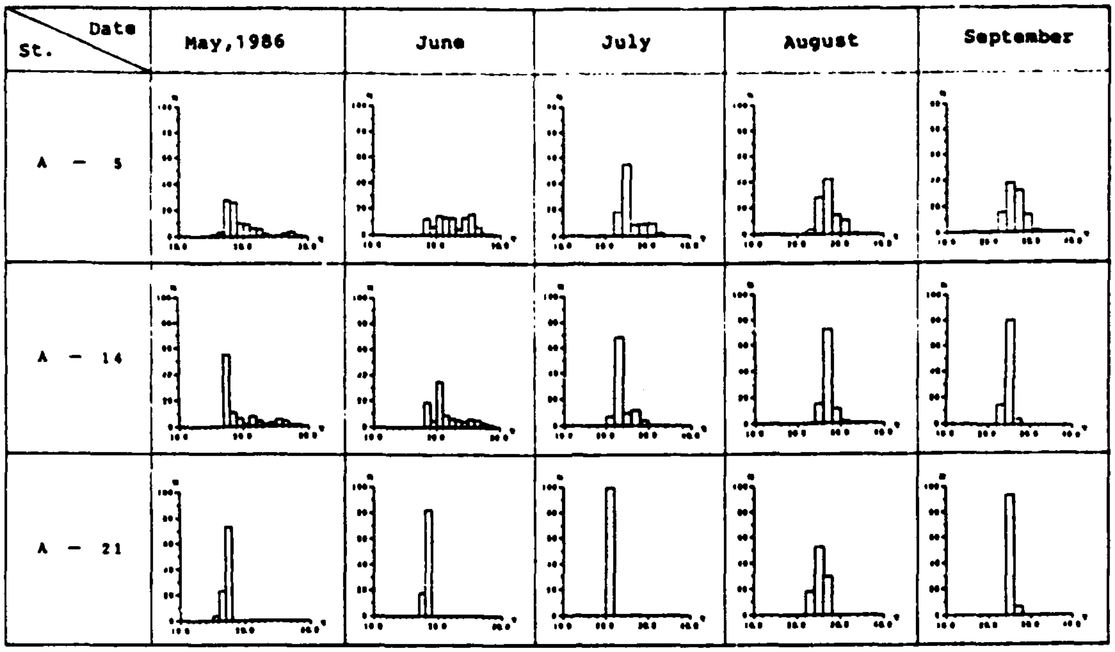


Figure 12. Fluctuations of seawater temperature at sampling stations

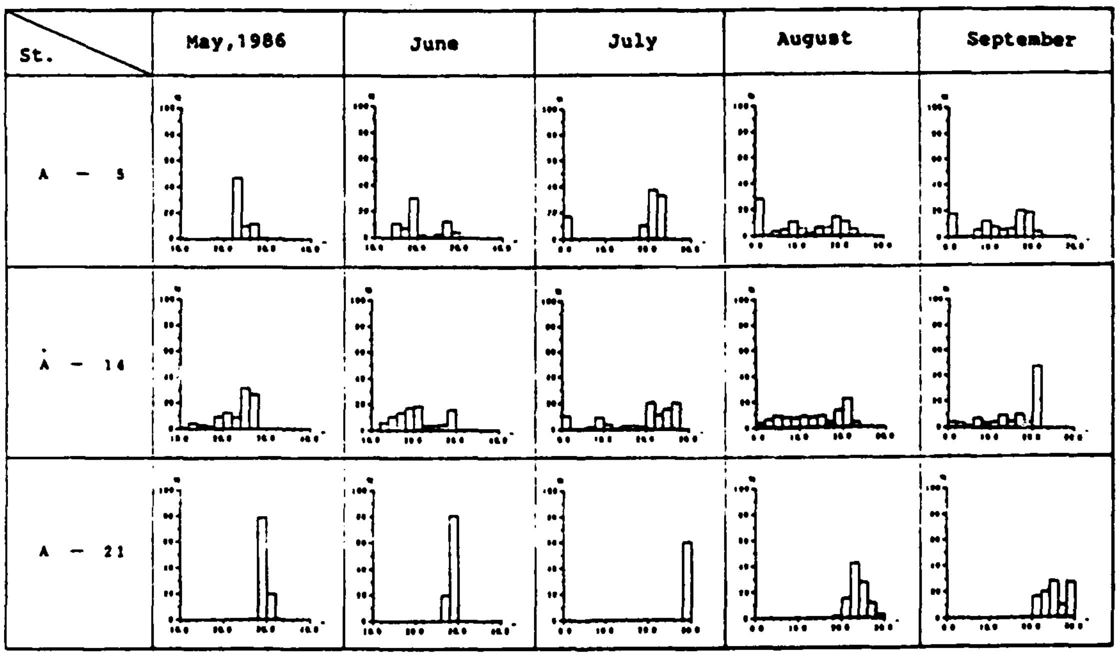


Figure 13. Fluctuations of salinity at sampling stations

Mixing rates of river and seawater based on the chlorine concentration of Edogawa River water, measured at a point 3 km from its mouth (Table 1), showed a 2 to 1 ratio of riverwater to seawater near the mouth of the river, though a 1 to 0.3 ratio of those far from the mouth. The dilution rates at the two stations were 0.7 except in July. These data suggest that river turbulence was not demonstrated during the survey periods.

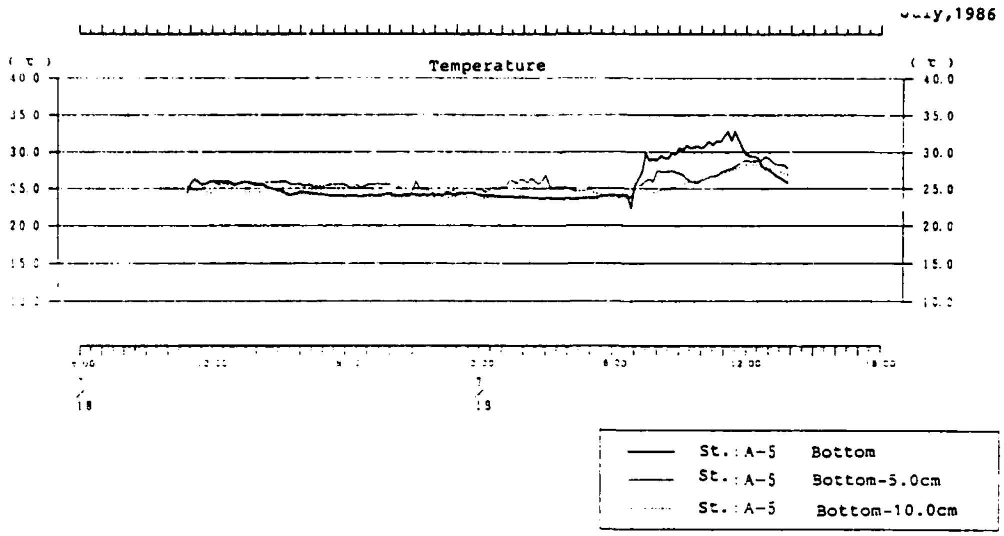


Figure 14. Temporal changes of seawater temperature at the stations at depths of 0, 5, and 10 cm

Figure 15 shows the distribution of the clam *R. philippinarum*, as a representative benthic organism in the area. Large quantities of this clam have been found fairly near the beach in spring and offshore in summer.

Table 2 shows the frequency of the seawater mass with specific gravity lower than 1.015 at each station. It was suggested that the distribution of clams in the area is controlled by the density of seawater, not by the properties of benthic substrate composition, as generally considered. This was based on the decrease of seawater density that was found at the stations near the mouth of the river in summer and the fact that the particle distribution of bottom samples did not agree with the distribution of clams collected coincidentally.

Park Usage Survey

The western beach will be used for shell gathering and for a fishing area, while the eastern beach will be used for natural environment preservation, after the opening. The surveys were made to obtain baseline data for future use.

Methods

Monthly surveys were made of the number of boats, users, and fishing methods used in the park area at daytime low water on each holiday from April 1986 to March 1987. Questionna' ' were used to record data on the age, sex, and visiting time of users from April to December 1986.

TABLE 1. CHARACTERISTICS OF BOTTOM WATER SAMPLES AT STATIONS A-5, A-14, AND A-21

Station	May Salinity	May Mixing Rate	May Dilution Rate	June Salinity	June Mixing Rate	June Dilution Rate	July Salinity	July Mixing Rate	July Dilution Rate
A-5	16.7	0.51	0.68	14.2	0.42	0.67	17.6	0.54	0.93
A-14	23.0	0.75		19.0	0.62		18.7	0.58	
A-21	29.4	1.00	--	28.7	1.00	--	29.8	1.00	--

Station	August Salinity	August Mixing Rate	August Dilution Rate	September Salinity	September Mixing Rate	September Dilution Rate
A-5	10.8	0.36	0.72	12.2	0.40	0.70
A-14	13.6	0.50		15.8	0.57	
A-21	23.8	1.00	--	25.2	1.00	--

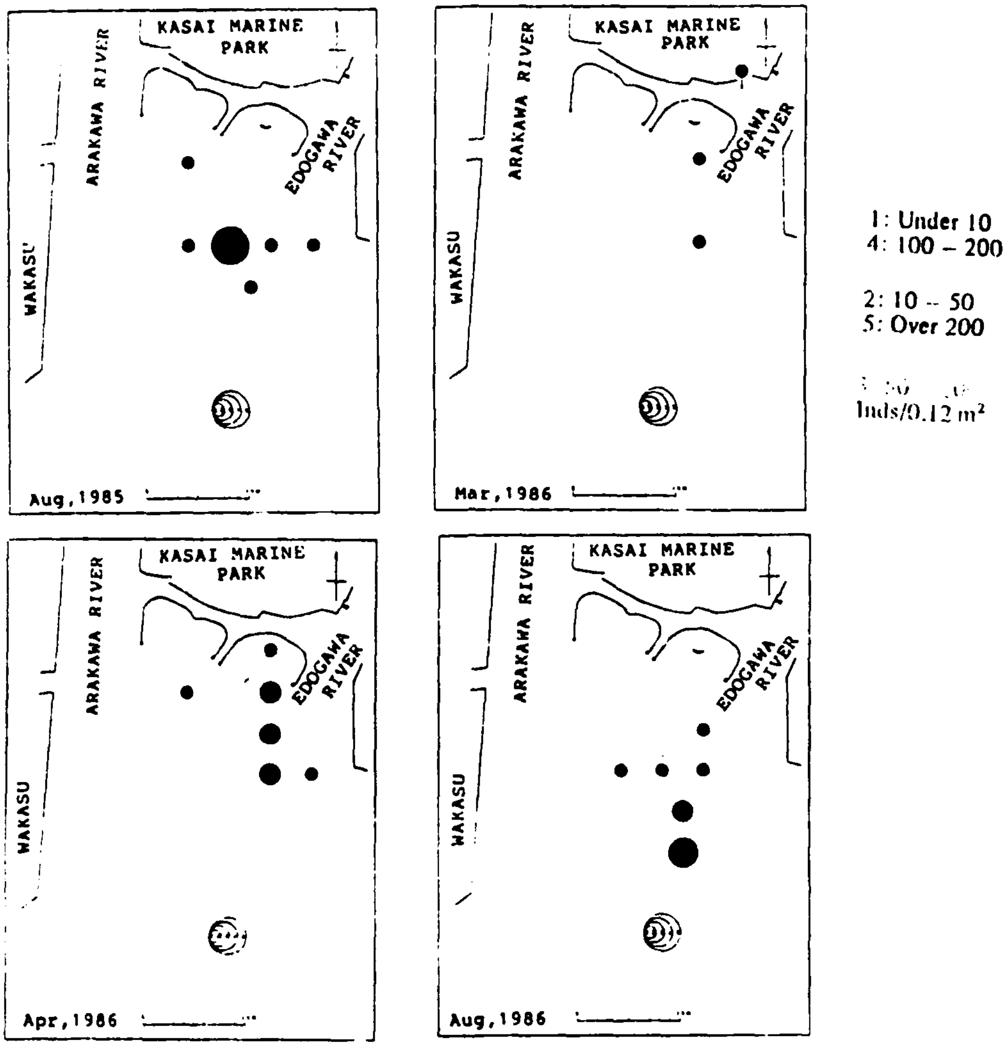


Figure 15. Horizontal distribution of the clam *R. philippinarum* on the tidal flats

TABLE 2. MONTHLY FREQUENCY OF SEAWATER SPECIFIC GRAVITY LOWER THAN 1.015 AT STATIONS A-5, A-14, AND A-21 FROM MAY TO SEPTEMBER 1986

	Station, %			
Date	A-5	A-14	A-21	Average, %
May	4.5	33.3	0.0	13.5
June	72.2	71.8	0.0	44.3
July	100.0	56.9	0.0	48.8
August	100.0	100.0	56.7	84.1
September	100.0	100.0	37.3	77.6

Results

Three rainy days occurred during the 12 monthly surveys. However, these probably had little effect on fishing use since the precipitation was <0.5 mm. Winds were calm on all survey days, except in April 1986, when the wind was approximately 10 m/sec.

Figure 16 shows the boats counted in the park area along with the shell gatherers on the Sanmaizu tidal flats. After that time, boats in general

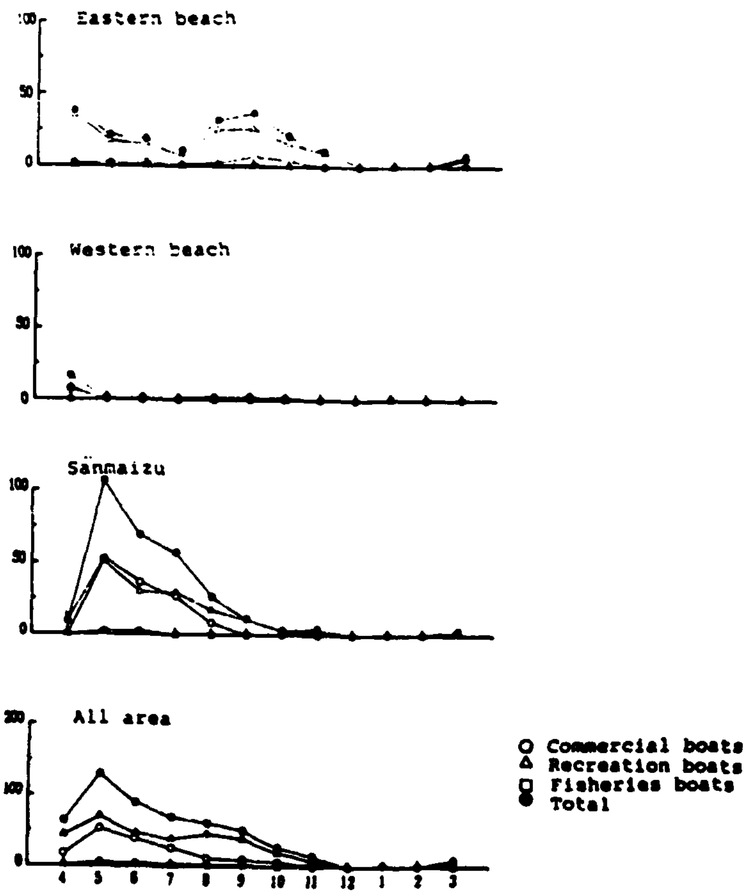


Figure 16. Monthly numbers of commercial, recreational, and fisheries boats

appeared fewer, with commercial boats (such as ferry boats) being counted more at specified periods than recreational boats. Around the artificial beach, 38 boats appeared near the eastern beach while only a few were seen near the western beach, except in April.

Though not in the park area, many boats fishing for the common brackish goby, *Acanthogobius flavimanus*, appeared at the mouth of the Edogawa River from September to November; also, several boats were resting on the artificial beach.

Table 3 shows that users appeared more on the Sanmaizu from April to August, but more on the eastern beach after August. (See Table 4 for monthly frequency of visitors during the period April-December 1986.)

The questionnaire data indicated that users aged 30 to 40 appeared more and also that many families visited the park from April to June, so that lower ages increased. Users from Tokyo were dominant, followed by users from Saitama or Chiba Prefecture.

As for the fishing methods, we observed the use of gill nets, tow nets, dredges for clam gathering, brush traps, and pot traps, which were used near the artificial beach.

Counts of users in the park area revealed that, at present, most users visited the eastern beach or the Sanmaizu, which is planned for development for conservation, while only a few visited the western beach, which is planned for recreational development. Further investigations are considered necessary for management and the maintenance of the park area before completion of the western beach.

CONSIDERATIONS FOR THE FUTURE

Investigation of the fauna around the Kasai Marine Park, with regard to fish distribution (Nakamura 1960) and shells collected at Sanmaizu tidal flat (Suzuki 1971), has been included as part of the working report on the fishery area of the Bay of Tokyo. The results have shown that sites around the park were leading fishing areas in Japan until 1960, with a plentiful commercial fishery including molluscs such as *R. philippinarum*, *Meretrix meretrix*, *Anadara subcrenata*, *Anadara broughtonii*, *Lateolabrax japonicas*, and *Sillage sihama*.

The pollution of the inner parts of the Bay of Tokyo, however, has been accelerated, mainly by the rapid industrial development and reclamation of lands around the Bay since the 1960s. Such conditions have continued to the present, with a peak in 1970, causing increased anaerobic conditions in the fishing area accompanied by red tides, hypoxia, and abiotic area, which prevent the growth of organisms in the bay.

Therefore, this area has gradually decreased as an effective fishery and has experienced a decline in biological productivity. This decline might be supported by the report that the commercial shell fishery in the bay has decreased because of the mass mortality of the clams *R. philippinarum* and *M. meretrix* in summer and autumn (Tamura 1970).

Recently, recognition has been given to the important roles of tidal flats, not only as resting areas for migrating birds and as the nursery grounds of fish fry, but also for their notable capacity for self-purification. Also, because most of the tidal flats are situated near the cities, the areas are likely to be affected by human activities.

Figures 17-19 show the sampling stations and the profiles of total sulfur and chemical oxygen demand (COD) of the bottom samples in the inner parts of the bay. The bottom conditions around the park have remained relatively good

TABLE 3. MONTHLY FREQUENCY OF BOATS AND PERSONS VISITING THE KASAI PARK AREA, APRIL 1986 - MARCH 1987

Parameter	Sunday 27 Apr	Sunday 11 May	Sunday 8 Jun	Sunday 20 Jul	Sunday 24 Aug	Sunday 7 Sep	Sunday 5 Oct	Monday 3 Nov	Sunday 7 Dec	Sunday 18 Jan	Sunday 15 Feb	Sunday 15 Mar
Wind												
Direction	SE > SW	NW > SW	SE > SSW	E > ENE	NNE > SE	NNE > S	NNW > ENE	NNW > SE	NNE > NNW	NNW > N	NNW > SSE	NNW > SE
Velocity, m/sec	1.2 ~ 9.5	0.5 ~ 3.7	1.7 ~ 3.6	2.6 ~ 4.4	2.2 ~ 3.6	1.3 ~ 3.2	3.4 ~ 6.2	0.9 ~ 2.2	1.6 ~ 9.3	3.0 ~ 4.5	1.4 ~ 3.9	2.0 ~ 6.9
Boats												
Eastern beach												
Commercial	2	0	3	0	3	8	5	0	0	0	0	0
Recreational	35	18	16	9	27	27	16	10	1	1	0	6
Fisheries	1	3	0	2	2	2	0	1	0	0	0	1
Subtotal	38	21	19	11	32	37	21	11	1	1	0	7
Western beach												
Commercial	7	0	0	0	0	2	2	0	0	0	0	0
Recreational	9	1	0	0	1	1	0	0	0	0	0	0
Fisheries	0	0	1	1	1	0	0	0	0	1	0	0
Subtotal	16	1	1	1	2	3	2	0	0	1	0	0
Sanmaizu												
Commercial	9	53	36	27	9	0	0	0	0	0	0	0
Recreational	0	51	30	30	18	11	4	0	0	0	0	3
Fisheries	0	3	3	0	0	0	0	4	0	0	0	0
Subtotal	9	107	69	57	27	11	4	4	0	0	0	3
All areas												
Commercial	18	53	39	27	12	10	7	0	0	0	0	0
Recreational	44	70	46	39	46	39	20	10	1	1	0	9
Fisheries	1	6	4	3	3	2	0	5	0	1	0	1
Subtotal	63	129	89	69	61	51	27	15	1	2	0	10
No. of users												
Eastern Beach	70	80	220	20	125	250	120	20	1	2	0	26
Western Beach	100	2	1	1	3	40	24	0	0	1	0	0
Sanmaizu	200	1,200	1,500	600	156	40	4	4	0	0	0	8
Other	10	30	60	26	90	63	54	23	0	0	0	0
Total	380	1,312	1,781	647	374	393	202	47	1	3	0	34

TABLE 4. MONTHLY FREQUENCY OF VISITORS TO KASAI PARK, APRIL-DECEMBER 1986

Date	First-Time Visitor	1-2 Visits/ Year	3-4 Visits/ Year	5+ Visits/ Year	Total	Total No. Users
27 Apr						
Number	8	5	1	5	19	380
Percentage	42.1	26.3	5.3	26.3	100	
11 May						
Number	14	3	4	5	26	1,312
Percentage	53.8	11.5	15.4	19.2	100	
8 Jun						
Number	13	3	4	5	25	1,781
Percentage	52.0	12.0	16.0	20.0	100	
20 Jul						
Number	14	3	4	1	22	647
Percentage	63.6	13.6	18.2	4.5	100	
24 Aug						
Number	3	12	3	8	26	374
Percentage	11.5	46.2	11.5	30.8	100	
7 Sep						
Number	1	1	4	3	9	393
Percentage	11.1	11.1	44.4	33.3	100	
5 Oct						
Number	0	0	0	1	1	202
Percentage	0.0	0.0	0.0	100.0	100	
3 Nov						
Number	1	0	0	3	4	47
Percentage	25.0	0.0	0.0	75.0	100	
7 Dec						
Number	0	0	0	0	0	1
Percentage	--	--	--	--	--	

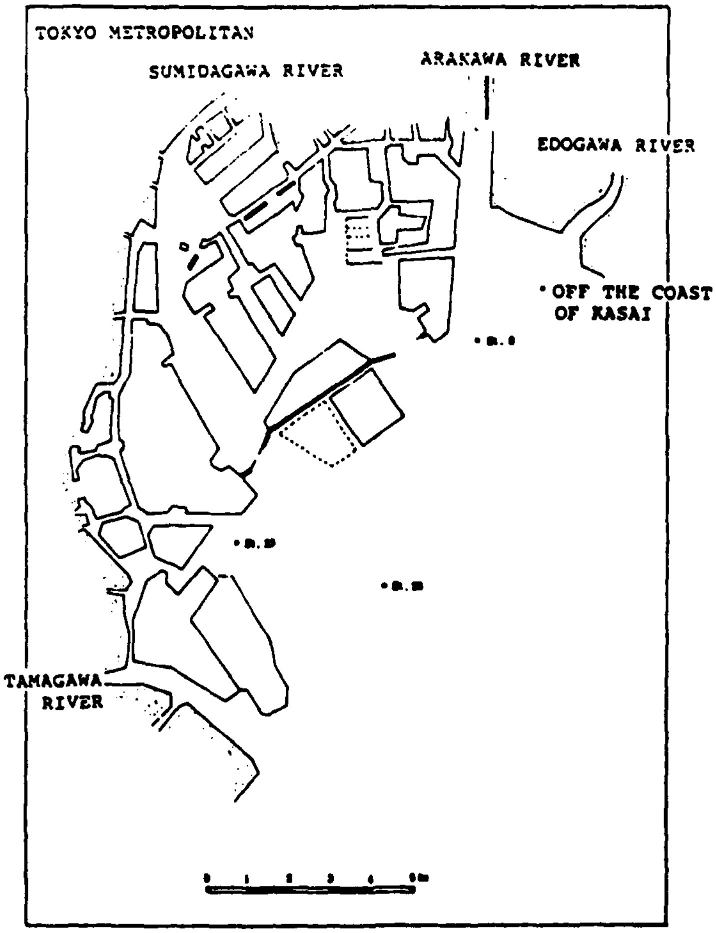


Figure 17. Sampling stations for sulfur and COD

compared with other areas of the Bay. Although the commercial fishing activities have been severely affected, the area around the park has not declined to the extent that inhabiting organisms have become extinct.

The artificial beach of Kasai Marine Park is scheduled for completion in 1988. This area will provide recreational facilities for the metropolitan residents (approximately 120 million people) and will preserve the sole tidal flat remaining in the region. To satisfy these two purposes, balanced management of the park is of extreme importance.

The expansion of the Sanmaizu tidal flat is predicted to recede toward the coast over time (see Figure 20). A tremendous decrease has been observed in the abundance of short-necked clams, *Ruditapes philippinarum*, and the common brackish goby, *Acanthogobius flavimanus*, compared with numbers from 1970. Therefore, it will be a significant future objective to establish suitable survey methods for dealing with these situations and to properly manage the park.

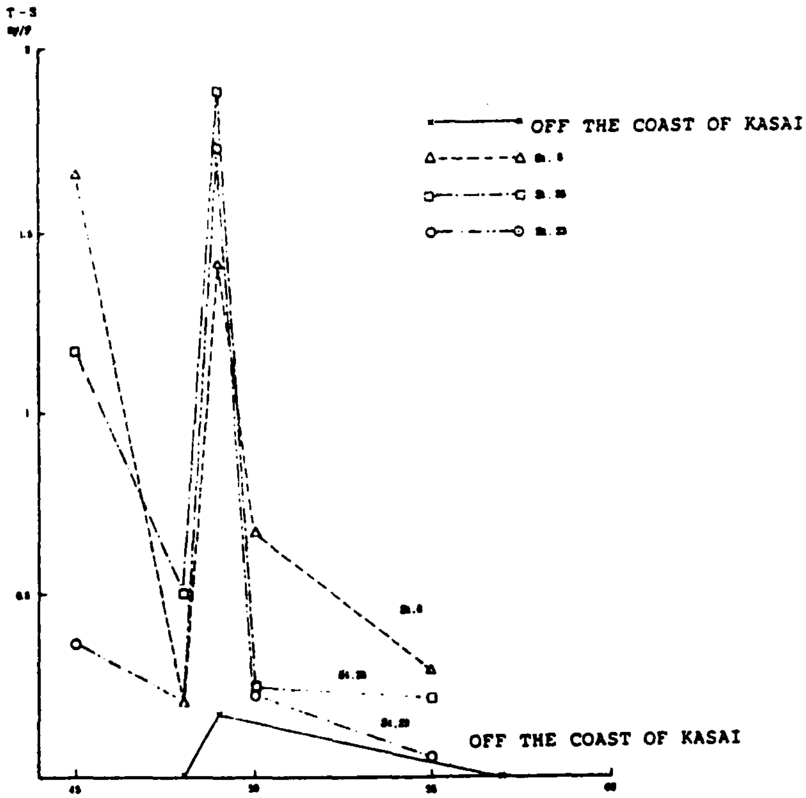


Figure 18. Annual fluctuation of total
sulfur contents in sediment

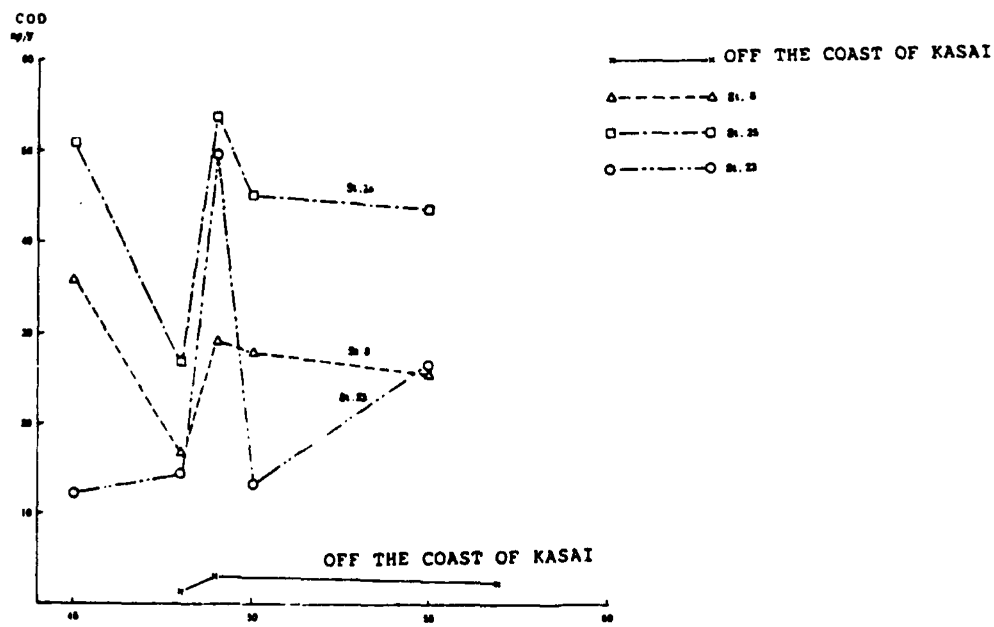


Figure 19. Annual fluctuation of COD in sediment samples

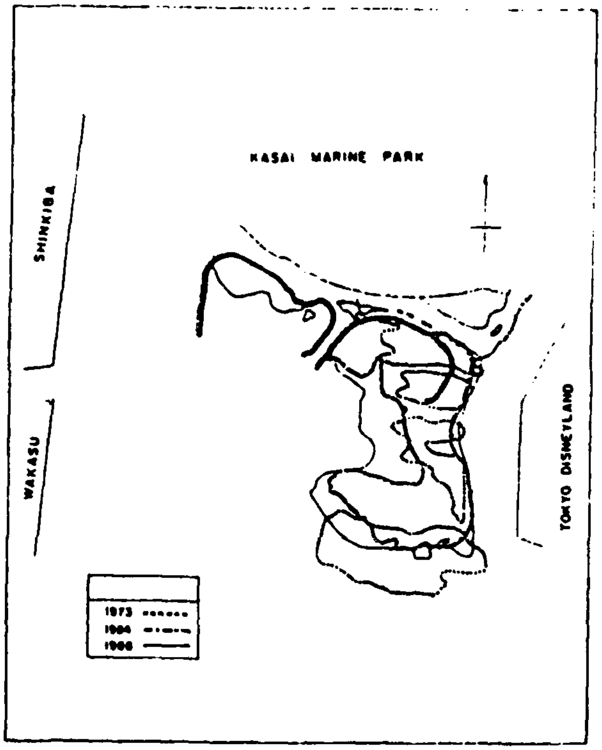


Figure 20. Annual fluctuation of the Arakawa Point Zero Meter contour

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VOLUME CHANGE PREDICTION OF PUMP-DREDGED CLAYEY SOILS

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ABSTRACT

In the disposal of dredged material in reclamation areas, the relationship between the volume of the dredged soil and the volume of the reclamation area must be rectified for proper disposal.

This report describes the results of a study on the state of sedimentation of soil particles and the state of consolidation of deposited soil for a tested reclamation area, an analytical method for self-weight consolidation of deposited soil, a comparison between the measured and theoretical results for an indoor deposition model, and a simple method for predicting the required volume for a reclamation area.

INTRODUCTION

In the disposal of soft, diluted dredged materials into reclamation areas using a dredging pump, the relationship between the volume of the dredged soil and the volume of the reclamation area needed to confine the slurry must be rectified. This will ensure that the planned height and the actual thickness of the deposited soil layer after disposal are the same. In estimating the height of the deposited layer, a number of geotechnical problems remain to be solved. At present, it does not seem possible to make an acceptable prediction of the thickness of the deposited soil layer (Koba and Miyake 1985).

The following problems have been identified: (a) the phenomenon of separate deposition in the reclamation area, (b) the method of analysis used for self-weight consolidation of deposited soil in the continuous deposition process of soil particles, and (c) the identification of the consolidation characteristics of deposited soil in the low-stress region.

In the study of the sedimentation of dredged cohesive soil and the characteristics of the deposited soil, experiments are conducted primarily using one-dimensional settling containers (Yano, Tsuruya, and Yamauchi 1984; Yano, Imai, and Tsuruya 1977). A dilute soil-water mixture with the water content adjusted to a prescribed value is placed in a cylindrical container, the contents are agitated, and settling of the soil particles is observed. From the ensuing process of self-weight consolidation, the characteristics of consolidation of the deposited soil are determined. While this method has merits--the experiment is simple and only a small sample is required--it also has demerits. The phenomena as they occur in an actual reclamation area cannot be correctly reproduced, because the reclamation area allows for expansion in three dimensions, whereas the model allows only one-dimensional expansion. To more correctly reproduce the settling state onsite, the study described herein used a two-dimensional deposition model (Watari, Shinsha, and Amiboshi 1936).

Terzaghi (1942) made it clear for the first time that the consolidation phenomenon of clay can be analyzed. During the reclamation of Osaka South Port, Mikasa (1963) analyzed the consolidation in the cohesive soil formed by disposal of dredged soil and pointed out that, in analyzing the consolidation of soft and weak clayey ground, it is necessary to take into consideration: (a) the influence of self-weight, (b) a nonlinear stress-strain relationship (the change in the coefficient of permeability with stress), and (c) the changes in layer thickness. He proposed a consolidation equation that takes these factors into consideration. Other methods, such as those of Gibson England, and Hussey (1967) and Monte and Kkizek (1967) have also proposed consolidation equations that take these three factors into consideration. On the other hand, as a result of the rapid progress of finite element method (FEM) analysis since its introduction in recent years, it has become possible to solve the consolidation problem by using a solution to Biot's consolidation equation (Sandhu 1982; Yokoo, Yamagata, and Nagaoka 1971). In this paper, the influence of self-weight, the nonlinear relationship between stress-strain, the change in the coefficient of permeability with stress, and the changes in layer thickness are investigated using FEM analysis (Watari et al. 1984), along with a comparison between the analytical and experimental results.

Lastly, a prediction diagram for the thickness of the deposited soil layer formed by dredging, prepared from the results of the analysis of self-weight consolidation of the deposited soil, is shown, and interpretation of the diagram is discussed.

SEDIMENTATION AND CONSOLIDATION OF SOIL PARTICLES IN THE RECLAMATION AREA

When dredged material is disposed in a reclamation area, the result is:

a. Because the dredged soil is diluted with a large volume of seawater at the dredge suction port and in the discharge pipe, the initial soil structure of the dredged soil is destroyed, and slurry is created with a water content at the outlet of the discharge pipe ranging from about 500 to 2,000 percent.

b. When the soil-water slurry is disposed in the reclamation area, it is again diluted by seawater in the reclamation area, and soil particles are transported to other parts of the reclamation area by the currents generated from the disposal process.

c. During this transportation process, the soil particles form flocs, which settle out.

Some sample investigations on actual reclamation areas are described below. Figure 1 shows an aerial view of the dredging and reclamation work conducted in Yanai in Yamaguchi Prefecture. The dredging was conducted in the anchorage area and the gut area (see Figure 1). The results of preliminary soil surveys showed that the dredged soil contained a large amount of sand,

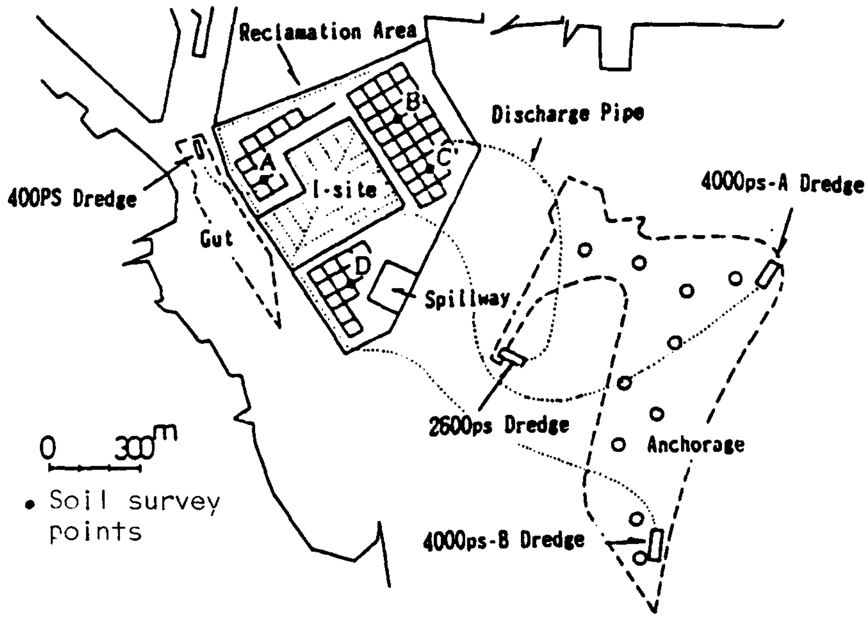


Figure 1. Aerial view of dredging and reclamation area

about 60 percent in terms of weight. The total volume of dredged soil was 2,400,000 m^3, and dredging was done with four pump dredges over a period of about 8 months.

To examine the settlement of soil particles during disposal and the changes in soil properties resulting from consolidation of the deposited soil, a stationary floating platform was set up at the four points (A, B, C, and D in Figure 1) in the reclamation area. Samples were taken at 0.5-m intervals from the water surface. The water and sand contents of samples from site D are plotted in Figure 2. For those results where the water content (W) was higher than 1,000 percent, the turbidity (T_b) was measured and converted into concentration of suspended solids (SS), and the water content was obtained from the following equation:

$$W = \frac{10^8 \cdot \gamma_w}{SS} \; (\%) \tag{1}$$

where γ_w is the unit weight of water.

The result $W < 1,000$ percent was obtained by compensating the results obtained by the drying method (JIS A 1203) (Imai, Tsuruya, and Yano 1979) for salinity. From Figure 2, a comparison of the point where the water content is nearest to 1,000 percent and a point 50 cm higher (one measuring point higher) shows that the water content increases to 10^5 to 10^6 percent for a decrease in depth of only 50 cm, a rapid increase of 1 to 2 orders. In view of the fact that the condition $W < 1,000$ percent represents deposited soil and the condition $W < 10^5$ percent represents suspension, the deposition surface that

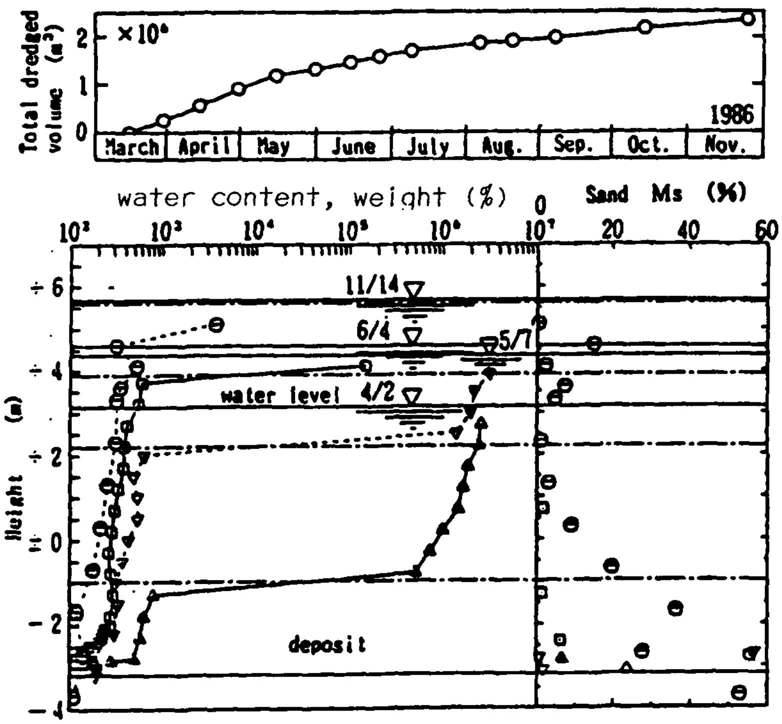


Figure 2. Measured water and sand contents (at site D)

is the interface between the two conditions should be located in this layer at a depth of 50 cm. Imai (1980) classified the soil particle settlement in seawater into three categories according to the observations from an indoor settling experiment. These categories are consolidation settling, interface settling, and flocculated free settling. If this classification is applied, flocculated free settling is occurring at the present site. This flocculated free settling is defined as the state in which the clay particles form flocs, which freely settle without interfering with each other.

As is evident from Figure 2, with the continuous disposal of dredged material, the level of the deposited soil surface rises gradually. On the other hand, the water content in the deposited soil layer decreases. This decrease in water content is attributed to the progress of self-weight consolidation.

METHOD OF ANALYSIS FOR CONSOLIDATION OF SOFT CLAY LAYER

Consolidation Analysis by Finite Element Method

When consolidation of an elastic body in analyzed by FEM, the five basic equations shown below are used to formulate the finite element.

Equation for equilibrium

$$\frac{\partial(\sigma - \gamma_w \cdot h)}{\partial z + F} = 0 \tag{2}$$

Equation for stress-strain

$$\frac{\partial\sigma'}{\partial\varepsilon} = E(\sigma') \tag{3}$$

Equation for strain-displacement

$$d\varepsilon = \frac{d_e}{(1 + e)} \tag{4}$$

Equation for void fluid motion (Darcy's law)

$$v = \frac{k\ \partial h}{\partial z} \tag{5}$$

Equation for assumed continuity

$$\frac{\partial\varepsilon}{\partial t} = \frac{-\partial v}{\partial z} \tag{6}$$

where

σ = total stress

h = water head

z = vertical coordinate in three dimensions

F = weight of unit volume of soil

σ' = effective stress

ε = strain

E = modulus of elasticity

e = interstitial ratio

v = flow speed of interstitial fluid

k = coefficient of permeability

Now to obtain a solution that satisfies basic Equations 2 through 6, introducing a functional based on the variational principle and rearranging the equations on the assumption that the first variation of the functional has a stationary value, we obtain the following equation:

$$\begin{aligned}(K)(u) + (C)(h) &= (R)\\ (C)^T(\dot{u}) + (H)(h) &= 0\end{aligned} \tag{7}$$

where

(K) = transformed rigidity matrix

(u) and (h) = node displacement and water head at node, respectively

(C) = coupling matrix

(R) = external force

$\cdot$ = differential with respect to time

(H) = permeability matrix

However, since Equation 7 has a time differential term, it is difficult to formulate Equation 7 as it is. Hence, integrating the lower Equation 7 with respect to t and using the integral approximation of Equation 8 called the α - algorithm (Nakanodo 1984), we obtain

$$\int_{t_0}^{t_1} h(\tau)d\tau = \Delta t[\alpha h_1 + (1 - \alpha)h_0] \tag{8}$$

Equation 7 can be rearranged as follows:

$$\begin{bmatrix} K, & C \\ C^T, & -\alpha\Delta t H \end{bmatrix} \begin{bmatrix} u_1 \\ h_1 \end{bmatrix} = \begin{bmatrix} R \\ C^T\ u_0 + (1 - \alpha)\Delta t H h_0 \end{bmatrix} \tag{9}$$

where suffixes 0 and 1 represent the values when $t = t_0$ and $t_0 + \Delta t$, respectively.

When only the self-weight consolidation of clay is considered, the initial water head h_{0_i} at each node occurring due to the self-weight can be obtained from Equation 10.

$$h_{0_i} = \frac{\gamma'_0 z_i}{\gamma_w} \tag{10}$$

where

γ'_0 = initial weight of unit volume of submerged clay

z_i = depth from ground surface to node i

When this h_{0_i} is obtained prior to the consolidation calculation, and assuming that an excess water head of h_{0_i} is present in the initial stage, Equation 9 can be rearranged as follows:

$$\begin{bmatrix} K, & C \\ C^T, & -\alpha\Delta tH \end{bmatrix} \begin{bmatrix} u_1 \\ h_1 \end{bmatrix} = \begin{bmatrix} K,C & \\ C^T, & (1-\alpha)\Delta tH \end{bmatrix} \begin{bmatrix} u_0 \\ h_0 \end{bmatrix} \tag{11}$$

The initial (u_0) is a null matrix (all elements 0).

Consolidation is calculated as follows. First, $\left(u_1, h_1\right)^T$ after Δt_1 is obtained by substituting $\left(0, h_{0_i}\right)^T$ at $t = 0$ into Equation 11. Then, $\left(u_2, h_2\right)^T$ at $t = \Delta t_1 + \Delta t_2$ is obtained by replacing $\left(u_1, h_1\right)^T$ at $t = \Delta t_1$ by $\left(u_0, h_0\right)^T$. By repeating this replacement in sequence, the total consolidation process can be obtained. Here, $\alpha = 1$ was adopted in the calculation of consolidation.

Consideration of Nonlinearity

It is known that the stress-strain relationship is not linear (elastic). In a nonlinear analysis of elasticity, therefore, it is necessary to change the modulus of elasticity in discrete steps. However, since the way the modulus of elasticity changes during the consolidation process is unknown, in the present experiment, it was assumed so as to satisfy the conditions of convergence described below.

First, an infinitely small element of finite length Δz_0 in the clay layer is considered, and for the initial state, let us assume that the whole of the clay layer has a uniform interstitial ratio e_0. Then, the excess interstitial water pressure generated by the self-weight of clay will be disturbed linearly as shown in Figure 3. Next, let us assume that the excess interstitial water pressure after Δt hours decreases as shown in Figure 3b, that it was distributed linearly, and that the quantity of the interstitial water pressure that dispersed is converted into effective stress. As a

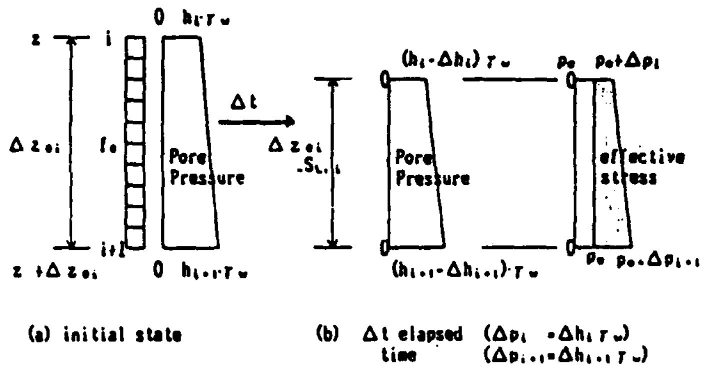


Figure 3. Conceptional drawing of the state of consolidation

result, the effective stress will be distributed $P_0 + \Delta P_i$ at the top end and $P_0 + \Delta P_{i+1}$ at the bottom end. This describes clay elements with a uniform P_0 at the initial stage having different stresses after time Δt. On the other hand, in consolidation analyses by FEM, the modulus of elasticity $E_i(p)$ must be constant within the elements. When this $E_i(p)$ is written as $\overline{E}_i(p)$, $\overline{E}_i(p)$ must be the mean value of the coefficient of elasticity as it varies with the element.

The linear equation log e - log p is used to represent the relationship between the void ratio of clay and the effective stress, as described in the following section:

$$\log e = a + \beta \log p \tag{12}$$

Then, since the modulus of elasticity can be represented by $E(p) = (1 + e)\, dp/de$, the following equation will hold:

$$E(p) = \frac{(1 + e)p}{e\beta} \tag{13}$$

And, let us assume that as a result of giving Δt and $\overline{E}_i(p)$ and calculating the consolidation, the result as shown in Figure 3b was obtained, and that the settling of this element, $S_{L,i}$, can be given as the difference between displacement at node i and node i+1.

$$\Delta S_{L,i} = u_i - u_{i+1} \tag{14}$$

In addition, taking the nonlinearity of the stress-strain relationship into consideration, the settling, $\Delta S_{non-L,i}$ resulting from the increase in the effective stress of this element can be obtained with reference to Figure 4 as follows:

$$\Delta S_{non-L,i} = \int_{z}^{z+z_{0i}} \frac{e_0 - e}{1 + e_0} dz$$

where

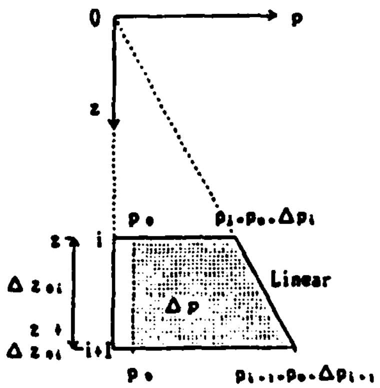
$$dz = \frac{\Delta z_{0i}}{p_{i+1} - p_i} dp$$

Hence,

$$\Delta S_{non-L,i} = \frac{\exp\ (a/0.4343)\Delta z_{0i}}{1 + e_0}\ p_0^{\beta} - \left[\frac{p_{i+1}^{(\beta+1)} - p_i^{(\beta+1)}}{(\beta + 1)(p_{i+1} - p_i)}\right] \qquad (15)$$

By satisfying the condition $\Delta S_{L,i} = \Delta S_{non-L,i}$ in the FEM analysis, nonlinearity of the stress-strain relationship can be considered.

Figure 4. Conceptional drawing of the state of the effective stress



Change in Permeability with Stress

To calculate consolidation, both the coefficient of permeability and the modulus of elasticity are needed. Here, the relationship between coefficient of permeability and stress was assumed to be

$$\log k = b + \xi \log p \qquad (16)$$

Now, supposing that the $e - p$ relationship can be represented by Equation 12 and that the coefficient of permeability can be represented by a function of effective stress, the coefficient of permeability $k_i(p)$ forms a pair with $E_i(p)$. In other words, if $E_i(p)$ is determined, P_i can be found from Equations 12 and 13, and $k_i(p)$ can be obtained by substituting this p_i into Equation 16. Here, $k_i(p)$ and $E_i(p)$ are taken as a pair.

Changes in Layer Thickness

Changes in layer thickness were considered as follows. Settling of the element after time t_1 can be obtained by satisfying the equation $\Delta S_{L,i}(1) = \Delta S_{non-L,i}(1)$ in the consolidation calculation in which Δt_1 is given, where (1) in $\Delta S_{L,i}(1)$ indicates the first time Δt_1 was given, and the decrease in layer thickness was calculated from $\Delta Z_i(1) = \Delta Z_{0_i} - \Delta S_{L,i}(1)$.

In the next consolidation calculation, changes in layer thickness are considered by increasing time Δt , using the layer thickness after deducting the consolidation settling.

A flowchart of the consolidation calculation is given as Figure 5, where

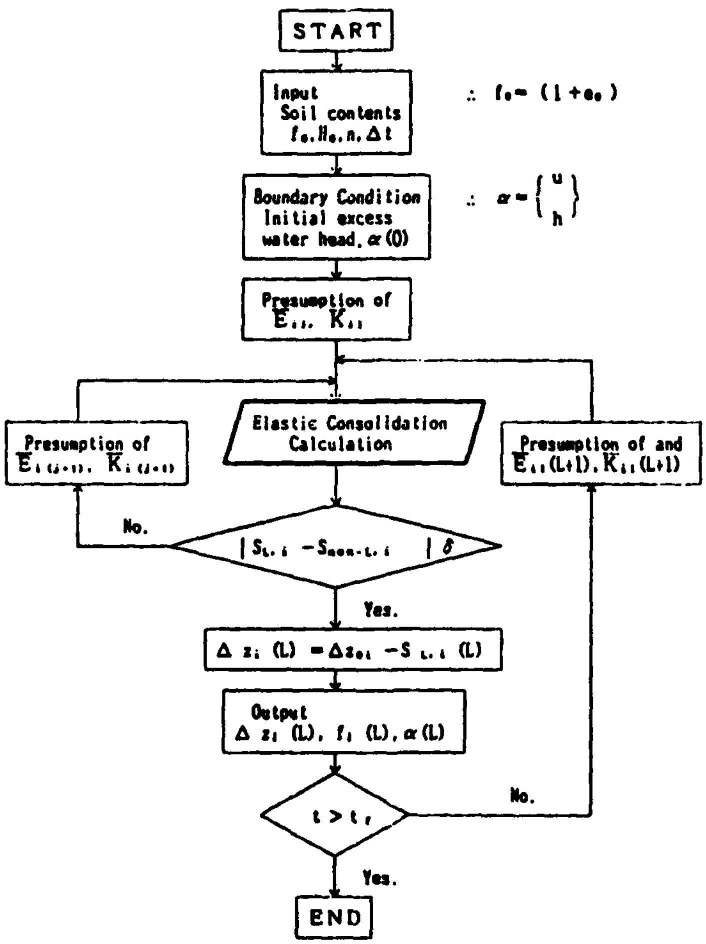


Figure 5. Consolidation calculation flowchart

H_0 represents the initial layer thickness, n is the number of divisions, $f_0 = 1 + e_{0,j}$ (the number of convergence calculations), and i is the number of consolidation calculations.

MEASURED AND THEORETICAL RESULTS FOR TWO-DIMENSIONAL DEPOSITION MODEL

Deposition Test

To identify the state of sedimentation and deposition of soil particles in the reclamation area, tests were conducted using the test equipment shown in Figure 6 and the test conditions described in Table 1.

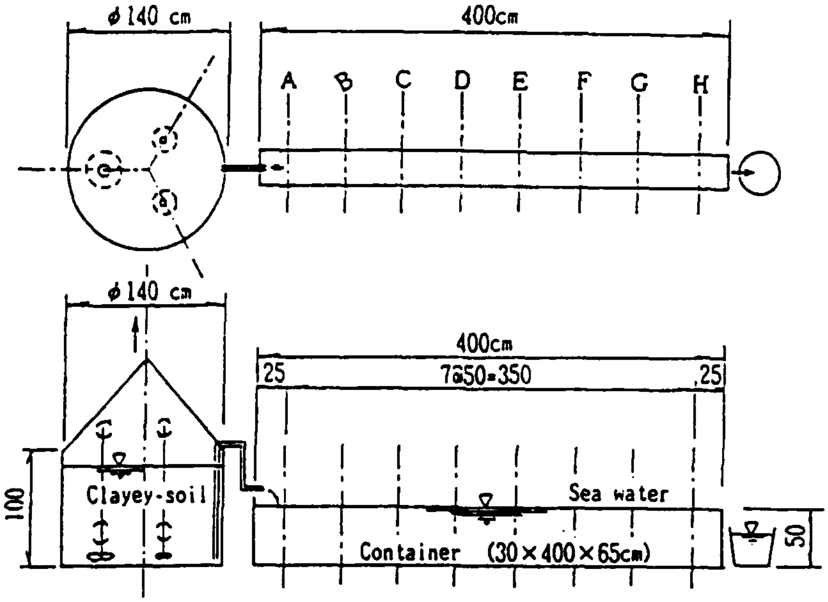


Figure 6. Test equipment

The test equipment consists of a 140-cm-diam × 100-cm-high agitating vessel and a 3-cm (W) × 400-cm (L) and 65-cm (H) depositing vessel. The test was conducted as follows. First, soil and seawater were placed in the agitating vessel and agitated. Then, in that state, the diluted soil-water mixture was siphoned into the depositing vessel at a fixed rate. The agitation is continued during siphoning to uniformly distribute particle sizes throughout the depositing vessel. An overflow weir is built into the end of the depositing vessel to maintain a constant water level in the vessel. The soil sample was prepared by mixing Tokyo Port clay and Toyoura sand at a dry weight ratio of 6:4.

Case I is continuous flow; in Case II, the diluted soil-water mixture was agitated for 6 hr and allowed to stand in the container for 18 hr. This cycle was repeated four times. Toyoura sand was mixed into the sample to examine separation in the dredged soil deposit, but the results (Watari, Shinsha, and Amiboshi 1936) are not described in this report.

Figure 7 and Photo 1 show the water content of the upper suspension and

TABLE 1. SOIL CHARACTERISTICS AND EXPERIMENTAL CONDITIONS*

	G_s	W_L (%)	I_P	Clay (%)	Silt (%)	Sand (%)
Tokyo port mud	2.60	83.3	43.2	57	35	8

	Sample	W_o (%)	q (l/min)	Disposal Condition
Case I	clay;6 +sand;4	1,000	0.712	Continuous
Case II	clay;6 +sand;4	1,000	0.700	Separate

* G_s = specific gravity of solids, W_L = water content at the liquid limit, I_P = plasticity index, and q = flow rate.

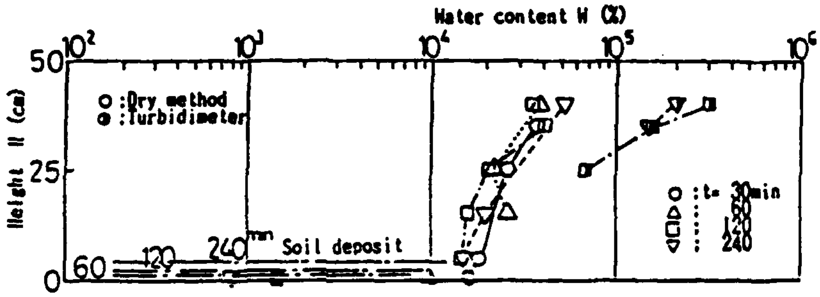


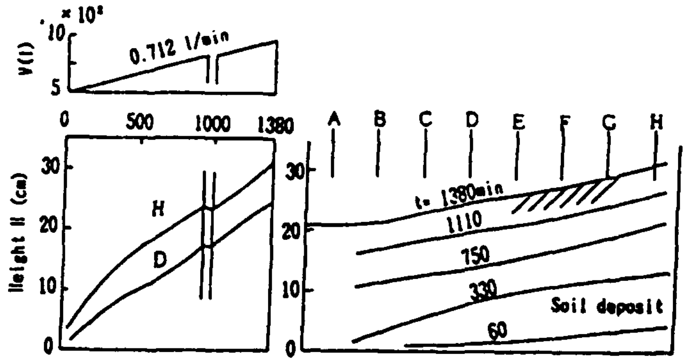
Figure 7. Water content distribution (Case I)

settling of soil particles during the siphoning period. The water content in the suspension showed little change during siphoning, and the deposited soil and suspension are clearly delineated in the photograph. Figure 8 shows the deposition during the siphoning period in Cases I and II.

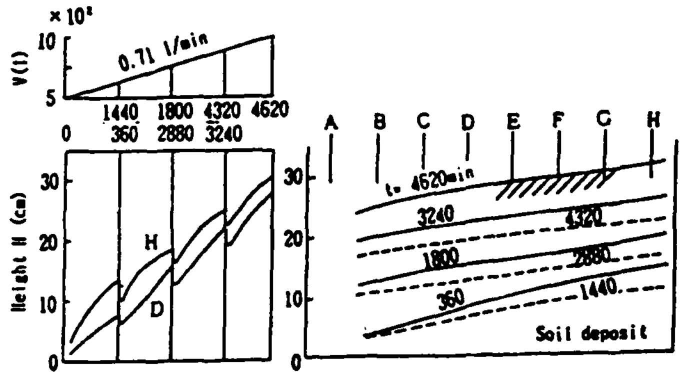
Continuous siphoning of the diluted soil-water mixture increased the deposition level, with the highest level at the end of the container.

Analytical Method

Where soil particles settle and deposit from the suspension phase, Monte and Kkizek (1967) proposed the following concept of the critical state. This concept refers to a phenomenon in which soil is deposited only when soil particles have settled and reached the bottom surface and the effective stress of the soil is generated. Following this concept of critical state and representing the interstitial ratio in the critical state by e* , the consolidation analysis of continuous deposition of soil particles needs only consider the case in which the soil in the state of e* deposits continuously and self-weight consolidation is generated.



a. Case I



b. Case II

Figure 8. State of deposition

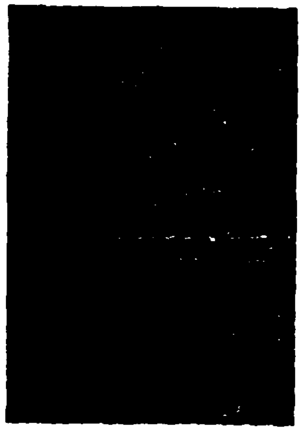


Photo 1. State of sedimentation of soil particles

The following method was used to obtain the value of e^*.

a. Assuming the linearity of $\log e - \log p$, a linear equation that coincides well with the results of consolidation test is obtained.

b. Assuming that the initial e_i is in a uniform state, the distribution of water content where e_i is changed variously is calculated.

c. The results of calculation are compared with the measured result, and the value of e_i closest to the measured result is selected as e^*.

Figure 9 shows the e and p relationship of the deposited soil in the $e - \log p$ coordinates. In the diagram, effective stress of less than 2×10^{-3} kg (force)(kgf)/cm^2 was obtained from the distribution of water content after self-weight consolidation. That is, the interstitial ratio $e = G_s W$ was obtained, and effective stress at the position $z_i = \sum_{j-1}^{i-1} \cdot \Delta z_j + 1/2 \cdot \Delta z_i$ was obtained from Equation 17. The relationship of e and p was plotted on the diagram.

$$p(z_i) = \sum_{j-1}^{i-1} \gamma_j' \Delta z_j + 1/2\ \gamma_i' \Delta z_i \tag{17}$$

The first point near $p = 2 \times 10^{-4}$ kgf/cm² corresponds to the depth about 1 cm from the deposition surface after self-weight consolidation. It was difficult to obtain the $e \sim p$ relationship in the lower stress region.

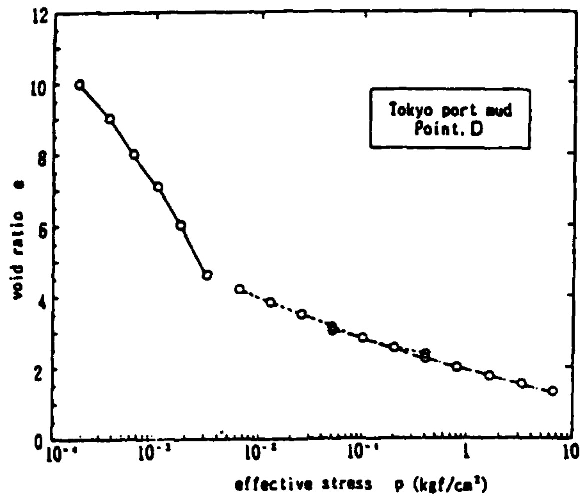


Figure 9. Interstitial ratio-effective stress relationship diagram

The result $3 \times 10^{-3} < p < 0.5$ kgf/cm² was obtained from the consolidation test using seepage force (Imai 1979), and the result $p > 0.5$ kgf/cm², from the standard consolidation t͏ест. As shown in Figure 9, the $e - p$ relationship of clay covering the low-stress region tends to form a convex curve on the $e - \log p$ coordinates. This relationship is shown in the $\log e - \log p$ coordinates in Figure 10. It is considered that an almost

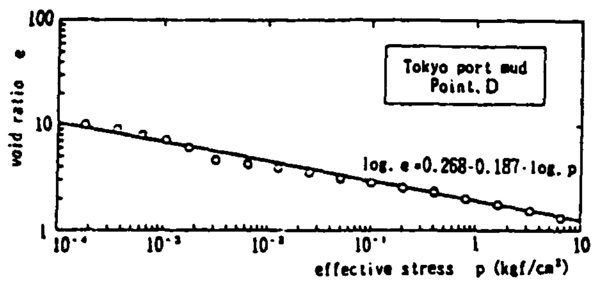


Figure 10. Interstitial ratio-effective stress relationship diagram

linear relationship holds true for the $\log e - \log p$ coordinates. Figure 11 is a comparison of measured and calculated results based on water content after self-weight consolidation at site D. The calculated result in the diagram shows the value, as illustrated in Figure 12, obtained on the assumption that, at depth z, the initial effective stress of clay (p_0) that balances the self-weight of clay is zero. The scattered measured results shown in Figure 11 indicate that the measured and calculated results do not satisfactorily coincide. However, with the gradual increase of e_i, the calculated values of water content after consolidation differ very little. In the calculation of consolidation, $e^* = 16$ is used.

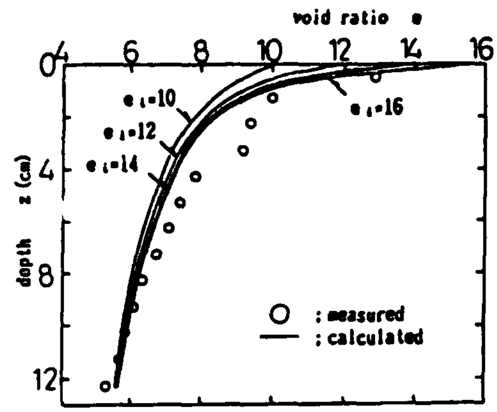


Figure 11. Distribution of void ratio after self-weight consolidation (at site D)

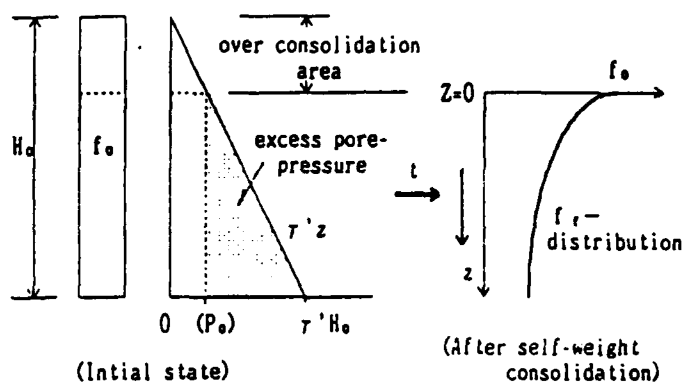


Figure 12. Typical drawing of consolidation load

To calculate consolidation, the depositing rate of the clay in state e^* is needed, together with e^*, $e - p$, and $k - p$ relationships. The depositing rate H^*/t is obtained from the following equation.

$$\frac{H^*}{t} = \frac{\eta \cdot Q_s}{A \cdot t} \cdot \frac{1 + e^*}{1 + e_s} \qquad (18)$$

where

H^* = height of the deposited soil in state e^*

η = volume compensation for separately depositing sand

Q_s = volume of diluted soil-water mixture siphoned over t hours

A = depositing area of clay

e_s = interstitial ratio of dilute soil-water mixture

Comparison Between
Measured and Analytical Results

With respect to site D of the two-dimensional deposition test, soil constants are arranged as follows. For the k - p relationship, the effective stress is obtained in the range of $p > 4 \times 10^{-3}$ kgf/cm^2 only, as shown in Figure 13. This equation of relationship is extended to the low-stress region.

- Interstitial ratio in critical state, $e^* = 16$
- Equation for e - p relationship, $\log e = 0.268 - 0.187 \log p$ (p, kgf/cm^2)
- Equation for k - p relationship, $\log k = -5.333 - 0.796 \log p$ (k, cm/min)
- Depositing rate, Case I, $H^*/t = 1.45$ cm/hr
  Case II, $H^*/t = 1.75$ cm/hr

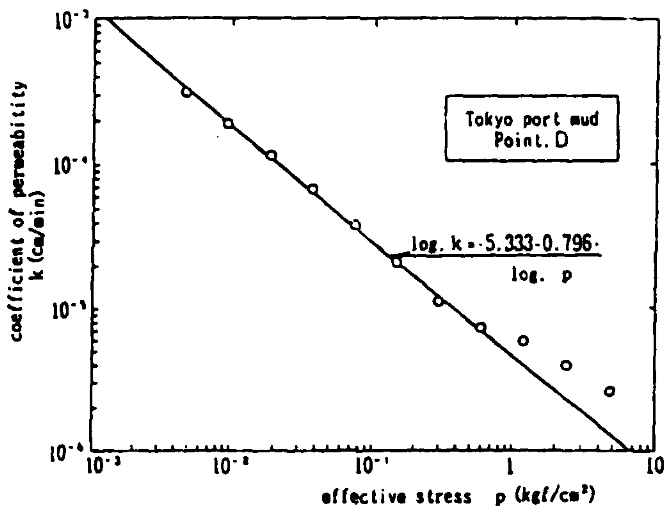


Figure 13. Coefficient of permeability-effective stress relationship diagram

Figure 14 is a comparison between measured values and analytical values for the increasing process of the deposited soil thickness during the disposal period and the ensuing sedimentation with respect to Cases I and II at site D.

In the finite element analysis, the deposition height ΔH^* for $\Delta t = 60$ min was calculated on the assumption that the dredged soil is deposited for 5 min followed by standing for 55 min. Continuous deposition was calculated on the assumption that this cycle of operation continued. In the element-division of ΔH^*, $n = 5$ was used, and the analysis was conducted on the assumption that the total number of elements will increase as clay deposition progresses. As shown in Figure 14, in both Case I and Case II, the measured and calculated results of the process of deposition thickening during the disposal period and the ensuing settling agree very

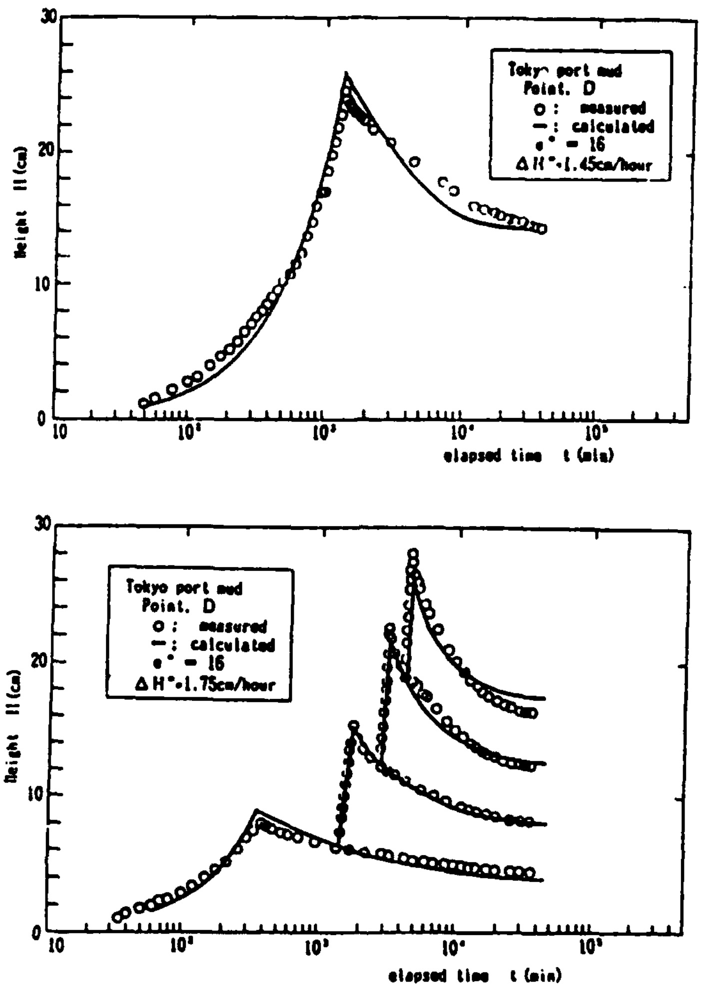


Figure 14. Comparison between experimental and analytical results (Case I)

well. Figure 15 shows, for example, the changes in interstitial ratio in the deposited soil layer with time and the dispersion process of excess interstitial water pressure (calculated result) in Case I.

PREDICTION OF HEIGHT OF DEPOSITED SOIL LAYER

Figure 16 shows the relationship between the volume of dredged material and the volume of the reclamation area. The parameters needed for drafting a dredging and reclamation plan are listed below.

Dredging area -- Total volume of dredged soil, $V_D = A_D \cdot z_D$

Mean interstitial ratio of dredging area, $\overline{e_D}$

Reclamation area -- Area, A_R ; planned deposition height, H_R

Other -- Dredging period, t_D

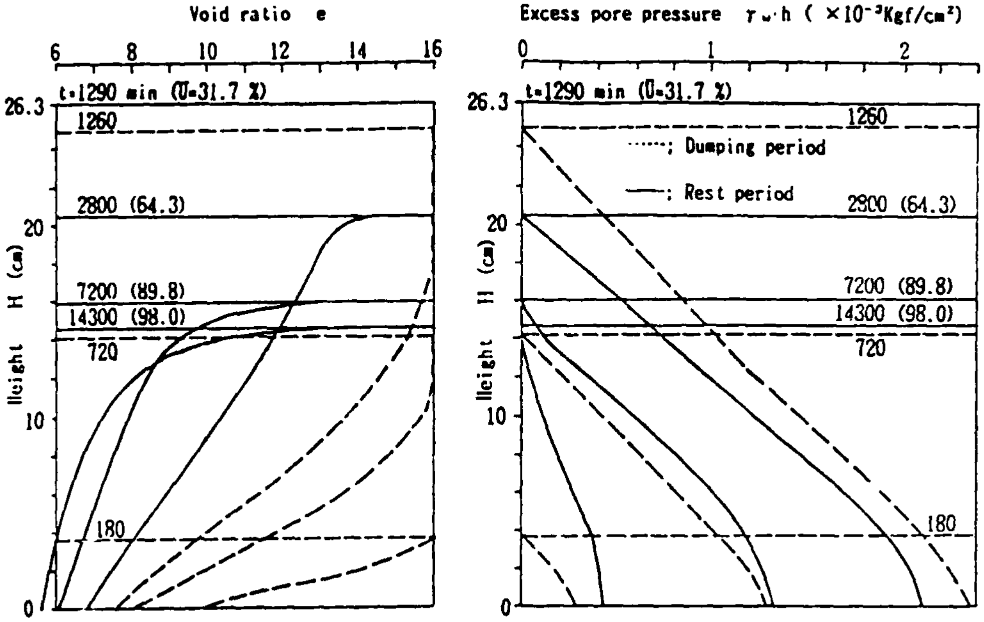


Figure 15. Changes in interstitial ratio and excess interstitial water pressure over time (Case I)

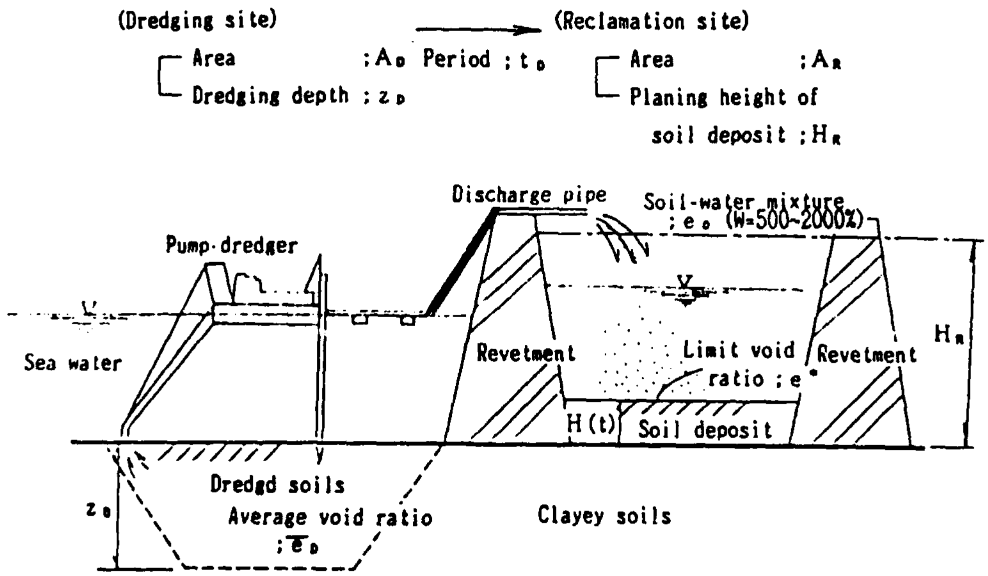


Figure 16. Conceptional drawing of relationship of dredged material volume and reclamation area volume

When the total volume of dredged material V_D is dredged and deposited in the reclamation area, if the deposition height H (t_D) in the reclamation area coincides with H_R after disposal of the total volume of dredged soil, the most ideal dredging and reclamation conditions have been met.

The deposition heights during continuous disposal of dredged cohesive soil were calculated by the FEM at various depositing rates, H^*/t . The FEM results are shown in Figure 17. Tokyo Port clay was used as the soil constant. The diagram can be used as follows.

a. First, the total soil height that will deposit per unit area in state e^* in the reclamation area is obtained by

$$H^* = \frac{V_D(1 + e^*)}{A_R(1 + e_D)} \tag{19}$$

When the total soil height H^* and H corresponding to the disposal rate H^*/t_D are obtained from Figure 17, this H corresponds to the soil deposition height $H(t_D)$.

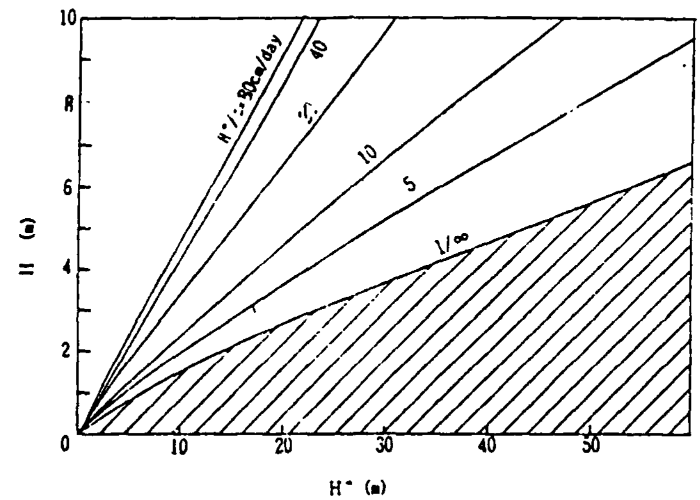


Figure 17. Prediction of deposition (Tokyo Port clay)

b. To dispose H^* into the reclamation area to height H_R , H $(= H_R)$ and H^*/t corresponding to H^* can be used for the disposal rate. However, when H and the point corresponding to H^* are located at a position below and right of the state after self-weight consolidation shown as $H^*/t = 1/\infty$, it is not possible to dispose the total volume of dredged soil into the reclamation area.

c. When H_R , A_R , and H^*/t_D are set up, the dredged soil volume V_D that can be disposed into the reclamation area can be obtained by reading H_R and H^* corresponding to H^*/t_D and substituting this H^* into Equation 19.

Also, according to Figure 17, when H is assumed as 3 m and H^*/t is changed, H^* becomes 7.2, 12.8, and 23.1 m where H^*/t is 40 cm/day, 10 cm/day, and $1/\infty$, respectively. This shows that the slower the dredged material is disposed, the faster self-weight consolidation of the deposited soil layer progresses, making it possible to dispose more dredged material in the reclamation land.

CONCLUSIONS

This paper described the state of sedimentation of soil particles and the state of consolidation of deposited soil for an actual reclamation area, and discussed a method for predicting of deposited soil layer thickness of dredged cohesive soil which the authors have studied for years. Specifically, an analytical method of self-weight consolidation, experimental verification of the analytical results, and a simple method for predicting deposited soil layer thickness are described. For the self-weight consolidation analysis of the deposited soil, the concept of critical state, proposed by Monte and Kkizek (1967), was used. It was then necessary to calculate consolidation from a very low-stress condition, and more detailed study is needed on the consolidation characteristics of the clay in the ultralow-stress region. In this regard, it is particularly important to evaluate the coefficient of permeability in the range of $p < 5 \times 10^{-3}$ kgf/cm^2. As to the prediction of deposited soil layer thickness shown in Figure 17, it is regrettable that there is no example in which analytical results are compared with reclamation site data. Further analysis of the site data and study of a prediction method closely based on reality are required.

ACKNOWLEDGMENTS

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INVESTIGATIONS OF SUBAQUEOUS BORROW PITS AS DISPOSAL SITES FOR CONTAMINATED DREDGED MATERIAL FROM NEW YORK HARBOR

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ABSTRACT

Past underwater sand mining has left many large depressions, called subaqueous borrow pits, on the floor of the Lower Bay of New York Harbor. Research has shown that borrow pits are natural "sinks" for contaminant-laden sediment and that they contain stressed benthic communities different from those found in nonpit areas. The disposal and capping of contaminated dredged material into borrow pits would *obviate* possible impacts at the ocean disposal site while reclaiming lost portions of the sandy bottom of New York Harbor. A demonstration project to prove the feasibility of borrow pit disposal was begun by the New York District (NYD). The project was not completed because of litigation, although research in other parts of the country showed that borrow pit disposal was technically feasible. Based on this information, the NYD is implementing an operational program for dredged material disposal into existing or new borrow pits. A Federal EIS is being prepared. A sediment characterization scheme has been developed to determine material eligible for borrow pit disposal. Evaluative criteria, based on physical and biological criteria, were used to rank existing pits in order of preference. Similar criteria were used to determine the areas in the Lower Bay that would be adequate for excavation of a new pit. A monitoring/management program is being developed to ensure that disposal operations in borrow pits are properly implemented without adverse impacts.

BACKGROUND

The floor of the Lower Bay of New York Harbor is composed predominantly of sand and gravel that were deposited as the last glaciers receded from this area about 18,000 years ago. It has been estimated that the surficial sand deposits under the Lower Bay alone have a total volume of about 2.6 billion cubic meters (Bokuniewicz, Cerrato, and Hirschberg 1986). Over the past several decades, sand and gravel have been mined from the floor of the Bay for use as construction aggregate and fill. Between 1950 and 1980, more than 32 million cubic meters of sand and gravel was dredged from the Bay (Bokuniewicz, Cerrato, and Hirschberg 1986). This mining activity has produced a number of subaqueous borrow pits of varying size and depth. The principal ones are shown in Figure 1.

Since 1973, sand mining activity in the Lower Bay has been restricted primarily by environmental concerns, and over the past decade a number of studies have been conducted to address those concerns. For example, some authors used mathematical models of the waves and tides to examine whether the borrow pits affected beach erosion (Kinsman et al. 1979, Wong and Wilson 1979). Their results indicated that the pits were large enough to noticeably affect the waves and tides. Both the tidal range and the wave energy reaching the shore were slightly increased by the presence of the pits. These changes would tend to aggravate shoreline erosion although the magnitude of the impact was considered small and difficult to assess.

A second concern arose from the fact that the pits on the West Bank were natural traps for mud. Little or no mud is deposited on the sandy bay floor around the pits, but in them, mud was accumulating at rates between 4 and 9 cm/year, or about 100 times faster than typical natural rates in other estuaries (Bokuniewicz, Cerrato, and Hirschberg 1986). The presence of the pits has changed about 1,053 acres (426 ha) of the seafloor from sand to mud. In fact, if mud continues to accumulate in pits as rapidly as it has over the past 10 years, the pits will completely fill within 50 to 100 years. Because of the affinity of many contaminants for fine-grained sediments, the pits are also sinks for contaminants in the Lower Bay (Benniger, Lewis, and Turekian 1975).

The mud accumulating naturally in the pits on the West Bank has a high organic content, and there was concern that the degradation of this organic matter would deplete the oxygen in the bottom water during the summer. In 1978, measurements showed that the pits on the West Bank did affect the oxygen demand, and lower oxygen concentrations were found there when compared with sandy shallow areas (Swartz and Brinkhuis 1978). Dissolved oxygen concentrations low enough to stress animals (<3.5 ml/ℓ) were observed near the bottom of the pits on several occasions (Conover, Cerrato, and Bokuniewicz 1985; National Marine Fisheries Service 1984; Swartz and Brinkhuis 1978).

Since the physical environment in the borrow pits differed substantially from the ambient seafloor, an additional concern was the effect of the pits on the community structure of the benthos within and adjacent to them. To address this concern, a seasonal benthic study was conducted between July 1980 and June 1983 (Cerrato and Scheier 1984). Results indicated that the fauna in borrow pits were distinctly different from the ambient seafloor in terms of species composition and in temporal patterns of abundance, species richness, diversity, and equitability. The fauna within the borrow pits were dominated by opportunistic species and were characterized by very large seasonal changes in abundance and species richness (Figure 2). Extremely low abundances generally occurred during the warmer months, suggesting oxygen stress as a possible cause for the observed pattern. In contrast, the benthic fauna at a control

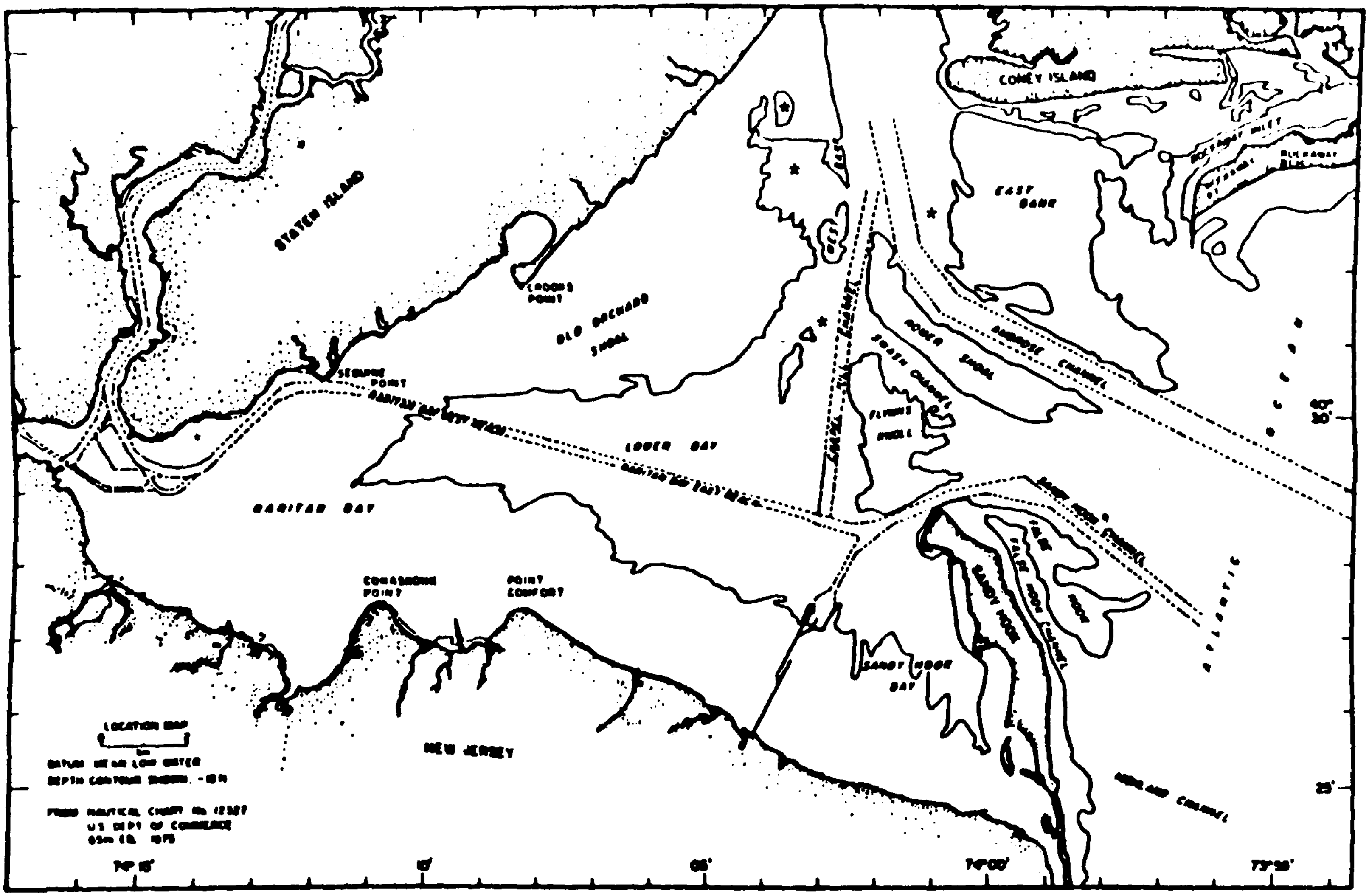
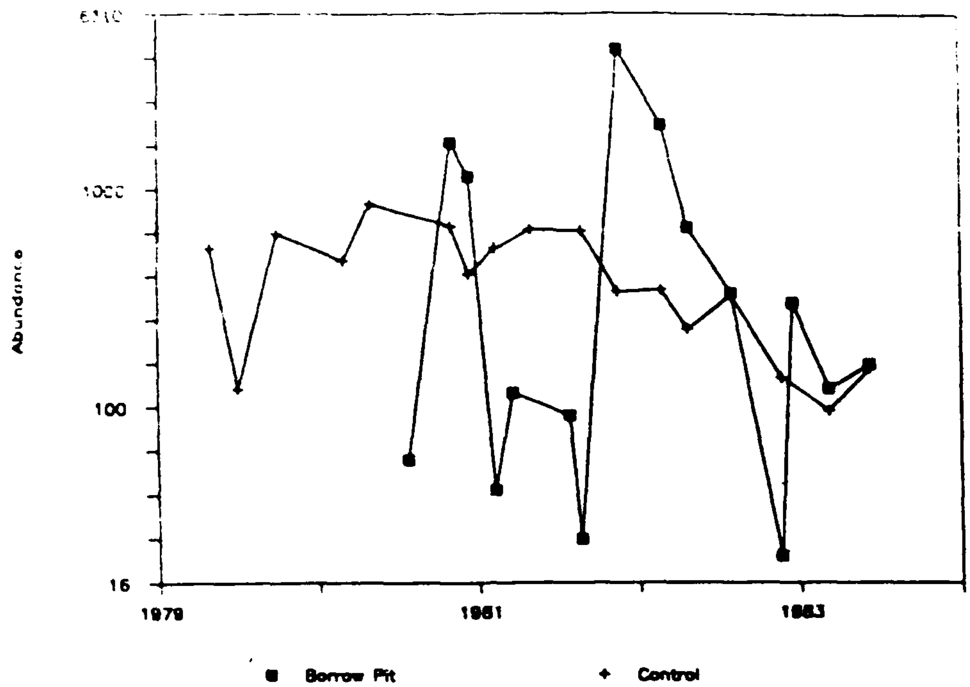
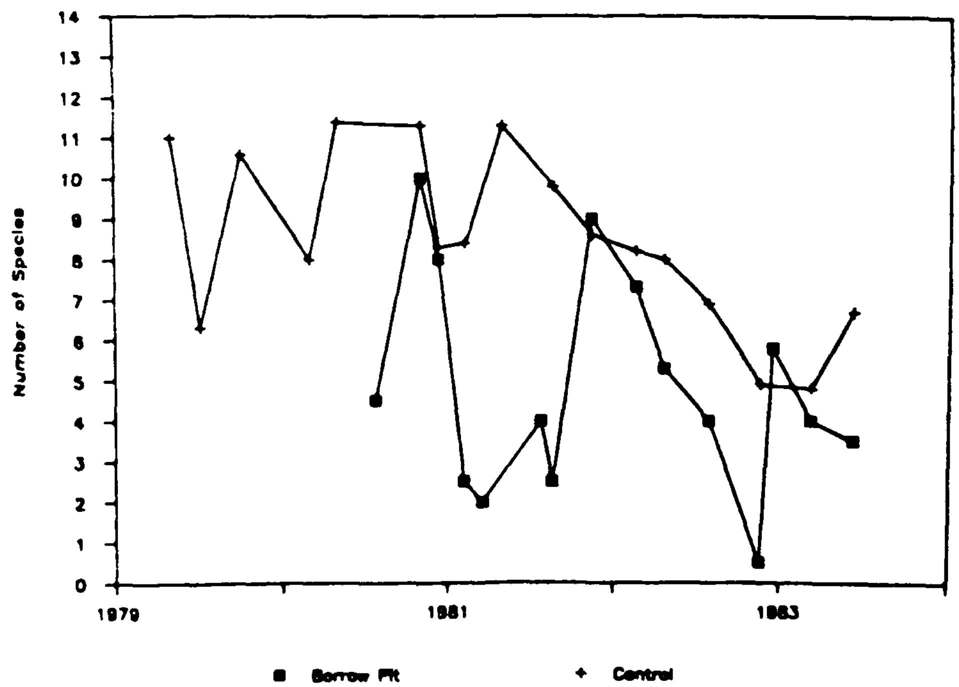


Figure 1. Index map of the Lower Bay. Locations of principal borrow pits are indicated by asterisks



a. Average abundance (per square meter)



b. Average number of species (per sample)

Figure 2. Comparison of benthic abundance and species richness at a borrow pit on the West Bank and at a control area approximately 2 km southwest

area were more stable and diverse over time. Evidence was also found that the borrow pits affected the structure of the benthos at locations close to the pits.

Given the documented impacts of existing borrow pits, filling them and reclaiming the sandy seafloor would appear to be a desirable goal. Even the smallest suitable pit, however, has a capacity of over 1.5 million cubic meters, and the total capacity of pits on the West Bank alone exceeds 19 million cubic meters. The cost of filling these pits would be prohibitive unless a source of free material is available. Dredged material can provide that material and, in addition, burying dredged sediment in subaqueous borrow pits has its own advantages. Most of the dredged material from New York Harbor is contaminated by agricultural, urban, or industrial products. Whatever the disposal technique used, it is desirable that the material be contained in a disposal site and isolated from the marine environment to the greatest possible extent. Subaqueous pits are attractive containment sites because mud is accumulating in them at very rapid rates, and the pit walls are sufficiently steep to limit the spread of dredged sediment during discharge (Bokuniewicz 1979). If the dredged material is deposited in the pit and covered, or capped, then not only could the Bay floor be restored to its premined condition, but the dredged mud could also be buried beyond reach of most burrowing animals and beyond the depth of disturbance by storm waves (Bokuniewicz, Cerrato, and Mitchell 1981). Burial keeps the mud in a reduced state so that particle-bound contaminants are unlikely to migrate. Burial in the pits also eliminates problems of ground-water contamination that may be a concern with landfill operations.

DEMONSTRATION PROJECT AND LITIGATION

Present investigations into the feasibility of using borrow pits for the disposal of dredged material began in 1979. Borrow pits were identified as possible sites for the disposal of large quantities of dredged material and, in special cases, for highly contaminated dredged material (Connor et al. 1979). For this reason, investigations of borrow pits were included in the Dredged Material Disposal Management Plan for the Port of New York and New Jersey, which also investigated other disposal alternatives such as containment facilities and upland disposal for dredged material (Coch et al. 1983, Suszkowski and Mansky 1981, Tavolaro and Zammit 1986).

In 1980, at the request of the New York District, the Marine Sciences Research Center of the State University of New York, Stony Brook (SUNY), began site-specific research on use of borrow pits. They identified 10 questions that needed to be addressed to determine if borrow pit disposal was feasible in New York Harbor, concerning the physical aspects of the creation of the deposit and the physical, chemical and biological integrity of the cap (Bokuniewicz, Cerrato, and Hirschberg 1986). Later, two additional questions were raised concerning gas generation within the deposit, potentially disrupting the cap, and the value of borrow pits to finfish populations of the Lower Bay.

Relevant literature was summarized, site-specific environmental information was obtained from representative borrow pits, and dredged material disposal modeling was performed. All indications were that borrow pit disposal with capping appeared to be feasible and practicable. However, to determine if borrow pits could be used on an operational basis, a demonstration project was the next logical step. The demonstration project involved disposing dredged material into one small portion of an existing borrow pit offshore of Staten Island, NY, capping it, and monitoring the deposit for 6 months to determine the environmental impacts (Mansky 1984). Since this borrow pit was very large, the demonstration project was designed as a three-phase operation to isolate its southern tip for the experiment. Phase I would be the construction of a sand berm to isolate the southern tip, Phase II would be the disposal of the dredged material behind that berm, and Phase III would be the sand cap over the entire deposit (Figure 3).

The Phase I berm was successfully placed in December 1981 by the Corps of Engineers Dredge GOETHALS. Approximately 167,000 m^3 of sand dredged from Ambrose Channel was used for berm construction. This left a disposal area behind the berm that was 200 m in diameter and 14 m deep. Before Phase II could begin, a local Staten Island conservation group, the Natural Resources Protective Association (NRPA) interceded. They strongly opposed the demonstration project because they considered the borrow pit to be in a prime recreational fishing area. They gathered a large amount of public support for their cause and enlisted the aid of their local US Congressmen and State elected officials to raise concerns to both the State regulatory agencies and the NYD. They so strongly opposed the demonstration project that they sued the State of New York for issuing a Section 401 Water Quality Certification for the project.

Specifically, their lawsuit stated three causes of action:

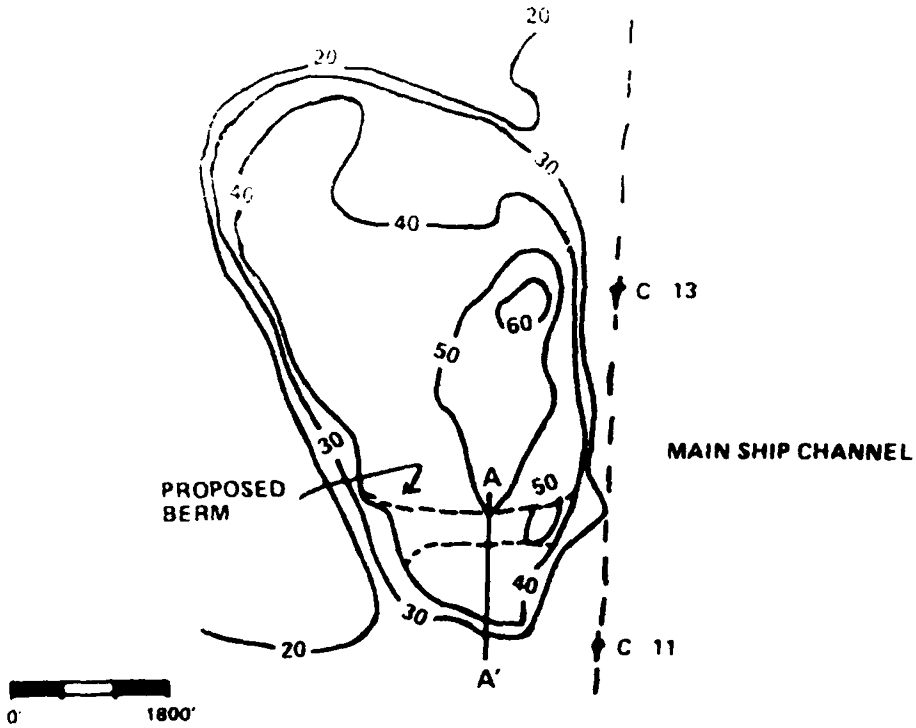
a. An environmental impact statement (EIS) was not submitted, which they felt was necessary to fully address the environmental impacts of the project.

b. The project was not reviewed under the State Coastal Zone Management Program policies (at the time, the New York State program was not yet in full effect).

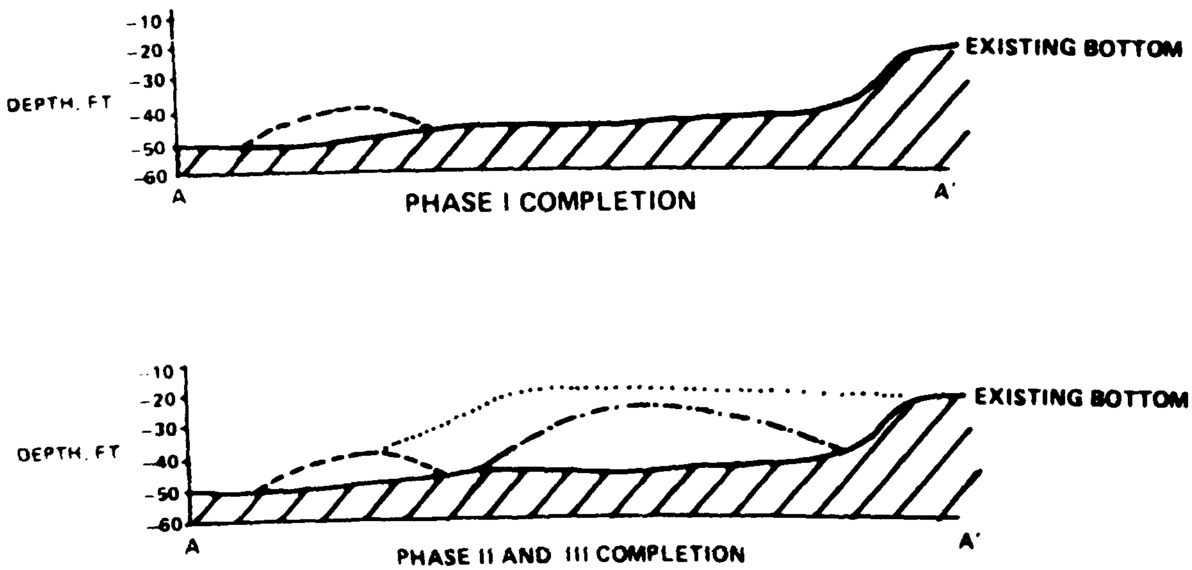
c. Ocean disposal testing criteria, which were used to evaluate dredged material for disposal in the borrow pit, were not felt to be stringent enough in such a highly utilized sport fishing area as the Lower Bay.

A temporary injunction caused delays while the issues were argued in court. The State of New York Supreme Court, Richmond County (Staten Island), decided that there was enough "disparity of scientific opinion" to "hold these motions in abeyance" until a neutral scientific panel "mutually selected by the parties" determined the impacts of the demonstration project and reported to the court. New York State appealed the decision, but the Appeals Court ruled that it was not "appealable" because a decision had not been rendered, but merely delayed until the scientific panel had made its report. Efforts by the State to assemble a scientific panel acceptable to both parties failed, further delaying the demonstration project.

Meanwhile, fisheries surveys of borrow pits in New York Harbor had been funded by the NYD to determine in detail the resource potentially being affected by the demonstration project. The first surveys were performed by



a. Plan view of borrow pit (depth contours in feet)



b. Cross section A-A' (1 in. = 400 ft)

Figure 3. Proposed borrow pit demonstration project

the National Marine Fisheries Service (NMFS) and SUNY, comparing the fisheries characteristics of two representative borrow pits with an undisturbed sand-bottomed control area (Conover, Cerrato, and Bokuniewicz 1985; Pacheco 1983). The same sampling locations were covered by both groups for a 1-year period, with each group using slightly different trawling equipment. The NMFS study used an unlined trawl to catch only adult populations of fish that would appeal to recreational fishermen. The SUNY study used a 65-mm cod-end liner to catch juveniles and smaller species. Both studies showed that although borrow pits did not support permanent fish populations and were not an important food source for migratory species, they did tend to congregate fish in higher numbers than the surrounding flat, sandy bottom for most of the year.

These results led us to look into the matter further and expand the fisheries surveys to include more than just the three previously sampled areas. Another year-long survey was initiated (NMFS 1984) to consider fish occurrence in eight locations, including other borrow pits, navigation channels, shoal areas, and flat sandy and muddy bottoms. This study further reinforced the previous conclusion that borrow pits do not support permanent or unique fisheries resources in the Lower Bay. Further analysis of all fisheries surveys showed that two types of stations were represented by the sampling, i.e., shallow sand-bottomed (Group I) and deeper, mud-bottomed (Group II). Group I stations were generally lower than Group II stations in terms of catch, number of species, and weight of species, but there were apparently no significant differences between stations included in each Group (Bokuniewicz, Cerrato, and Hirschberg 1986).

Based on this new information, the State of New York revoked the Section 401 Certification for the demonstration project, despite our protests. This revocation made the lawsuit a moot issue, therefore resolving it. The NYD reapplied for a Section 401 Certification, this time submitting the recently completed fisheries studies at the State's request as "new and relevant" information. They decided that a State EIS was required (previously it was not) pursuant to the New York State Environmental Quality Review Act. It should be noted that the lack of an EIS was one of the litigant's original complaints. The NYD began preparing a State EIS for the demonstration project.

Meanwhile, other pertinent research on the effectiveness of capping and borrow pit disposal had been completed (Brannon et al. 1985, 1986; Sumeri 1984; Truitt 1986). The NYD realized that the demonstration project as planned was no longer necessary. The questions it was designed to answer had already been answered, and the results showed that borrow pit disposal could be done effectively. The NYD suggested that all parties work toward developing an operational program of borrow pit disposal, selecting an existing pit or an area environmentally suitable for construction of a new borrow pit, or both. Surprisingly, both the State of New York and the NRPA agreed to work with the NYD toward this end. The NRPA stated that they were not opposed to borrow pit disposal, in principle, but were mainly concerned that the site ultimately chosen for disposal be acceptable from their perspective. They also believed that existing pits are "productive," and only new pit sites should be explored.

The NYD withdrew the Section 401 Certification application for the demonstration project, applied for new certification for an operational program, and proceeded to prepare a Federal EIS on borrow pit disposal. The State of New York agreed to overlap the respective regulatory processes to the maximum extent possible, with the ultimate intent of granting a Section 401 Certification for use of the disposal site selected for an operational program (assuming that a suitable site could be found).

SUBAQUEOUS BORROW PIT FEDERAL EIS

The NMFS, the US Environmental Protection Agency (EPA), the New York State Coastal Management Program, and the New Jersey Department of Environmental Protection all agreed to be cooperating agencies on the EIS, which is now in preparation. Although the US Fish and Wildlife Service is not a cooperating agency, it has expressed general support for the project. The NYD is continuing to coordinate will all parties, including Staten Island Federal and State elected officials, who continue to remain interested in the effect of the project on their constituents.

The document is to be released as a Supplemental EIS (SEIS) to the 1983 Dredged Material Disposal Alternatives EIS prepared by the NYD (US Army Engineer District, New York 1983, 1987). The 1983 EIS evaluated all possible alternatives for dredged material disposal for the Port of New York and New Jersey. One of the conclusions of the Alternatives EIS was that subaqueous borrow pits are the preferred alternative for the disposal of contaminated dredged material that exhibits potential for toxicity or bioaccumulation.

The goal of the borrow pit Federal SEIS process is to obtain all necessary regulatory approvals for implementation of an operational program for the disposal of dredged material from the Port of New York and New Jersey into subaqueous borrow pits. The SEIS is a site-designation document with the anticipated result being the authorization to use an existing borrow pit and/or to construct a new pit to be used as a disposal site.

Sediment Characterization

A characterization scheme for the types of sediment that would be deposited was developed based on the standard bioassay/bioaccumulation tests required by the Ocean Dumping Testing Criteria for dredged material (EPA/CE 1977). Category I material has acceptable toxicity and bioaccumulation effects on tested marine organisms and would not be considered for borrow pit disposal. These sediments are considered suitable for unrestricted ocean disposal. Placement of a sand cap over them to prevent adverse environmental impacts to the marine environment would not be necessary. Category II sediments have some toxicity or bioaccumulation effects and would not be considered for unrestricted ocean disposal. Presently, Category II sediments can be disposed in the ocean, provided they are expeditiously capped to protect against adverse impacts. Category II sediments would be candidates for borrow pit disposal. Category III sediments have unacceptable toxicity or bioaccumulation effects and do not meet the Ocean Dumping Testing Criteria. These sediments would not be considered for ocean disposal but would be candidates for borrow pit disposal. In summary, sediments of Categories II and III would be considered for borrow pit disposal, while Category I sediment would be disposed in the ocean.

After developing the sediment characterization scheme, the next task was to estimate the approximate volume of dredged material per year that would be eligible for borrow pit disposal. This yearly average would be used to compute the pit capacity needed for a suitable long-term (10 years) disposal site. Data from the development of the currently used Ocean Dumping Testing Criteria (1980 to the present) were reviewed to calculate what percentage of dredged material required capping. It was determined that approximately 7 percent of the dredged material deposited in the ocean disposal site since 1980 required capping. This amounted to nearly 1,760,000 m^3 of dredged material. Adding another 135,000 m^3 of material that was not allowed to be disposed of in the ocean during this time gives a total of approximately 1,900,000 m^3 that would have been eligible for borrow pit disposal. Possible increases in the volume of dredged material that would not meet the criteria for unrestricted ocean disposal, as well as additional amounts of dredged material that may be needed for use as interim caps, increases the volume requirements of a borrow pit disposal site. Taking into consideration the yearly average of the above, as well as modifications to the Testing Criteria that could increase that average and the possibility of interim caps, it was determined that a borrow pit disposal site should have a minimum capacity of 3,000,000 m^3.

Evaluative Criteria for Existing Borrow Pits

The first consideration in evaluating borrow pits in lower New York Harbor is that the pit meet the minimum physical requirements for retention of the deposited dredged material (Wong and Wilson 1979). These requirements include a minimum water depth to the ambient bottom of at least 5.5 m, and a minimum pit radius of 228 m. The depth requirement is to prevent erosion of the deposited sediment by wave action. The minimum radius requirement takes into consideration average barge size, water depth, the character of the sediment, the slope of the pit walls, and the dynamics of the bottom surge as it makes contact with the pit bottom and spreads outward. Of the 20 existing pits identified in lower New York Harbor and adjacent areas, only seven pits (Nos. 2, 3, 4, 6, 7, 14, and 15) meet the minimum requirements (see Figure 4). Three of these pits (Nos. 2, 3, and 4) are in the West Bank area of lower New York Harbor, two (Nos. 6 and 7) are in the East Bank area of the Harbor, and the remaining two (Nos. 14 and 15) are in Jamaica Bay, a body of water east of the Harbor.

The seven existing borrow pits that passed the minimum criteria were then evaluated by using physical and biological criteria to qualitatively rank them in order of preference as a disposal site. The physical criteria included the following factors:

a. Pit size and depth--adequate volume to be a long-term dredged material disposal site. One of the Jamaica Bay pits (No. 14) has the largest capacity, followed by the two pits on the East Bank.

b. Erosion potential--the location of a given pit in relation to wave and current action, which would affect the stability of disposed material. Jamaica Bay pits, being in a sheltered body water, would have the greatest protection from erosional effects.

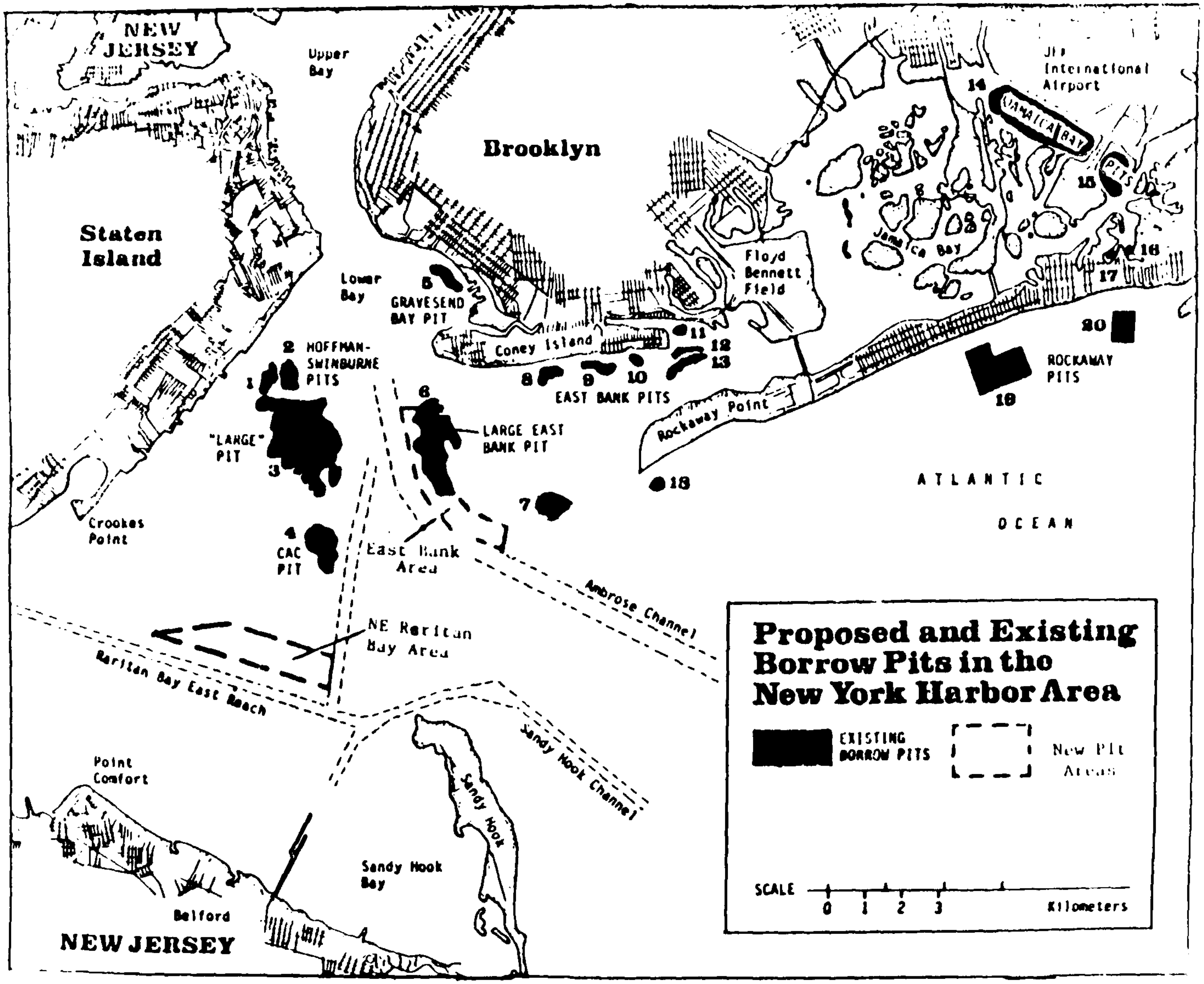


Figure 4. Proposed and existing borrow pits in New York Harbor area

c. Need for modifications--the degree to which a pit would require physical modification, such as the need to dredge and maintain access channels from main channels to the pit site. Pits 4 (West Bank) and 6 and 7 (East Bank) would need the least amount of modification.

d. Water quality impacts--the short-term impacts associated with dispersion of suspended material during disposal operations. Projections of suspended material plumes and hydrographic conditions at given pit locations were evaluated. The most exposed pit (No. 7) would be the best suited to disperse and dilute the suspended material plume resulting from disposal operations.

e. Conflicting uses--possible conflicts in the use of certain pits as disposal sites, which may contravene planned uses of the areas in which the pits are located. For example, the East Bank pits are located in an area that has been designated as a possible sand-mining area by the State of New York. A borrow pit disposal site in this area may create a conflict with the sand-mining activities.

The biological criteria were developed to compare and rank the pits to determine which pits would have the least biological constraints for use as a disposal site. The biological criteria included the following factors:

a. Benthic impacts. The possible effects of borrow pit disposal on benthic communities within and adjacent to pits were evaluated using existing data (Bokuniewicz, Cerrato, and Hirschberg 1986; Cerrato and Scheier 1984; McGrath 1974), as well as the preliminary results of an extensive benthic survey of lower New York Harbor funded by the NYD (Cerrato, Bokuniewicz, and Ellsworth, in press). These studies suggest that pits on the West Bank of the Harbor generally contain stressed benthic communities with low diversity and fairly low abundances, as compared with the East Bank pits, which were generally characterized by high benthic abundances and diversity. The pits in Jamaica Bay were also determined to have a poorer benthic community as compared with the East Bank pit community.

b. Fishery impacts. The use of existing borrow pits by fishery resources in lower New York Harbor was evaluated by using past studies of borrow pit areas (Conover, Cerrato, and Bokuniewicz 1985; NMFS 1984; Pacheco 1983), as well as a new comprehensive fishery study of the Lower Harbor (Woodhead and McCafferty 1986). Among all the existing pits, the Jamaica Bay pits were determined to have the lowest value of fishery resources, and would be most preferable as disposal areas from a fisheries standpoint. The West Bank pits had a higher fisheries value than the Jamaica Bay pits, and the East Bank pits were found to have the highest value of all the pits evaluated.

c. Wildlife/wetlands impacts. The only existing pit sites where this would be a concern would be the two pits in Jamaica Bay, which has extensive wetland areas and is a migratory stopover for waterfowl.

Combining the rankings of the biological and physical criteria, pit 4 on the West Bank, which was used in the demonstration project, was determined to be the most preferred disposal site. This pit would have the least physical and biological constraints of the existing pits evaluated. The two large Jamaica Bay pits (Nos. 14 and 15) would be next on the preferred list, followed by the large West Bank pit (No. 3) and the large East Bank pit (No. 6). It should be noted, however, that these five pits are very closely ranked, so the differences in preference are not great. The remaining smaller pits are ranked similarly and are the least preferred.

Evaluate Criteria
for New Borrow Pits

Criteria were also developed to evaluate locations for the construction of new borrow pits. One purpose of constructing a new borrow pit would be to avoid possible impacts to biological communities in and around existing pit sites. Further, new pit construction allows for the specific design of a pit as a dredged material disposal site, which provides operational advantages to using an existing pit site. A negative impact of new pit construction would be the disturbance of a previously undisturbed portion of the lower New York Harbor bottom, which could affect the benthic and fisheries communities in and around the site. To lessen these possible impacts, new pit sites should ideally be chosen in areas of low biological use and productivity. Moreover, new pits must be in areas that have usable sand or gravel deposits to avoid a disposal problem that would result from constructing a pit in mud-bottom areas. The sand or gravel deposits could be excavated by private concerns, who would be allowed to keep the material in return for excavation of the pit. Another consideration for construction of a new pit is that no existing cultural or archeological resources, such as sunken ships, be disturbed. This is not a concern in using existing pits because, presumably, any cultural or archeological resources were disturbed during the original sand-mining operations that created the pits.

The first step in determining new borrow pit disposal sites was the evaluation of four areas in lower New York Bay suggested by the environmental groups (New York Bight Restoration Group 1984) affiliated with the Dredged Material Disposal Management Plan for the Port of New York and New Jersey. This evaluation was based on their review of existing biological and hydrographic data and information from recreational and commercial fishermen in the area.

Criteria based on physical and biological factors were then developed to determine which proposed new pit areas ·ıld have the fewest constraints as an operational borrow pit disposal site. The physical criteria for new pit sites were:

a. The suitability of the sediment type for use as construction-grade sand or gravel. A previous survey shows several types of sediments in the Lower Bay suitable for use in construction activities, with the East and West Bank areas containing the greatest amounts of these types of material (Kastens, Fray, and Schubel 1978).

b. Water depth and hydrological regime. The new pit site should not be situated in water too shallow to allow the safe navigation of disposal barges nor be subject to wave disturbance that could disrupt the deposited dredged material. The new site should not be situated in an area of extreme water depths that could cause operational problems.

c. Shore erosion effects from the construction of a new borrow pit. Mathematical models (Wong and Wilson 1979) were evaluated to determine if new pit construction in the Lower Bay could affect the rate of shoreline erosion in adjacent areas, such as Staten and Coney Islands. It was determined that any erosional impacts would be minor, but construction of a new pit on the West Bank of the Lower Bay would be preferable.

Based on the physical criteria for the construction of new borrow pits, areas in both the East and West Banks appear similar in preference, with East Bank areas having deeper sand deposits with a range of construction uses but also a greater possibility of shoreline erosion. The biological criteria for new site selection consisted of the following:

a. Benthic criteria. Existing data (Cerrato, Bokuniewicz, and Ellsworth, in press; McGrath 1974) were used to identify areas of low benthic abundance and diversity.

b. Fishery criteria. Recent fishery surveys of the Lower Bay (Woodhead and McCafferty 1986), coupled with previously mentioned existing fishery data (Conover, Cerrato, and Bokuniewicz 1985; Pacheco 1983), were used to identify areas of low fish usage.

Based on the combined benthic-fisheries criteria, it was determined that the most preferred new pit sites (the sites with the lowest biological use) are in the East Bank and in northeast Raritan Bay (Figure 4).

After considering both the physical and biological criteria, it was determined that an area approximately 1 by 2 km in the East Bank adjacent to Ambrose Channel is the most preferred area for siting a new pit (Figure 4). This is an area of comparatively low benthic abundance and diversity and fishery usage. Further, it has ample construction-grade sand resources that would be attractive to sand-mining interests. The next preferred site is an area 4.5 by 1 km in Raritan Bay (the "NE Raritan Bay" site in Figure 4). It should be noted that these two proposed pit areas are large tracts, and any new pit would occupy only a small portion of an area.

To comply with existing regulations protecting marine archeological and cultural resources, a remote sensing survey of the two proposed pit areas is being done to ensure that undocumented resources would not be destroyed during construction of a new pit. If archaeological resources are identified, the location of the proposed pit could be shifted to other sections within the new pit areas to avoid impacts.

MONITORING AND MANAGEMENT

A monitoring and management plan is being developed by the NYD to ensure that disposal operations in borrow pits are properly implemented without adverse impacts. The physical aspects of the monitoring program would outline procedures for proper filling of the pit, measuring the integrity of the sediment cap on the deposited material, and determining whether any sediment is escaping during disposal operations. These procedures would involve bathymetric surveys, grain size analyses, and the use of remote sensing apparatus. The biological aspects of the monitoring program would focus on determining whether contaminants from the borrow pit disposal site are bioaccumulating in marine organisms. Benthic organisms will be sampled along a transect crossing the borrow pit site and adjacent areas, as well as a control pit site. Organisms at these sampling stations will be tested to determine if there are differences in the uptake and bioaccumulation rates between the borrow pit site and the control site. If there are statistically significant differences, a determination would be made whether the differences are environmentally significant and whether the borrow pit disposal site is the cause of this situation.

The management plan that is being developed for the operational program will encompass a wide array of topics, from the sediment characterization scheme, to the monitoring program, to a decision framework that will determine what steps have to be followed to ensure that a borrow pit disposal site is operated at an optimal level with minimal environmental impact.

CONCLUSION

From the evaluative criteria and the input of all of the interested governmental agencies, environmental and industrial interests, and others involved in the project, it appears that the best method for implementing an operational program for disposal in borrow pits is to use an existing pit while at the same time beginning construction of a new pit.

The draft SEIS will be released for public comment and review in January 1988.

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DISPOSAL AND TREATMENT OF CONTAMINATED DREDGED MATERIAL

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ABSTRACT

This paper describes the dredging and upland disposal of about 30,000 m^3 of polychlorinated biphenyl (PCB)-contaminated (>10 ppm) dredged material for the purpose of determining a treatment method that is safe and does not induce secondary contamination.

A cutterless pump dredge was used, and the dredged material was transferred to the discharge basin by pipeline. The dredging depth averaged 76 cm, as compared with the planned depth of 70 cm. No increase in turbidity was observed during dredging.

The basin was subdivided, and the residual water treatment was carried out by transferring the dredged material alternatively to each basin, where dredging and plain sedimentation were conducted. The segregated water was sand filtered. About 400,000 m^3 of water was disposed, with turbidity under 10 degrees (draining standard was below 30 degrees) throughout the work.

The final disposal was made by draining the disposal area, surrounding it with embankment, and covering with impervious sheeting. The dredged material was allowed to solidify, and the surface was covered with sand and gravel and sealed with asphalt.

INTRODUCTION

The contamination that results from municipal and industrial wastes deteriorates the quality of the water and the bottom sediment and has significant impact on marine life. These contaminants tend to accumulate on the bottom, creating a source of pollution. Therefore, in developing a water purification plan, it is necessary to remove this pollution source by dredging or isolating it from the water area, in addition to controlling inflow to the area.

This paper describes the development of a plan for the removal and disposal of PCB-contaminated dredged material, with emphasis on safety and minimizing secondary pollution. Also discussed are methods of treatment, facilities, and actual results obtained in the residual water treatment tests.

DISPOSAL AND TREATMENT PLAN

Background

Polychlorinated biphenyls have been widely used in insulating oils and synthetic resin plastics because of their insulation and incombustibility. They have also been added to ship paints in quantity for improved waterproofing and durability. However, the manufacture and sale of PCBs was forbidden in 1972 because their toxicity had been proven.

The work reported herein arose from PCB contamination that occurred before the ban. In the dockyard, as ships were repaired, paint fragments were washed or chipped off, and had been drained and piled in the foreground area.

In the disposal and treatment of the dredged materials, especially those containing harmful materials, it is necessary to dispose of them using a safe, secure, and efficient method, with considerable care about the environmental effects--not inducing secondary pollution by stirring and diffusion, as well as preventing escape from the disposal area.

This project involved dredging in the area shown in Figure 1 and upland disposal, considering the following basic policies.

a. The subject material is removed by dredge and discharged at the disposal area.

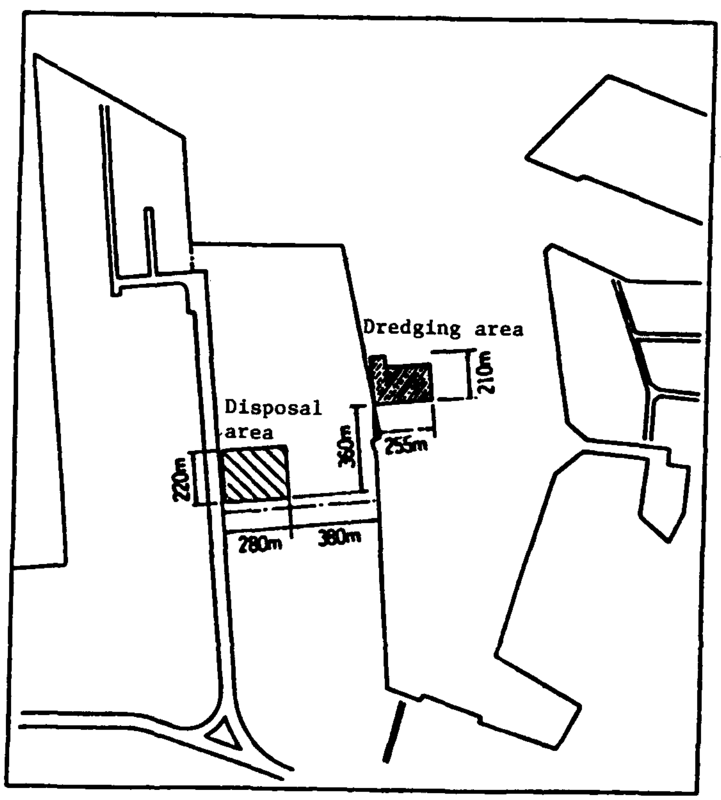

Figure 1. Project location

b. The dredged material is to be allowed to settle in the disposal area. The segregated water is controlled under the disposition rule and drained into the sea after the drain water standard is fulfilled.

c. In the final disposal, the dredged material, which will have been reduced as much as possible, is to be sealed in the area.

Preliminary investigations and tests were conducted, the results of which are referred to as the "Interim Policy Concerning Treatment and Disposition of the Bottom Material." This involved examination of the disposal and treatment engineering system, with the main object to prevent secondary pollution. This procedure is shown in Figure 2.

Preliminary Tests and Method Selection

The preliminary tests that were conducted included examination of the bottom material to confirm the range of the work and to select engineering methods (Table 1).

Table 2 shows the selection criteria for work methods concerning dredging, transportation, discharge, residual water treatment, and final disposal, based on the disposal and treatment plan for the project.

Operational Conditions

Dredging Area

The range of the contaminated bottom material (PCB content >10 ppm) was determined to be: area (A) = 40,000 m^2, thickness (t) = 40 cm, and volume (V) = 16,000 m^3.

In order to clear the work area of contaminated material, 5 m in area and 30 cm in depth were added to the contaminated range of area. Final dimensions were: A = 43,550 m^2, t = 70 cm, and V = 30,500 m^3.

Dredged Material Characteristics

The average properties of the bottom material are shown in Table 3. The PCB elution and all other contaminants were below acceptable standards.

Water Depth

The water depth in the dredging area was in the range of 9.9 to 20.7 m from the existing ground level and tide level. On the quay side of the removal area, a 25-m section makes a steep slope, the cross section of which is represented in Figure 3.

Discharge Basin and Final Disposal Area

An area of about 60,000 m^2 was designed for disposal, including the discharge basin and the residual water treatment facilities. The final disposal area was created by reducing the area of the discharge basin.

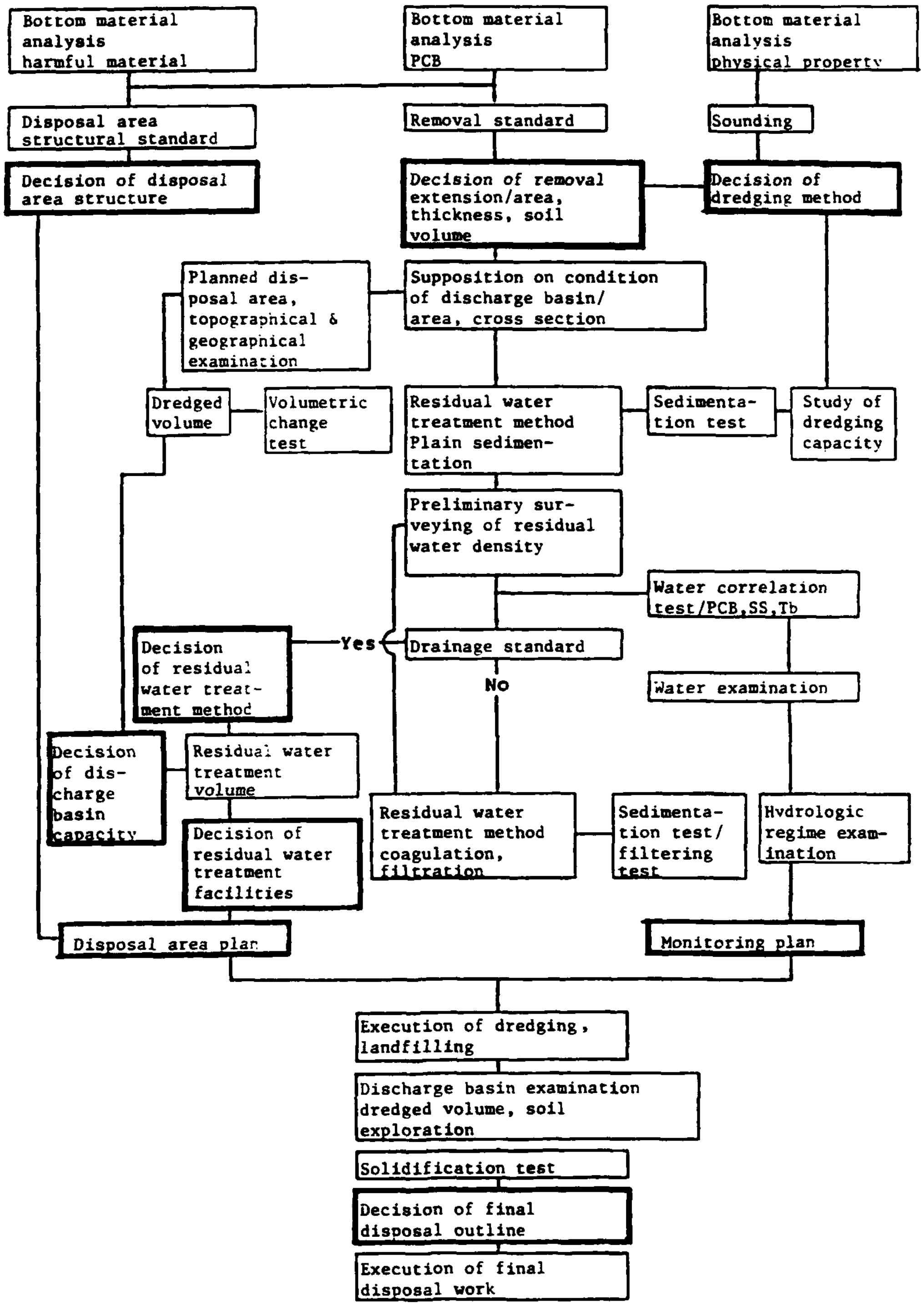

Figure 2. Examination procedure of disposal and treatment plan

TABLE 1. OUTLINE OF PRELIMINARY TESTS

Area	Test	Parameter	Dredging	Disposal	Residual Water Treatment	Final Disposal	Monitoring
Dredging area	Bottom material examination	PCB (content)	X	X	X	X	X
		Harmful material (elution)					
		Cr, Cd, CN, Pb, As, T-Hg, Org-P, PCB	X	X	X	X	X
		Organic materials - Ignition loss, sulfide	X	X	X	X	X
		Physical property Grading, water content, weight of soil constituents, liquid limit, plastic limit	X	X	X	X	X
	Water examination	pH, COD, DO, PCB, SS, turbidity, degree of transparency			X		X
	Sounding	Water depth, existing ground shape	X				X
	Hydrologic regime examination	Flow direction, flow speed	X				X
Disposal area	Topographical survey	Ground height, topography		X		X	
	Geographic examination	N-value, water content, weight of soil constituents, grading, unconfined compression strength		X		X	
Residual water treatment	Water correlation test	PCB, SS, turbidity, degree of transparency			X		X
	Sedimentation test (plained, coagulated)	Volume of material, consolidation, turbidity, and pH of segregated water			X		
	Sand filtering test	Amount, turbidity, SS			X		
Discharge basin	Discharged material property examination	Water content, grading				X	
	Discharge volume examination	Dredged material volume				X	
	Solidification test	Unconfined compression strength				X	

TABLE 2. SELECTION OF METHODS

Activity	Feature To Be Examined	Method Selected
Dredging	Shallow dredging (little unnecesary dredging) Accurate dredging of stipulated thickness along the existing ground (No "left-over" material) No water pollution should occur Adaptability for water depth Compatibility with transportation and discharge methods	Exclusive pump dredge Cutterless submarine type
Transportation	Accuracy No leakage	Pipeline connection from dredge to discharge basin
Disposal	Discharge basin of partition type Stability of surrounding embankment Adequate basin size Ease of final disposal	Embankment closing Impervious sheeting
Residual water treatment	Adherence to drainage standard Stable treatment throughout work period Adaptability for the volume of treatment	Two-part partition of basin. Stationary sedimentation by alternating discharges Sand-filtering treatment of segregated water
Final disposal	Disposal area of partition type Stability of disposal area Sealing of disposal area	Embankment partly sheet pile Solidification of dredged material Impervious sheeting, overlaid with asphalt

Residual Water Quality Standards. Table 4 summarizes these standards.

DREDGING

Since the quay side made a steep slope of about 17 percent and was littered with obstacles such as wire, this part was worked first by grab dredge and then by a mixed-air jet pump. The remaining area was dredged by an exclusive pump dredge (cutterless submarine type). Figure 4 shows the dredging work areas.

TABLE 3. BOTTOM MATERIAL PROPERTIES

Parameter	Average Value (Range)
Water content, %	156.1 (127.8-210.7)
Weight of soil constituents	2.670 (2.649-2.688)
Grading	
Gravel, %	0.1 (0-0.5)
Sand, %	1.8 (0-5.8)
Silt, %	44.3 (36.0-53.3)
Clay, %	53.8 (45.0-64.0)
Soil classification	Clay
Liquid limit, %	109.3 (101.8-123.3)
Plastic limit, %	30.4 (27.4-35.2)
Organic material	
Ignition loss, %	11.0 (1.3-16.4)
Sulfide, mg/g	1.53 (0.03-4.78)
Contaminant	
Hg compound, mg/ℓ	<0.0005*
Cd compound, mg/ℓ	<0.02*
Pb compound, mg/ℓ	<0.2*
Cr compound, mg/ℓ	<0.05*
As compound, mg/ℓ	<0.02*
CN compound, mg/ℓ	<0.1*
Org-P compound, mg/ℓ	<0.0001*
PCB compound, mg/ℓ	<0.001*

* Below acceptable standard.

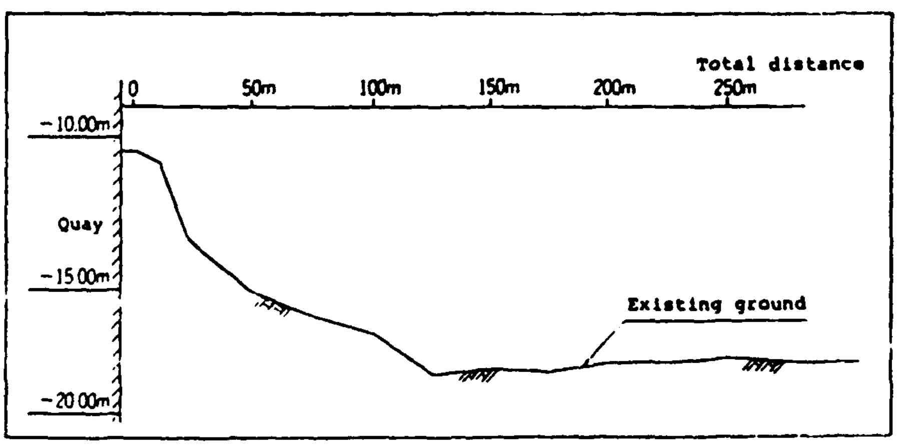

Figure 3. Existing ground shape of dredging area

TABLE 4. STANDARDS FOR RESIDUAL WATER

Parameter	Standard Value
PCB	Below 0.003 mg/ℓ
Suspended solids	Below 30 mg/ℓ
Turbidity	Below 30 degrees
Hg and alkyl Hg and other Hg compound	Below 0.005 mg/ℓ
Alkyl Hg compound	None detected
Cd and its compound	Below 0.1 mg/ℓ
CN compound	Below 1.0 mg/ℓ
Org-P compound	Below 1.0 mg/ℓ
Pb compound	Below 1.0 mg/ℓ
Cr compound	Below 0.5 mg/ℓ
As and its compound	Below 0.5 mg/ℓ

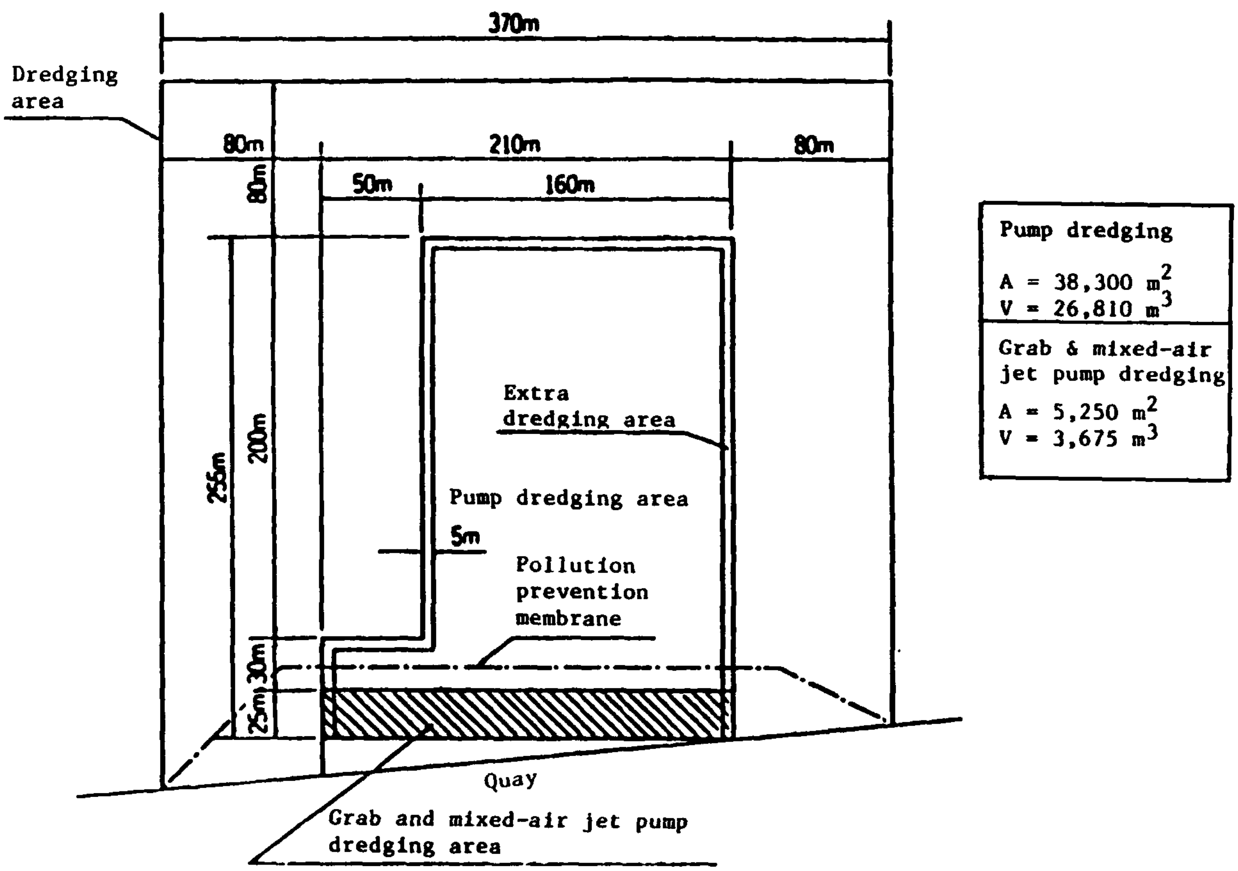

Figure 4. Dredging area by work type

Pump Dredging

Figure 5 shows the process used for transfer and discharge of dredged material by pump dredging.

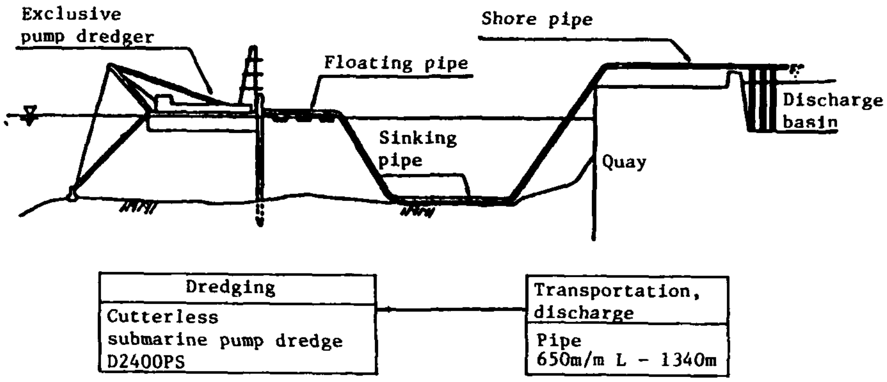

Figure 5. Pump dredging work flow

The dredge used is described in Table 5 and shown in Figure 6 and Photos 1 and 2.

Grab Dredging

In grab dredging, a closed-type grab was used to prevent generation and diffusion of turbidity. A pollution-prevention membrane (340 m long, 10 m deep) was stretched around the work area. This process is illustrated in Figure 7.

TABLE 5. SPECIFICATIONS OF PUMP DREDGE DAINI-TAIAN MARU

Feature	Description
Hull, total length	81.50 m
Length between verticals	47.40 m
Width	14.50 m
Depth	3.50 m
Draft	2.25 m
Dredging depth	25.00 m
Ladder pump, 2,300 $m^3/hr \times 23\ m \times 500$ rpm, driving motor (underwater variable-speed type), 300 kW	1 unit
Onboard pump, 3,000 $m^3/hr \times 68\ m \times 356$ rpm, diesel driving engine, 2,400 ps	1 unit
Ladder winch, electric, single-barrel type (20 t × 18 m/min × 100 kW)	1 unit
Swing winch, electric, double-barrel type (11 t × 0-16 m/min × 75 kW)	1 unit
Spud winch, electric, double-barrel type (16 t × 18 m/min × 75 kW)	1 unit

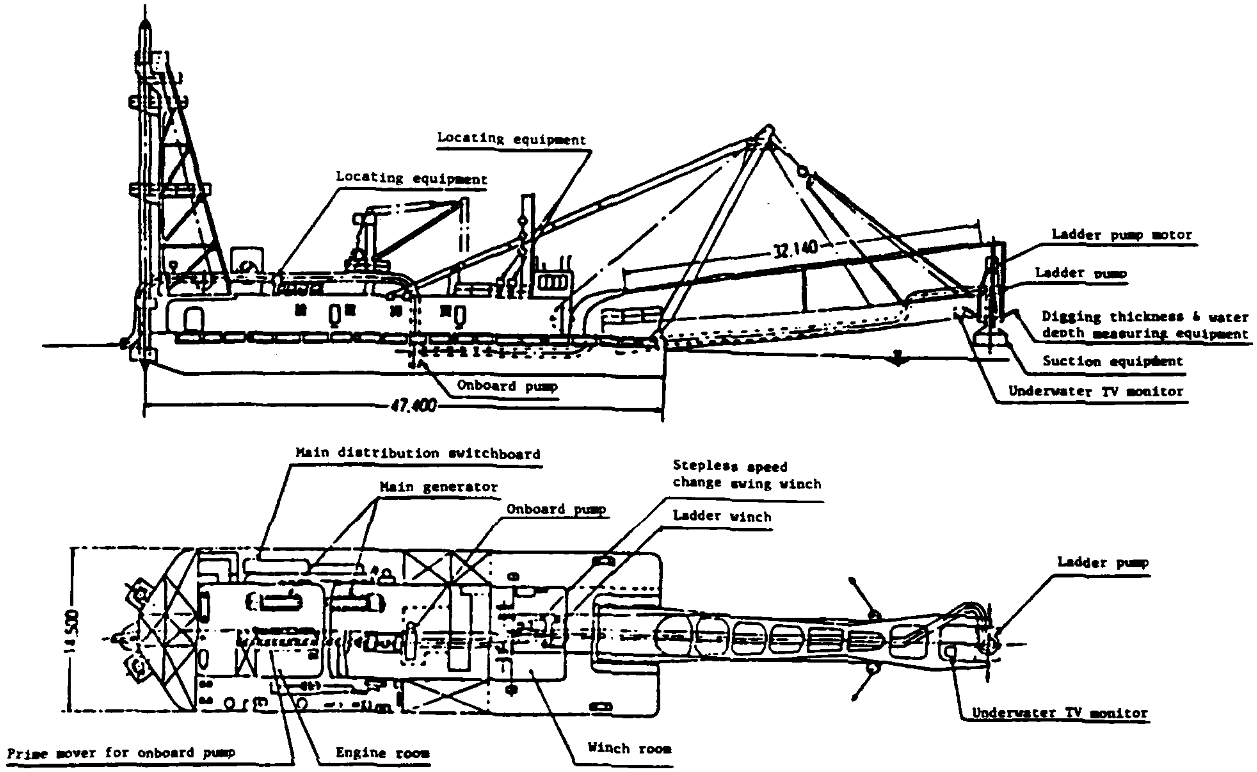

Figure 6. Pump dredge

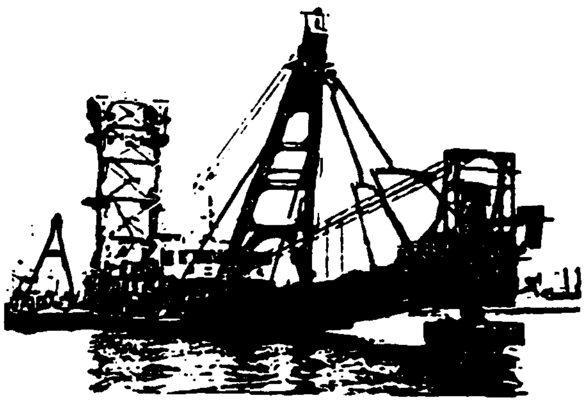

Photo 1. Pump dredge

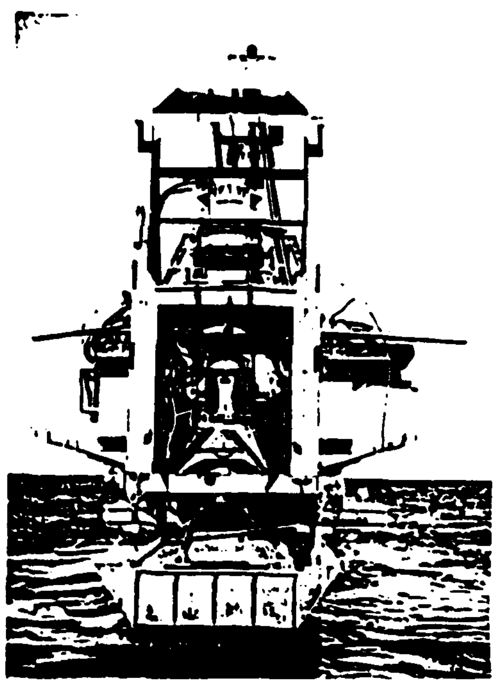

Photo 2. Bow of pump dredge

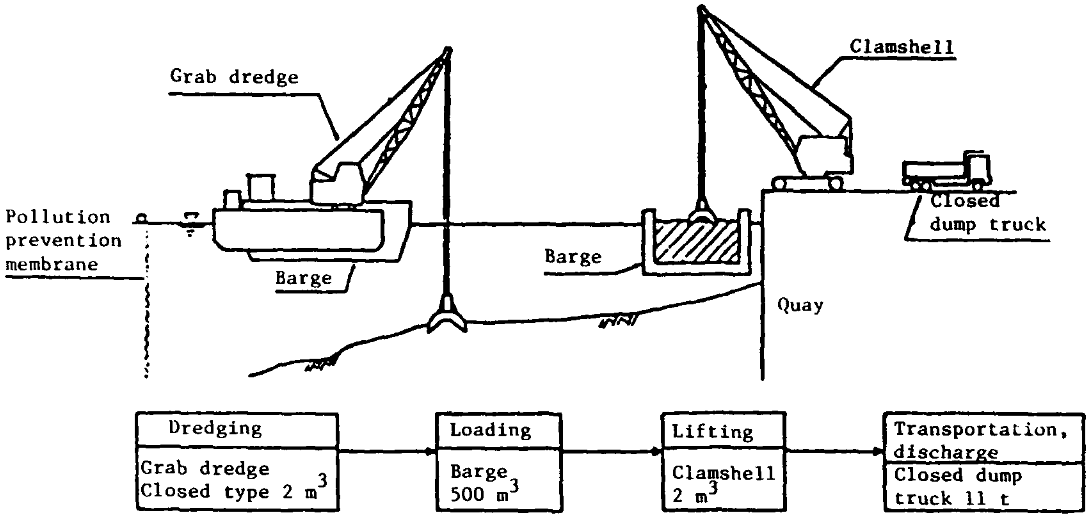

Figure 7. Grab dredging

Mixed-Air Jet Pump Dredging

After grab dredging, the mixed-air jet pump dredge (Figure 8) was used.

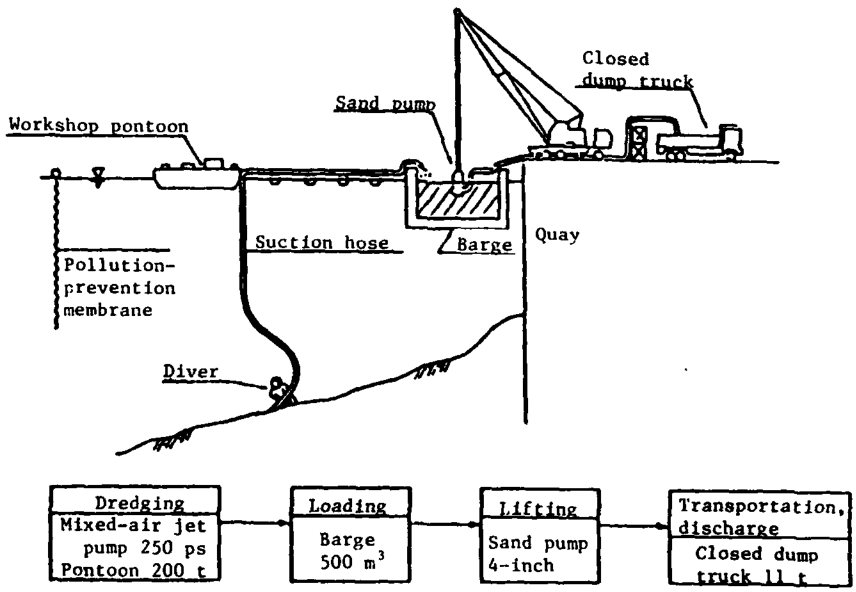

Figure 8. Mixed-air jet pump dredging

CONSTRUCTION OF DISCHARGE BASIN

Within the 60,000-m^2 disposal area, a discharge basin and residual water treatment facilities were installed. The discharge basin was erected with embankment by spot excavation. Inside, an impervious sheet was spread to prevent water seepage and scouring. The arrangement of the disposal area is shown in Figure 9 and Photo 3.

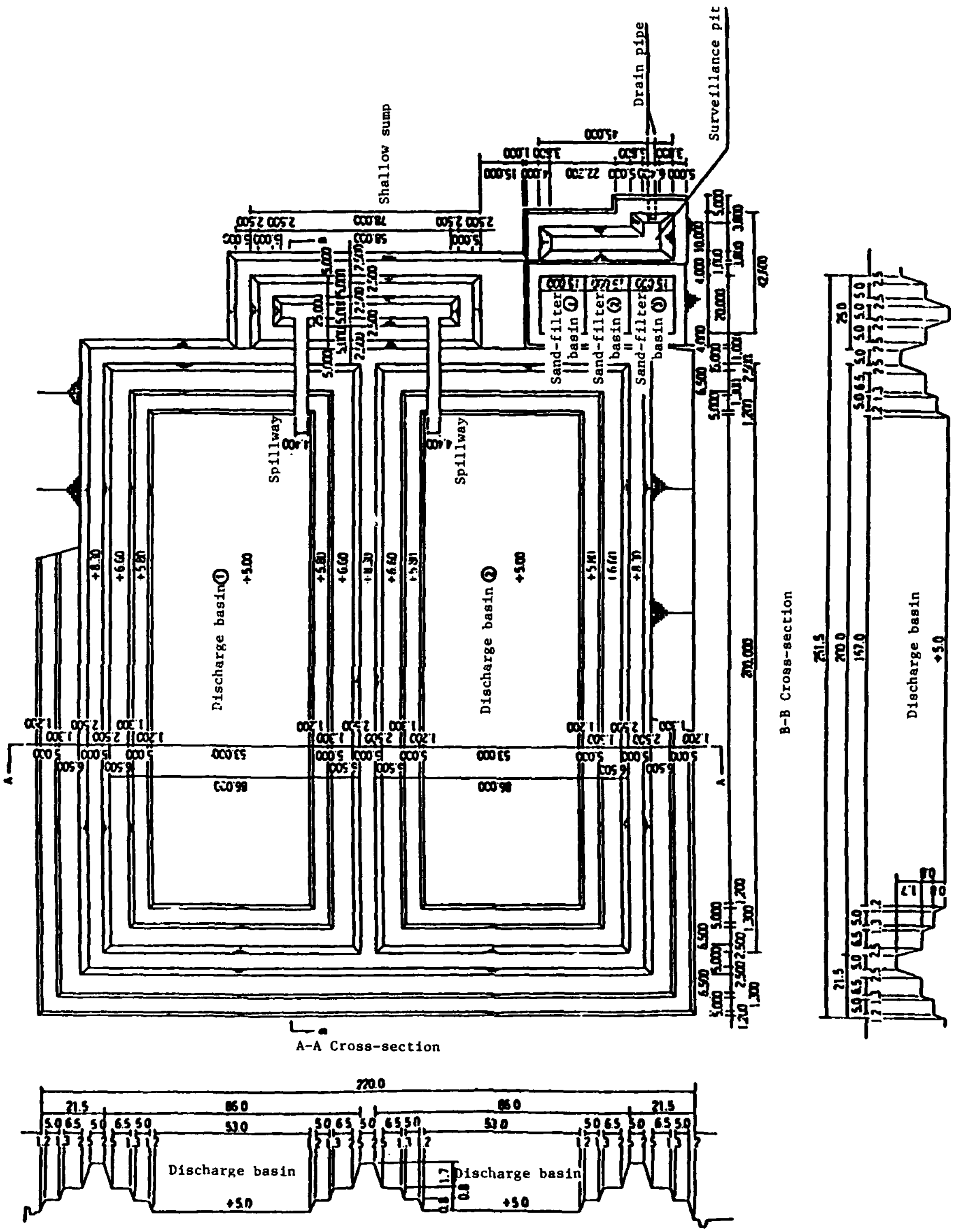

Figure 9. Plan view of disposal area

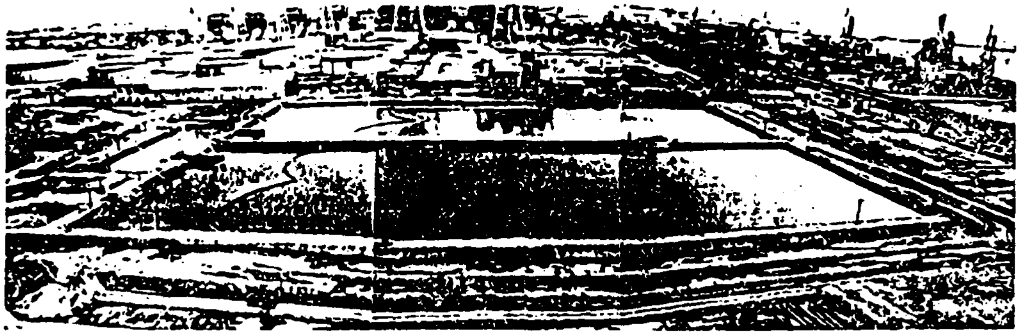

Photo 3. View of disposal area

RESIDUAL WATER TREATMENT

The residual water was treated by two-part separation of the discharge basin, alternating discharge and sedimentation. The segregated water was sand-filtered. This treatment is illustrated in Figure 10.

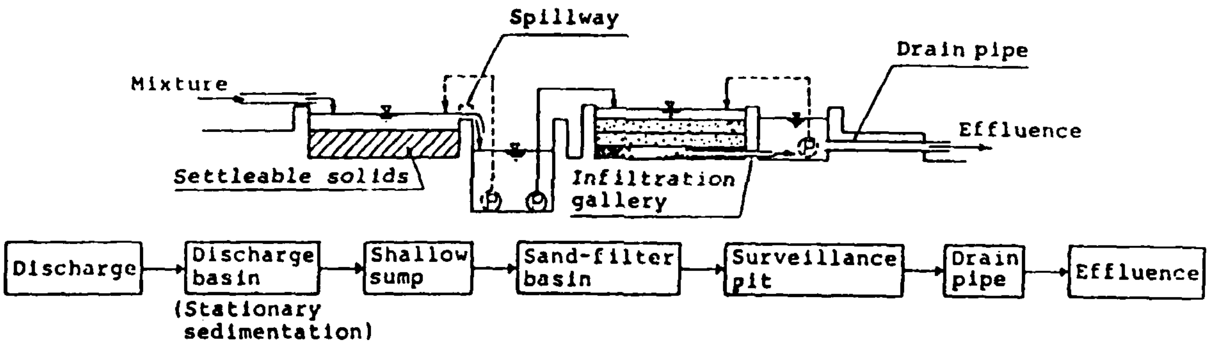

Figure 10. Residual water treatment

DISPOSAL

The accumulated material in the discharge basin was enclosed in an area about half the size of the basin. The final disposal area is shown in Figure 11.

The structure of the final disposal area includes embankment, as for the discharge basin, partially closed in by sheet piling and covered with impervious sheeting. The dredged material was allowed to solidify, and was transferred to the final disposal area and covered with sand (10 cm thick), gravel (15 cm thick), and asphalt. Figure 12 illustrates the final disposal process, and Figure 13 presents a cross-sectional view of the disposal area.

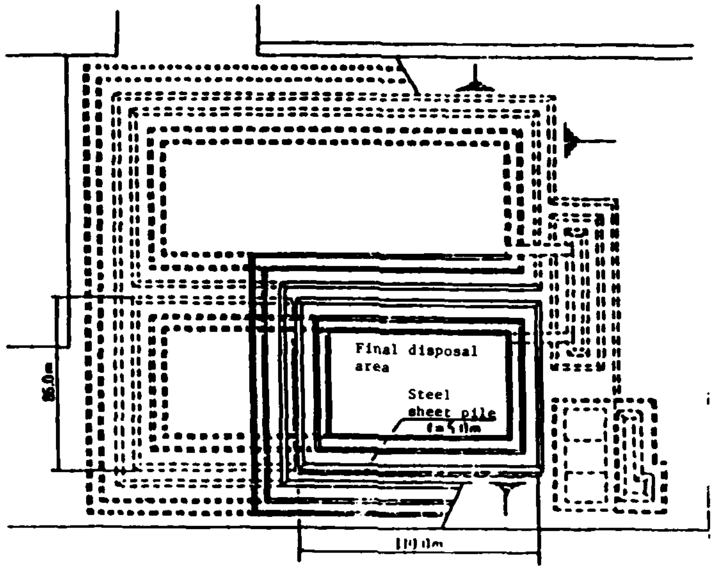

Figure 11. Final disposal area

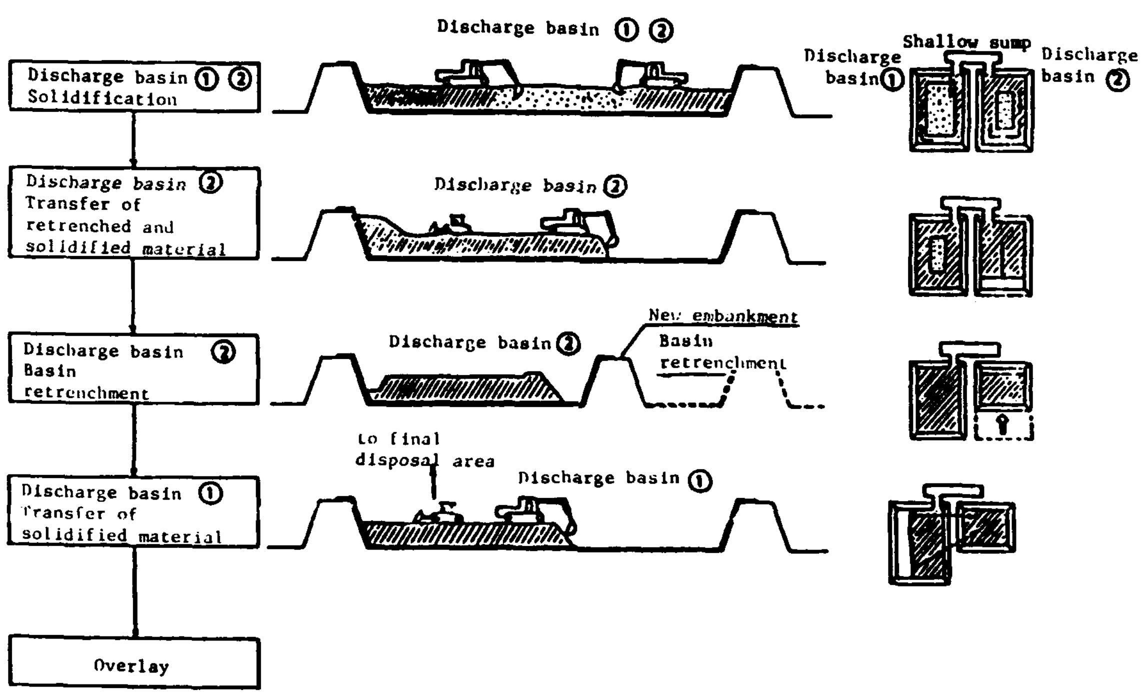

Figure 12. Final disposal process

MONITORING

Monitoring of the dredging and disposal activities was conducted to ensure that no secondary pollution was occurring. A diagram of the monitoring stations and a summary of the monitoring plan are presented in Figure 14 and Table 6, respectively.

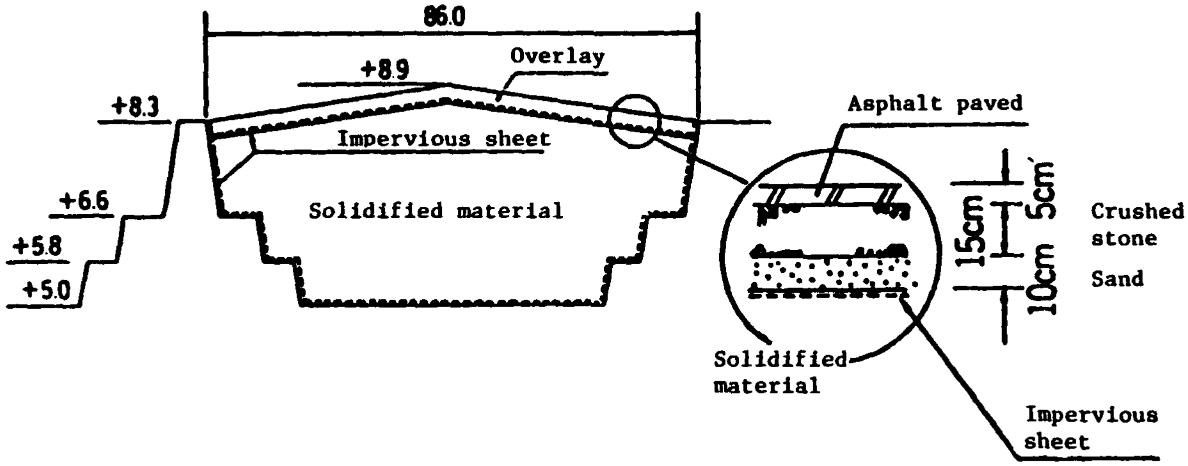

Figure 13. Cross-sectional view of final disposal area

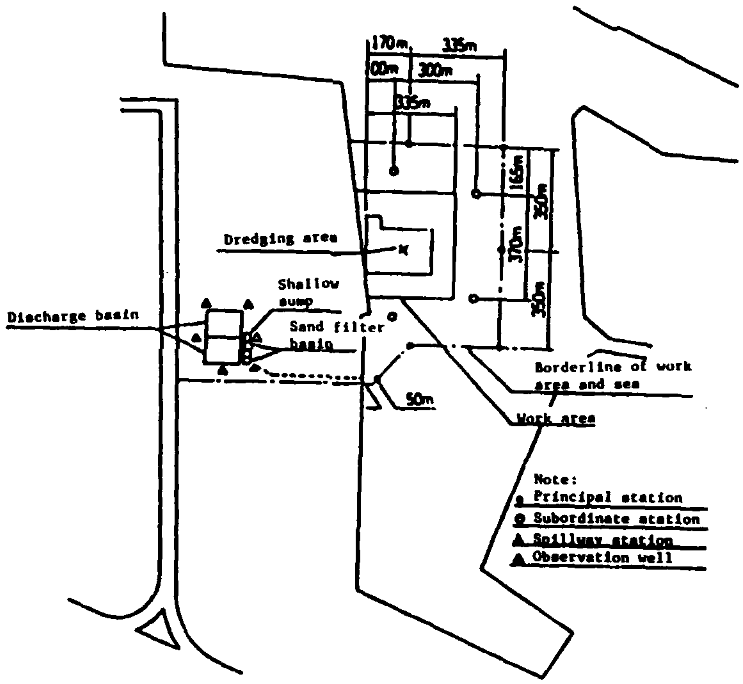

Figure 14. Monitoring stations

TEST RESULTS

Dredging Efficiency

A summary of the operational conditions and efficiency of the pump dredging is presented as Table 7.

Accuracy of Dredging

Representative dredging cross sections are shown in Figure 15. The average dredging depth was 76 cm in the level area and 97 cm in the sloping area.

TABLE 6. MONITORING PLAN*

Monitoring Station	Location (No.)	Parameter: PCB Test Frequency	PCB Standard Value	Other Contaminants (Cd, CN, Org-P, Pb, Cr, As, T-Hg, R-Hg) Test Frequency	Other Contaminants Value	Turbidity Test Frequency	Turbidity Standard Value	Human Environmental Parameters** pH	COD	DO
Principal	Borderline of general sea area (6)	2/wk**	ND†	--	--	--	Below 25 degrees	7.0-9.0	Below 8 mg/ℓ	Over 2 mg/ℓ
Subordinate	Within work sea area (4)	--	--	--	--	4/day	Below 30 degrees	--	--	--
Spillway	Surveillance pit (1)	2/wk**	Below 0.003 mg/ℓ	Twice	Below: Cd 0.1 mg/ℓ; CN Org-P, Pb 1 mg/ℓ; Cr, As 0.5 mg/ℓ; T-Hg 0.005 mg/ℓ; R-Hg none detected	2/day	Below 30 degrees	--	--	--
Ground	Immediate work area (5)	1/wk	ND							

* Also included was constant observation of oil film, turbidity, etc., in the immediate work area.
** Tested daily at initiation of dredging; twice weekly thereafter.
† Not detected.

TABLE 7. PUMP DREDGING EFFICIENCY*

Operational Feature	Value
Work days	26
In-situ sediment volume	33,370 m^3
Dredged material (sediment + water)	417,020 m^3
Operation hours	195
Dredging rate (in-situ)	171 m^3/hr
Dredging rate (sediment + water)	2,131 m^3/hr
Solids concentration (percent)	8.0

* Dredging width, 40-60 m; swing speed, 4-6 m/min; dredging depth, 40 cm (first dredging), 30 cm (repeat).

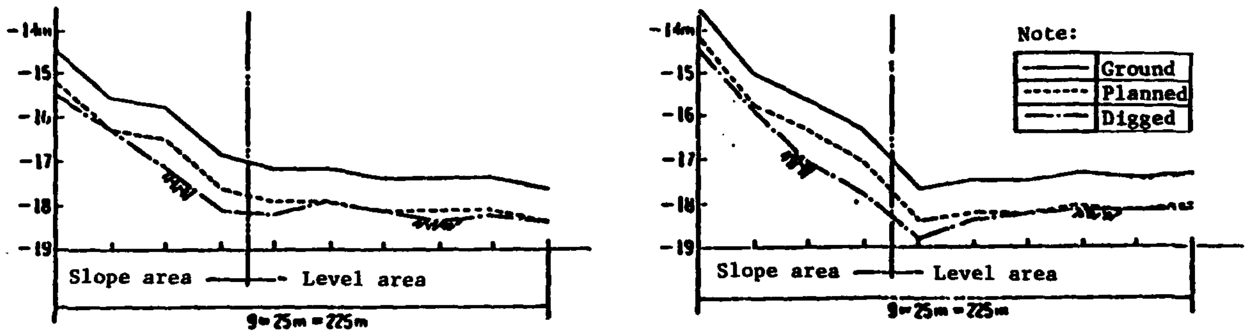

Figure 15. Cross-sectional view of pump dredging

Use of the exclusive (cutterless) pump dredge requires greater depth accuracy than the cutter pump because the dredging would be ineffective if all contaminated material were not dredged, and excess dredging would create management and disposal problems. The dredge was equipped with a depth control device that recorded the dredging depth continuously. As a result, accuracy was obtained, with little additional dredging required to achieve the planned depth of 70 cm (6 cm for the level area, 27 cm for the sloping area).

Turbidity

Figure 16 shows the results of water quality monitoring at the principal stations during dredging. Throughout the work period, turbidity was <5 degrees (standard value: <25 degrees), confirming that dredging created no problems of generation and diffusion of turbidity.

Volumetric Change

Dredged material increases in apparent volume by being mixed with water, and after dredging, does not compress and dehydrate until a mound forms in the discharge basin. Changes of volume must be considered in planning the

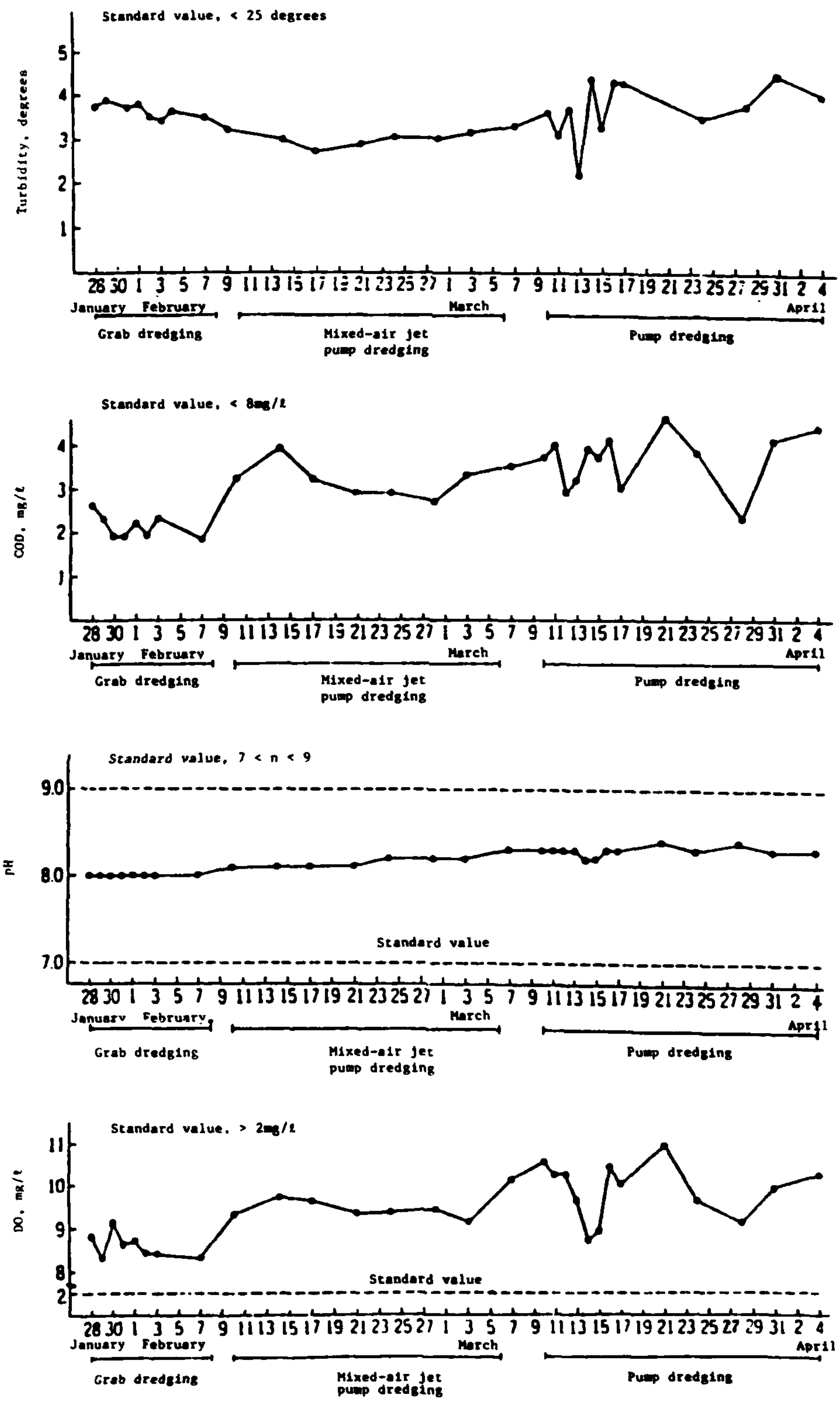

Figure 16. Results of water quality monitoring

discharge volume. The modulus of volume change was 1.41, comparing the total dredged volume of 37,500 m^3 with the discharge basin volume of 52,900 m^3 4 days after completion of dredging.

Residual Water Quality

Figure 17 shows the turbidity of the treated water after sand-filtering. The treated water volume through the work period amounted to 388,100 m^3, the turbidity of which remained less than 10 degrees. This clearly met the standard value of 30 degrees.

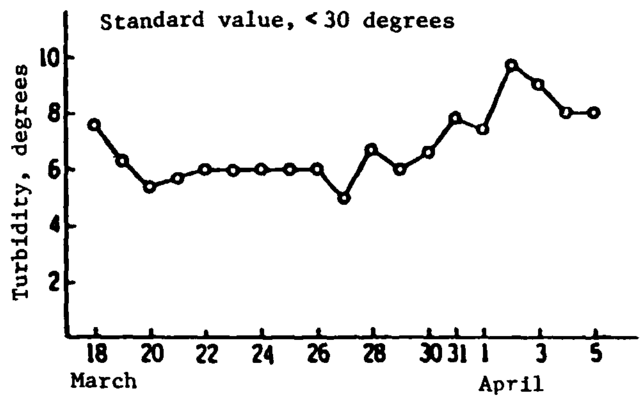

Figure 17. Residual water quality after treatment

INVESTIGATION OF RESIDUAL WATER TREATMENT METHODS

Since pollution by PCBs was a major concern, meticulous treatment of residual water was emphasized during the planning stage of the project. Various tests were conducted at each step of the treatment processes to identify the basic design elements for developing the best possible treatment method.

Generally, the focus of residual water treatment is on suspended solids (SS). Processes applied include solid-liquid segregation such as plain sedimentation, coagulated sedimentation, and filtering.

In consideration of the work objectives and the residual water quality standards, the treatment methods were applied separately or in combination. Figure 18 shows these methods.

Water Quality Standards

Standards provided in the Prime Minister's Office Ordinance stipulate that the "water quality standards of the seawater draining from the residual water outlet" have a PCB concentration below 0.003 mg/ℓ. Standards for this project include SS and turbidity as visual indices, in addition to PCB. Since heavy metals generally adhere to soil grains, SS in water and heavy metal concentration are said to have correlation. Therefore, correlation tests for PCB, SS, and turbidity were conducted, as shown in Figures 19 and 20.

Correlation among items is clearly indicated and, in the case of PCB and SS, the cohesion rate was about 1/36 against the theoretical line (in which all PCB is adhered to soil grains). The PCB content of the sample grain was

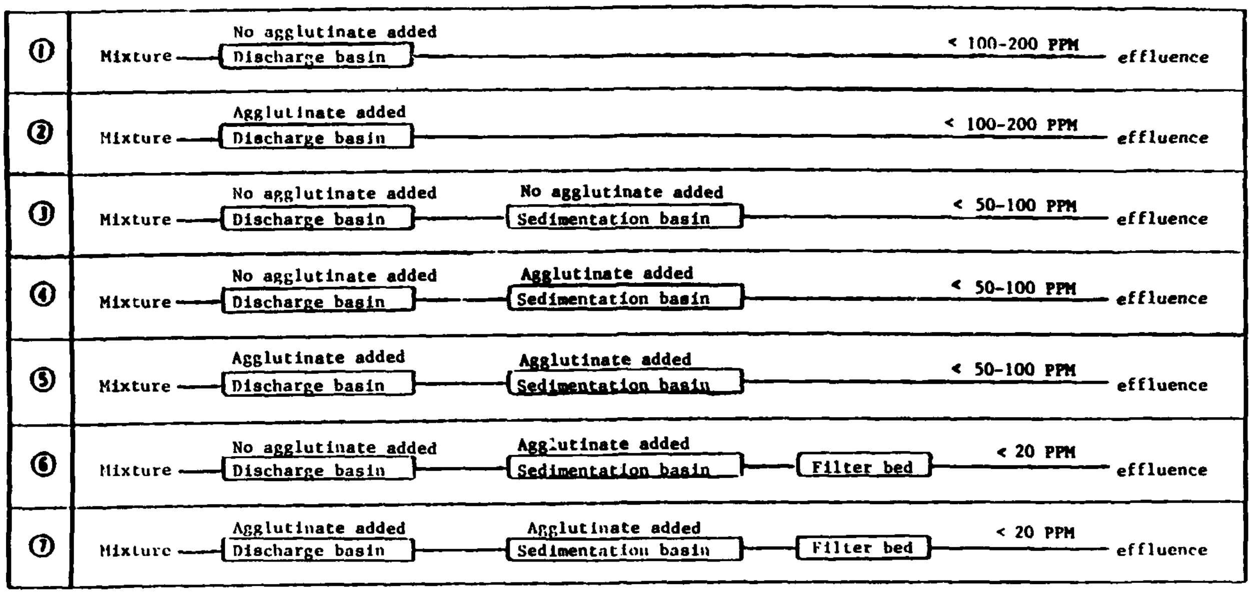

Figure 18. Residual water treatment methods

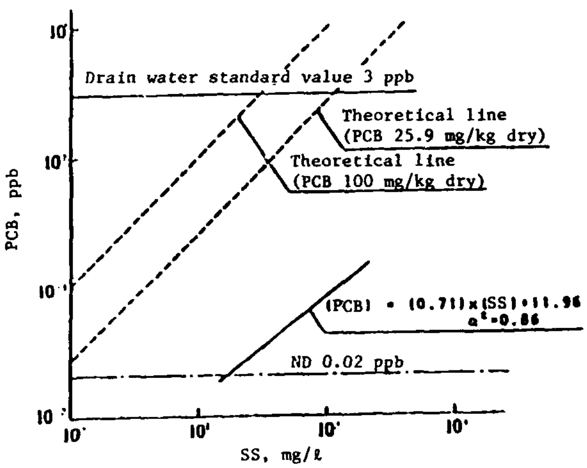

Figure 19. Correlation between PCB and SS

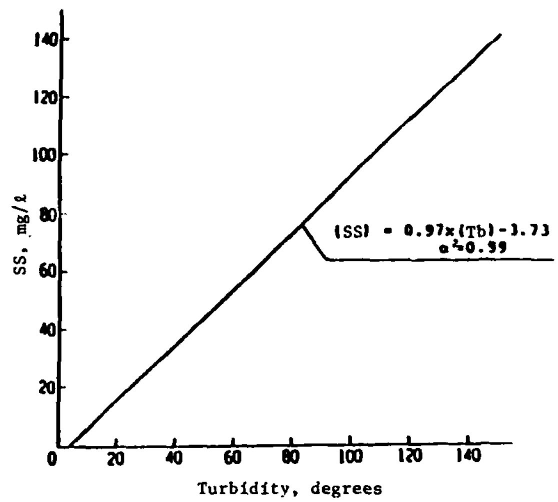

Figure 20. Correlation between SS and turbidity

25.9 mg/kg, and the SS corresponding to the standard value 0.003 mg/ℓ was calculated to be 30 mg/ℓ from the theoretical line of the maximum concentration of 100 mg/kg.

Though the SS standard concerning dredging is not provided in law, the Water Pollution Prevention Act and related local government regulations concerning specific factory facilities stipulate less than 30 mg/ℓ as the daily average and 35 mg/ℓ as the maximum. It was determined for this project that ≤30 mg/ℓ SS will achieve the PCB standard value.

Since analyses of PCB and SS take time and monitoring during dredging was difficult, turbidity (30 degrees) was selected as the control value, since it can be readily determined.

Table 4 lists the residual water quality standards that were based on the considerations described above and legal requirements.

Treatment Tests

Plain Sedimentation Test

The turbidity change of the segregated water by plain sedimentation (sediment content, 5 to 30 percent) is shown in Figure 21.

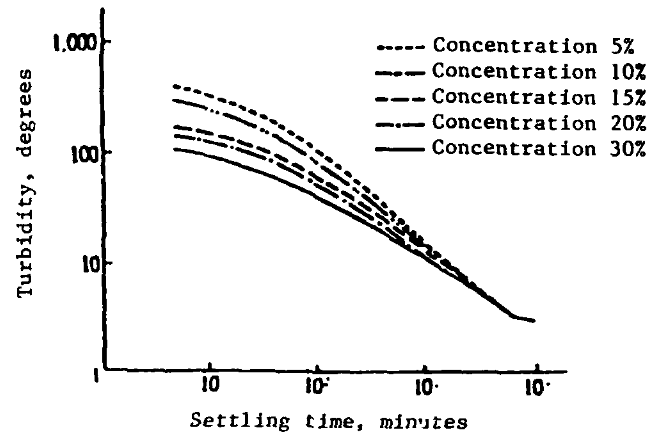

Figure 21. Turbidity of segregated water by plain sedimentation

Coagulated Sedimentation Test

Two methods of coagulation, one to add coagulant to dredged material directly (direct method) and the other to add segregated water in the discharge basin (shower method), were considered. Figure 22 shows the turbidity change by the direct method; Figure 23 shows the treated water turbidity after 30 min by the shower method and the required amount of coagulant to lower the turbidity below 30 degrees.

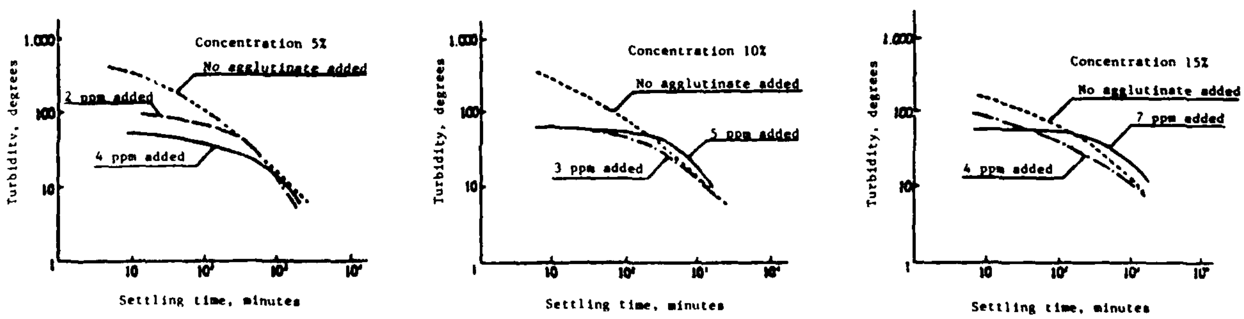

Figure 22. Turbidity of segregated water by coagulated sedimentation (direct method)

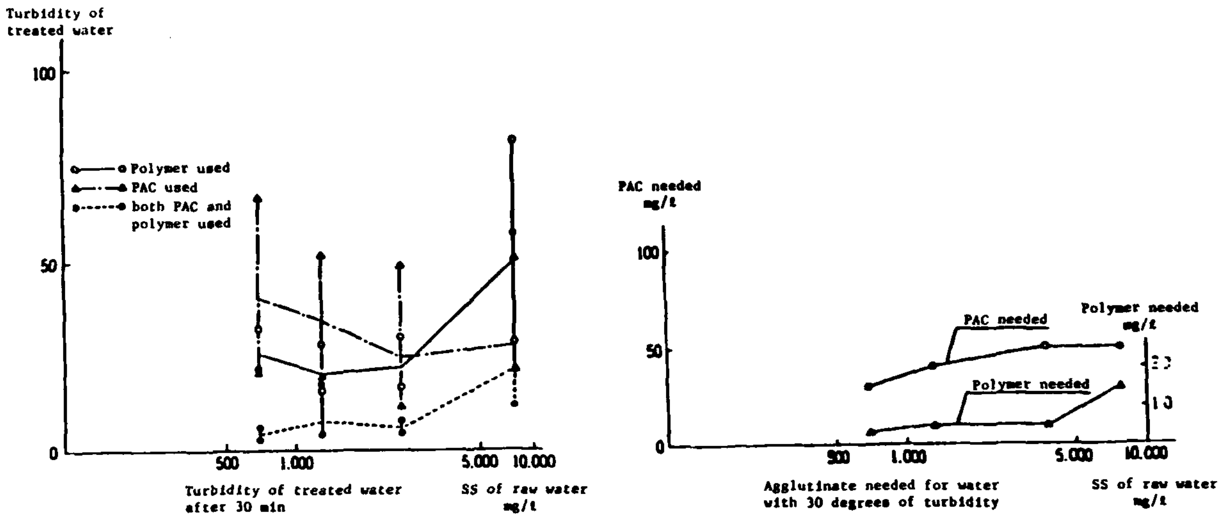

Figure 23. Coagulated sedimentation (shower method)

Volumetric Change Test

The modulus of volume change, which is indispensable in calculating the discharge basin volume, is shown in Figure 24 with regard to plain and coagulated sedimentation of dredged material with water content 5 to 15 percent.

Sand Filtering Test

Using the filter device shown in Figure 25 and two kinds of sand, the rate of filtration versus sand thickness and filter head and also the filtered water density versus the raw water were computed. The results are shown in Table 8 and Figure 26.

<u>Selection of Treatment Method</u>

Based on a comparison of the test results and treatment methods, the following conclusions may be drawn:

<u>a</u>. As to the natural stream sedimentation in the discharge basin, the concentration estimated from the water area load was 110 to 600 mg/ℓ and the coagulated stream sedimentation was 25 to 600 mg/ℓ. This is because the precipitation function in the discharge basin deteriorates as the work progresses. It is difficult to maintain the treatment standard throughout the work period. (Treatment methods 1 and 2, see Figure 18.)

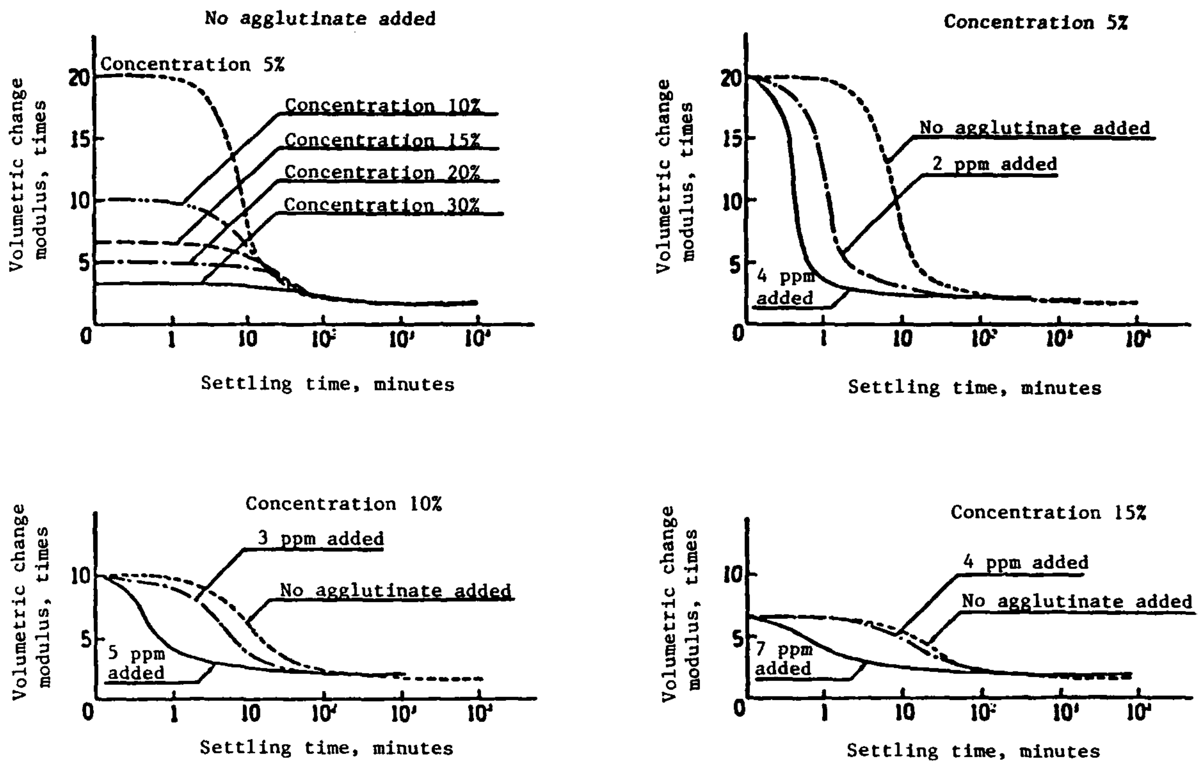

Figure 24. Volumetric change modulus of dredged material

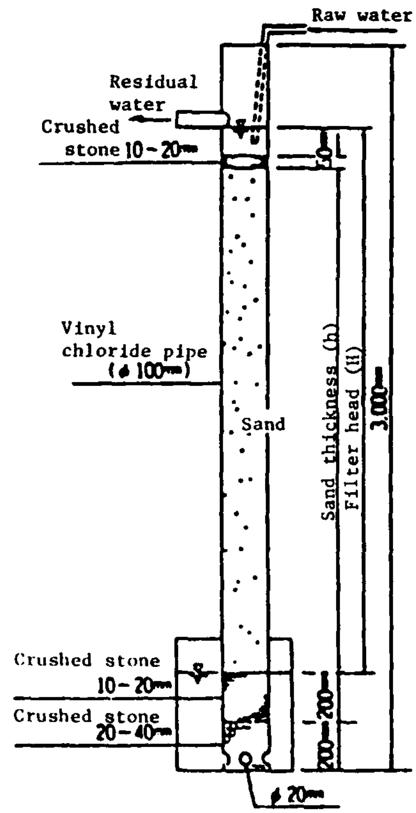

Figure 25. Sand-filter test equipment

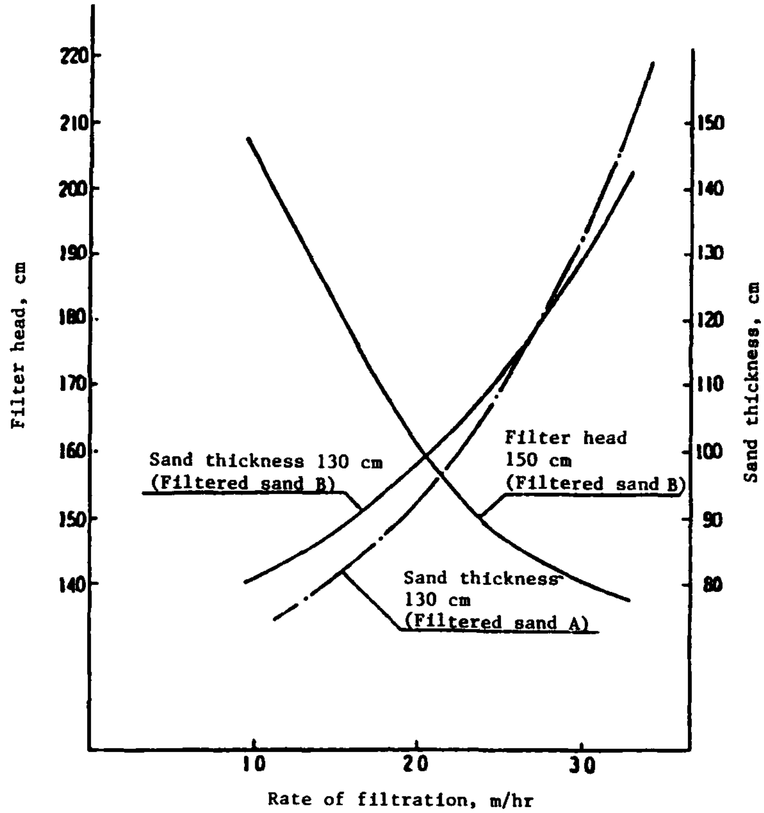

Figure 26. Rate of filtration by sand thickness and filter head

f. The volume change of dredged material in 7 days is 1.5 to 1.8 in the case of natural sedimentation and 1.9 to 2.1 in the case of coagulated sedimentation, showing the tendency of aggutinate to increase volume.

Based on the test results and the operational conditions, stationary sedimentation treatment in the discharge basin and sand-filtering of the segregated water were chosen as the most promising techniques.

Treatment Facilities

When stationary sedimentation treatment is done in a single operation daily, the time for sand-filtering and draining of the segregated water is inadequate to attain the desired result, and the scale of the facilities as well as the water volume must be very large. Therefore, the discharge basin was subdivided, and discharge and sedimentation were alternated. Figure 27 shows the treatment cycle, and Table 9 outlines the use and scale of the treatment facilities.

The sand-filter basin (Photo 4) was designed with a filter head of 190 cm, a sand thickness of 130 cm from the planned water volume of 1,650 m^3/hr, and a filtering speed (as an example) of 3.0 m/hr. Thus, the

TABLE 8. TREATMENT RESULTS

Turbidity of Raw Water, degrees	Turbidity of Treated Water, degrees	Elimination Rate, %
	Filter Head 150 cm, Sand Thickness 90 cm, Sand A	
75	2	97
100	2	98
	Filter Head 150 cm, Sand Thickness 130 cm, Sand A	
50	2	95
103	2	98
160	3	98
220	2	99
265	2	99
315	2	99

b. In the case in which the segregated water is treated in the natural sedimentation pond after the stream sedimentation in the discharge basin, its SS structure of small grains is very slow to precipitate; therefore, it is difficult to fulfill the standards. (Treatment method 3.)

c. Likewise, in the case of coagulated sedimentation, it is assumed that the amount of agglutinate can be managed to attain the desired result, but the basin should be 40 to 45 m wide and 120 to 130 m long to fulfill the facilities design standard (basin stream velocity <40 cm/min and settling time 3 to 5 hr). Therefore, it is difficult to obtain the land to construct such facilities. (Treatment methods 4 and 5.)

d. By the sand-filter treatment, the density of treated water (2 to 3 mg/ℓ) can be obtained from the raw water (50 to 300 mg/ℓ), which is highly efficient and stable. (Treatment methods 6 and 7.)

e. The natural stationary sedimentation in the discharge basin can produce 30 to 65 mg/ℓ of segregated water in 3 hr, and the coagulated stationary sedimentation, 20 to 55 mg/ℓ.

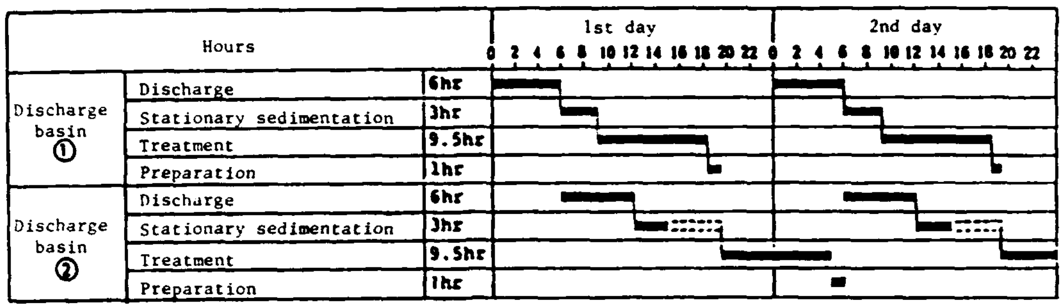

Figure 27. Residual water treatment cycle

TABLE 9. RESIDUAL WATER TREATMENT FACILITIES

Facility	Purpose	Features	Scale
Discharge basin	Storage and precipitation of dredged material	Volume change rate: 1.73 Storage volume: 20,800 m^3 Marginal height: 0.5 m	200 m × 86 m × 3.3 m 45,000 m^3 (2 basins)
Spillway	Draining of segregated water to sump	Rainfall increase est. 1.2 hr (1,350 m^3/hr)	4.4-m width (2 units)
Shallow sump	Storage of water from spillway	Storage volume: for 2.1 hr (1,350 m^3/hr)	78 m × 25 m × 3.3 m 2,870 m^3 (1 pond)
Sand-filter basin	Filtering of residual water	Volume, safety rate: 1.2 (1,650 m^3)	15 m × 20 m (3 ponds)
Monitoring pit	Observe filtered water quality	Storage volume: for 0.6 hr	45 m × 17.6 m × 2.5 m 1,000 m^3 (1 pond)
Drainway	Drainage to sea of filtered water that meets the standard	(1,650 m^3)	ϕ 650 m/m L = 380 m (2 routes)

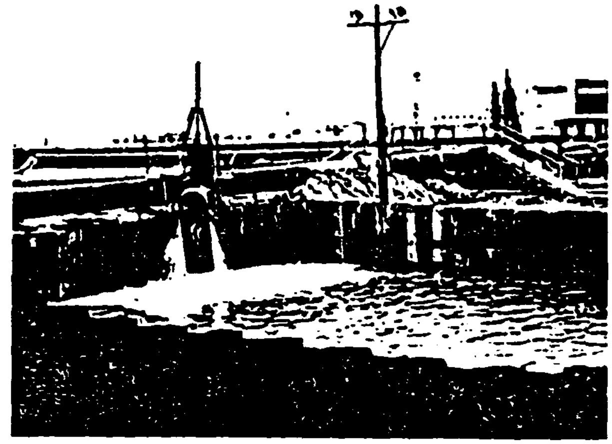

Photo 4. Sand-filter basin

required filter area was calculated and designed to be 550 m, with three ponds each with the area of 15 by 20 m. Two ponds were put into operation, and the third was set aside for sand exchange.

The cross section of the sand-filter basin is shown in Figure 28, and the arrangement of the infiltration gallery is shown in Figure 29. The monitoring pit is shown in Photo 5.

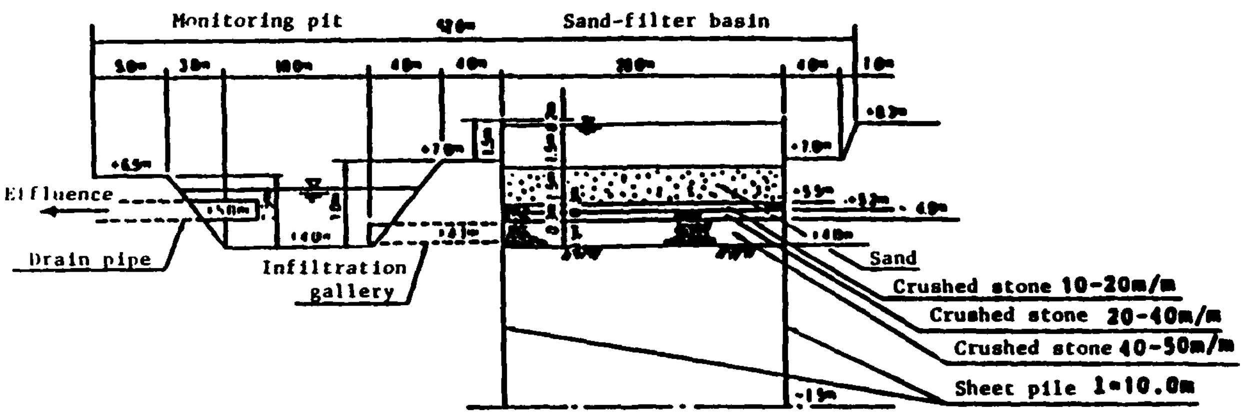

Figure 28. Cross section of sand-filter basin

Treatment Results

Results of the sand-filter treatment are plotted in Figure 30. The raw water turbidity ranged between 10 and 100 degrees, which tended to be higher in the latter part of the work period. However, the treated water turbidity was kept stable at <10 degrees throughout the period, a highly satisfactory result. The total volume of treated water was 388,100 m^3.

CONCLUSIONS

In disposal of dredged material, especially that containing harmful materials, prevention of secondary pollution that may accompany the work is of utmost importance. This paper reported a project that involved dredging and

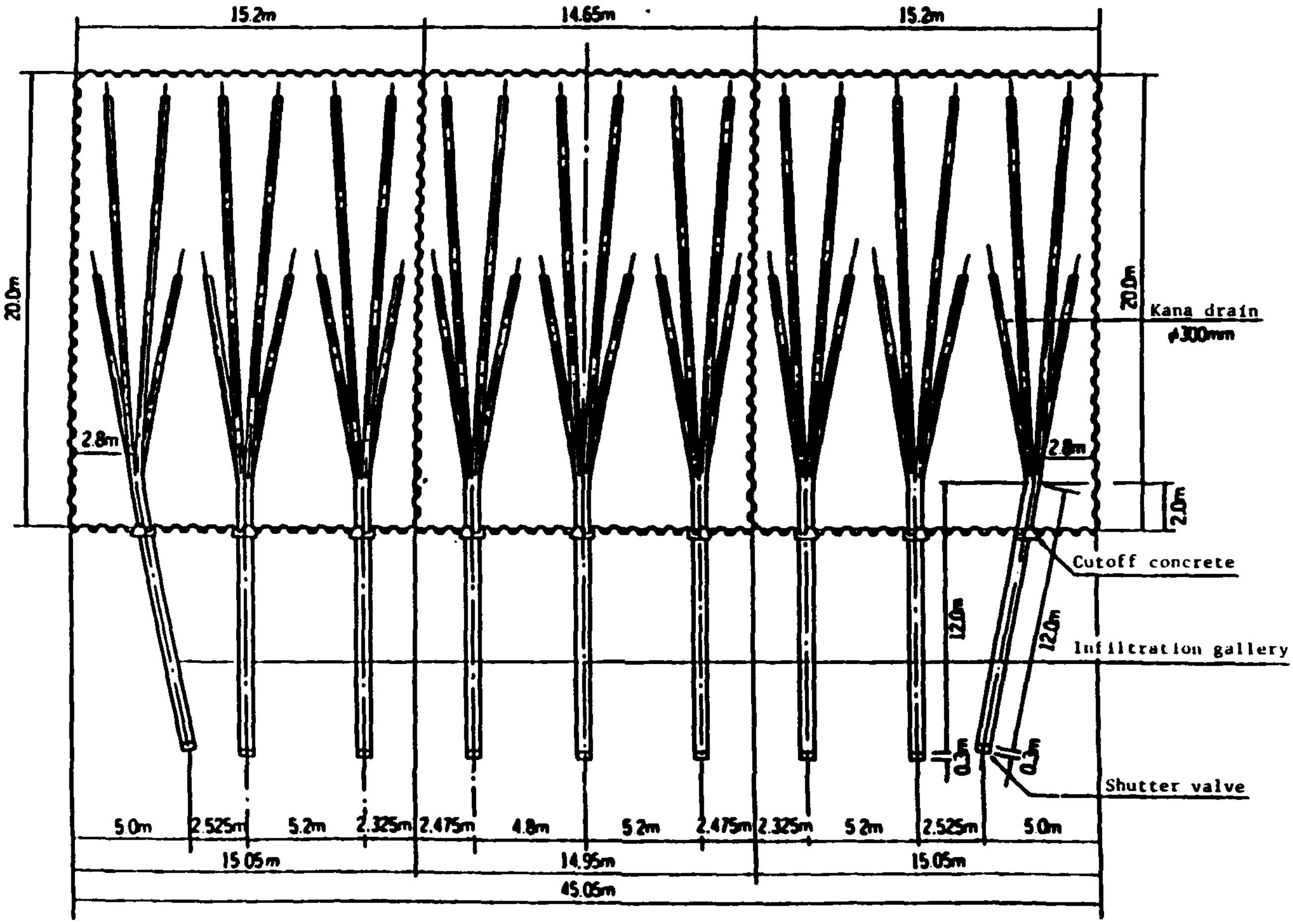

Figure 29. Arrangement of infiltration gallery of the sand-filter basin

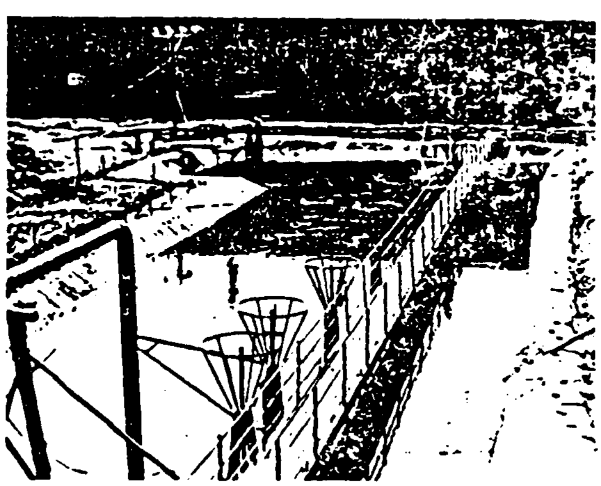

Photo 5. Monitoring pit

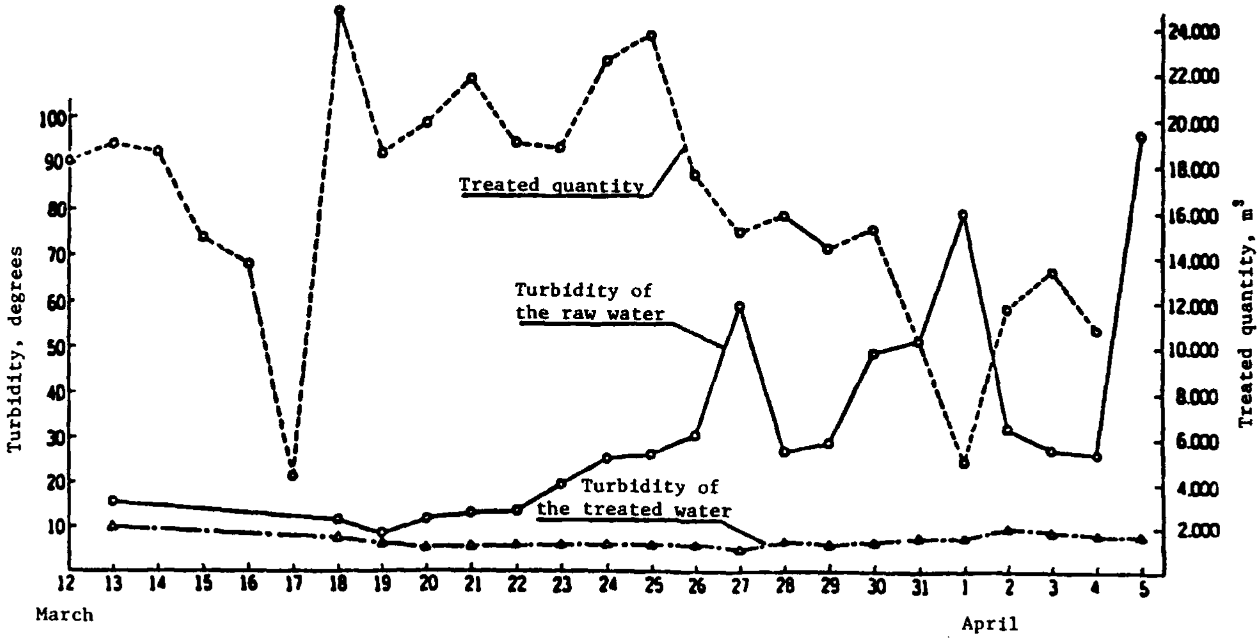

Figure 30. Results of sand-filter treatment

upland disposal of PCB-contaminated material. In this project, preliminary investigations were conducted to select safe and effective work methods. The work progressed safely as planned. No serious problems occurred, and the objectives were met. The landfill area is now used as a parking lot.

Care and countermeasures to prevent adverse environmental effects are always required in conducting water projects, regardless of the sediment quality. Therefore, the fundamental problems reported herein can be applied to other dredging work. However, since the landfill disposal has inherent problems, such as volume change of dredged soil and estimation of residual water concentration, continuous studies may be required.

LAKE RESTORATION BY DREDGING

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ABSTRACT

This paper is a summary overview of the $17 million Vancouver Lake Restoration Project, the largest project of its type ever undertaken through the Federal Clean Lakes Program. It was funded jointly by the US Environmental Protection Agency, the Washington State Department of Ecology, and the Port of Vancouver. Although the project was conceived in 1965, a nationwide program to help fund such projects did not exist until 1976. Then, final approval was not received until 1981, after many volumes of studies and reviews. Construction was completed in June 1983, after 30 months--6 months ahead of schedule and underbudget.

A great deal of time, money, and energy was expended to demonstrate to Federal and state environmental agencies that dredging was a key tool in effecting this lake's restoration. Their collective resistance to this notion has been challenged by the project's success. This paper focuses primarily on the dredging aspects of the project. It identifies the concerns raised, the dredging and materials handling methods used, and the relative success of the techniques, not only in terms of operational effectiveness but in terms of environmental protection.

BACKGROUND

Vancouver Lake is a 2,600-acre (6,425-ha) lake lying in the floodplain of the lower Columbia River in the southwestern corner of Washington State on the west side of the City of Vancouver and north--across the Columbia River--from the City of Portland, Oreg. It is within a 45-min drive of the million-plus residents of the Portland-Vancouver metropolitan area and, in its restored condition, has become an immensely popular recreational resource for our regional community.

Until the early years of this century, Vancouver Lake was a relatively clear, moderately deep (6 to 8 m) lake cleansed twice yearly by the spring and fall freshets of the Columbia River. Over the years, construction of dams on the Columbia and dikes on the lowlands surrounding the lake virtually eliminated this natural flushing system.

At the same time, urbanization in the 27-square mile (70-km^2) drainage basin feeding the lake's only tributary contributed substantial siltation and pollution. At the start of project construction in early 1981, the lake's depth averaged 1 m (at low water). It was not safe for human use and was in a highly advanced state of eutrophication.

APPROACH

The $17 million Vancouver Lake Restoration Project is the largest project of its type ever undertaken in the United States under the National Clean Lakes Program. By the phrase, "of its type," I refer specifically to a project having three key elements:

a. Limiting the inflow of pollutants from both urban and agricultural nonpoint sources.

b. Flushing the lake with relatively clean Columbia River water.

c. Deepening and contouring the bottom of the lake.

Limiting the inflow of pollutants involved three actions, all of which are being phased in over several years:

a. Elimination of septic tanks in the basin by a major expansion in the city's sewer system.

b. Institution of a storm drainage and runoff control management plan in the tributary drainage basin.

c. Establishment of an agricultural practices management program to control erosion, manage the application of fertilizers, and contain animal wastes to prevent entry to the waterway.

Flushing the lake with relatively clean Columbia River water was the key, however. In constructing the 4,300-ft (1,310-m) flushing channel from the Columbia River, we were merely imitating the natural system, based on the fact that water flows downhill.

Specifically, the water flows on an 18-in. (46-cm) gradient over the length of the channel and enters two 7-ft (2-m) culverts fitted with flap gates that lead into the lake. Whenever the river water elevation is higher than the lake water elevation, the riverflow opens the gates and flushes the lake; at equilibrium or lower, the lake waters close the gates and backflow is prevented.

Before construction, it was estimated that the waters of the lake turned over every 25 to 28 years; with the flushing system in place, the waters of the lake are renewed every 21 days or so. The improvement in water quality has been significant.

The benefits of this system are twofold. First, and most obvious, is the cleansing action itself. Secondly, the infusion of this "new" water inhibits algae blooms. In short, the lake becomes a better habitat for fish and safer for human contact.

As complex as this hydrological problem was, the key was dredging the lake and handling the dredged material--about 9 million cubic yards (almost 6.9 million cubic meters). The intent and purpose of the dredging was threefold. The first and most important objective was to aid the flushing action. The point was not simply to deepen the lake, but to contour and sculpt the bottom of the lake to maximize the benefits of the flushing action.

Second, deepening selected portions or segments provided sump areas for heavy sediments to settle. Three were built--one where the river enters the flushing channel, one where the flushing channel enters the lake, and one where the lake enters its only outlet, appropriately called "Lake River." These "holes" also provide for ease of any future maintenance dredging, for that is where the sediments collect.

Third, dredging and periodic overdredging provided environmental and recreational benefits. This deepening allowed more year-round boating and fishing and closer-to-shore swimming areas. The holes provided deeper and cooler water for the fish species in the lake, and the deepening somewhat reduced turbidity caused by wind and wave action stirring the bottom sediments.

Several concerns had to be addressed:

a. What kinds of materials would be dredged.

b. How much material should be dredged.

c. Where in the lake would dredging occur.

d. Were any of the materials contaminated.

e. How would contaminated sediments be handled and disposed.

f. How would the uncontaminated sediments be handled and disposed.

g. What types of equipment would be used for dredging.

h. How would dredging occur, that is, where and when.

i. What would the total environmental impacts be and how would they be minimized.

As it turned out, the bulk of the sediments dredged were fine silts, some with clay, others more sandy in nature. There were also pockets of sands, sands and gravel, and clays. Dredge production throughout was greater than predicted.

Determination of the amount of material was the result of a carefully designed hydrological plan to maximize the benefits of flushing, including channel width, depth, distance from shore, and specific locations for overdredging and for disposal of certain materials. The "operations plan," as it was called, was executed with very few problems.

After much study it was discovered that some areas of the lake had contaminated sediments, specifically, with heavy metals and certain pesticides.

However, the studies and bioassays also demonstrated that these contaminants were bound up in the soil particles and not available to the biota. This also proved true with land disposal. No leaching of contaminants into the ground water occurred. In short, no unique dredging or disposal methods were necessary to handle these sediments.

As one might imagine, identifying disposal sites for such a large volume of material proved difficult. During the project, we constructed one island, modified the shoreline on the east side of the lake, and filled about 600 acres of uplands (about 243 ha) in five locations (Figure 1).

Because of the nature and quantity of the material, the upland disposal sites were constructed with large cells to provide sufficient time for decanting the dredged material before the return water went back to the lake. In fact, the lake became the last "settling pond" in the chain; however, no water quality standard violations occurred during the entire project.

Initially, we had intended to build two islands, using silt curtains. However, these did not perform as predicted. They did not contain the fine sediments, and the outer rim of the one island that was built finally had to be constructed using a clamshell dredge. In place of the second island, we filled a portion of the east shore. Silt curtains proved only marginally successful in containing that site.

The Port went through a lengthy evaluation of dredging methods and equipment, including the "Pneuma" system used in Japan and Europe, a system that, in spite of its lower production and higher operating costs, might have been required had our studies not shown that the contaminated sediments posed no danger.

The contractor used a 24-in. (64-cm) cutter suction dredge (after dry land excavation to the water table) to construct the flushing channel from the Columbia River. As indicated above, a clamshell was used in constructing the outer edge of the island.

The real ingenuity of the contractor was demonstrated in the lake dredging. Because of the shallow water, the boom on a 30-in. (76-cm) cutter suction dredge was shortened. However, to maximize production, the hull length was doubled by welding another dredge hull with it. The arc of the dredge swath was huge. Finally, to minimize costs, the dredge was electrified. An 18,000-ft (5,500-m) electrical cable supplied power. Further, transponders were set up at key locations around the lake. The dredge captain always knew exactly where he was operating relative to the dredging plan.

SUMMARY

The lake project not only resulted in improved water quality and aquatic habitat but provided additional wetlands (east shore), additional waterfowl habitat (the island), and better and higher agricultural land (the sediments are quite fertile). The project actually increased the shoreline length in the lake. Usage of the park on the lake's west shore went from a few hundred visitors per day during the summer months to several thousand.

Figure 1. Vancouver Lake, Washington, restoration project area

The Vancouver Lake Restoration Project has, thus far, been a success. The water quality improvements exceeded prediction, and after nearly 5 years, it appears that dredging maintenance will be much less than had been predicted--once every 5 to 7 years in the flushing channel sediment sump (estimated at 40,000 to 45,000 yd^3 (about 3,060 to 3,440 m^3) and perhaps once every 40 to 50 years in the lake itself. Moreover, the environmental and recreational benefits are substantial.

That success would not have occurred without two key ingredients. First, the documentation developed by the US Army Engineer Waterways Experiment Station's Dredged Material Research Program was vital in demonstrating that the dredged materials would behave as predicted. Second, the dredging industry and our contractor, Reidel International, in particular, demonstrated an ingenuity and knowledge that not only overcame problems and reduced costs, but proved irrefutably that dredging is a tool not only for waterways development but for environmental restoration and enhancement as well.

In conclusion, projects such as this one affirm that man can lay a kind hand on the environment. Conferences such as this allow us to share these experiences and our growing knowledge and practical expertise. One wishes such understanding could be spread to a broader audience.

THE LONDON DUMPING CONVENTION (LDC): REGULATION OF DREDGED MATERIAL THROUGH GUIDELINES FOR APPLICATION OF THE ANNEXES TO DREDGED MATERIAL

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ABSTRACT

The prevention of pollution of coastal/marine waters is a major concern of the 61 nations signatory to the LDC. The goal of the LDC by the member countries is to take all practical steps to prevent any pollution of the sea and marine life, damage to amenities, or interference with other legitimate uses of the sea (Article I of the LDC). All waste materials dumped into the sea or proposed for sea dumping, including dredged material, are regulated on a global basis by member nations through the LDC. The LDC construction is quite simple and straightforward. The Articles comprise the legal framework, while the Annexes (i.e., I - Prohibited Materials, II - Materials Requiring Special Care, and III - Provisions for Developing Regulatory Criteria) are the technical framework for implementation of the Articles. Technical Guidelines for interpreting the Annexes comprise the day-to-day working-level application of the LDC. The LDC was formed in 1972 and did not distinguish among waste materials. All were handled in precisely the same manner, even though there were no technical reasons to do so. Through the application of the LDC, guidelines were developed that began to separate dredged material from other materials (e.g., sewage, industrial waste). Recently (October 1986), after several years of technical negotiation at the annual LDC Consultative and Scientific Group meetings, special guidelines for dredged material were developed. This paper will discuss the evolution of the "Guidelines for the Application of the Annexes to the Disposal of Dredged Material," their implementation, and their meaning to the dredging and port interests.

INTRODUCTION

The Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter--known as the London Dumping Convention or LDC--was negotiated in November 1972. After ratification by 15 member nations, the LDC came into force in the United States on August 30, 1975. The contracting nations have met annually since September 1976. There are now 61 nations signatory to the LDC.

The policy, regulatory, and technical aspects of the US Army Corps of Engineers (USACE) and the US Environmental Protection Agency (EPA) ocean dumping programs for dredged material are directly affected by the United States being signatory to the LDC. Domestic criteria must, at a minimum, be equivalent to and contain all of the basic constraints set forth in the international regulations.

A Scientific Group (SG) was formed to make technical and scientific recommendations to the LDC concerning the ecological aspects of regulating dumping at sea. The SG met in September 1977 and has since met annually approximately 6 months prior to each annual LDC meeting.

Intersessional working groups of experts meet on an ad hoc basis to develop special guidelines, to discuss legal implications, and to intensely evaluate new approaches to the technical aspects of the international regulations. Examples are groups to develop guidance for incineration at sea, guidelines for the implementation of Annex III, guidance for allocation of substances to the prohibited or special-care lists, and guidelines for the application of the LDC annexes to disposal of dredged material.

The Deputy Director of Civil Works, USACE, and a representative of the Assistant Secretary of the Army for Civil Works generally attend the annual meetings of the LDC as Army policy representatives. The author is the Corps' technical representative at LDC, SG, and special intersessional experts meetings.

Application of the LDC

The signatory countries take all practical steps to prevent any pollution of the sea that is liable to create hazards to human health, to harm living resources and marine life, to damage amenities, or to interfere with other legitimate uses of the sea (Article I of the LDC).

The construction of the LDC is simple and straightforward. The articles that comprise the legal framework of the Convention develop the formal regulatory foundation. The annexes (i.e., Annex I - Prohibited Materials, Annex II - Materials Requiring Special Care, and Annex III - Provisions for Developing Regulatory Criteria) develop the technical framework for implementation of the articles. Interim technical guidelines for interpreting the annexes of articles comprise the day-to-day working-level application of the LDC. The simplicity ends here.

Many legal and technical terms and constraints were ill defined or even undefined by the founders, leaving to the signatory countries the very difficult job of implementation through their domestic procedures. The LDC meets annually and conducts business on a consensus basis after debating the issues at hand. A vote is rarely taken and is regarded as the choice of last resort. Issues, questions, legal and technical positions, rule changes, modifications, or proposals can be submitted to the annual consultative meetings only by member nations and debated and acted upon by said member nations. Technical and legal issues can also be referred to intersessional groups for further study or resolution. The LDC is an active and dynamic treaty organization that tries to incorporate the state of the art in its deliberations while remaining responsive to many opposing views regarding ocean disposal.

Activities from LDC VIII to LDC X

LDC VIII met in February 1984 and endorsed comprehensive Annex III Implementation Guidelines for all material proposed for ocean disposal. The structure of the Annex III Guidelines includes the following sections:

Section A - Characteristics and Composition of the Matter.

Section B - Characteristics of Dumping Site and Method of Deposit.

Section C - General Considerations and Conditions.

The LDC VIII concluded that all parts of the Annex III Guidelines might not be applicable to dredged material, tasked SG VIII to review this issue, and asked member nations to submit technical proposals to SG VIII.

SG VIII met in March 1985, and the US submitted proposed Annex III Guidelines for dredged material. Discussion led to the consensus that special guidance might be necessary, but the group could not agree on the final structure of and the absolute need for the guidelines. The SG VIII then recommended that an intersessional group of dredging experts meet to discuss the need for and the structure of guidelines for dredged material disposal. The expert group was proposed to meet in November 1985 (pending approval of LDC IX) and consider guidelines for application of Annexes I, II, and III to dredged material.

LDC IX met in September 1985 and agreed on the need for separate standalone dredged material guidelines for implementing the LDC annexes. The meeting approved an intersessional experts work group to develop the guidelines and limited attendance to those nations that made technical submissions.

The Intersessional Work Group on Dredged Material met in November 1985 and developed and approved the technically acceptable Guidelines for the Application of the Annexes to the Disposal of Dredged Material. The structure of the dredged material guidelines is such that it replaces Section A of the Annex III Guidelines and subsequently includes Sections B and C of the Annex III Guidelines in their entirety. The sections of the dredged material guidelines are: Introduction (Background); Conditions Under Which Permits for Dumping of Dredged Material May Be Issued; Assessment of the Characteristics and Composition of Dredged Material; and Disposal Management Techniques. The dredged material guidelines are shown in their entirety in Appendix A of this document.

The SG IX met in April 1986 and approved a slightly modified but technically acceptable version of the dredged material guidelines. The LDC X met in October 1986 and unanimously approved the dredged material guidelines with deletion of a minor section that did not legally comply with the LDC. The adoption of the dredged material guidelines is considered a major breakthrough, where the unique characteristics of dredged material are recognized such that the regulation represents a holistic approach to contrasting ocean disposal with land disposal alternatives.

The guidelines are founded on a comprehensive domestic and international research base. These guidelines separate the regulation and assessment of dredged material from that of sewage sludge and industrial wastes and include exemptions and exclusions appropriate to dredged material. The guidelines present the availability of ocean disposal management techniques and define critical LDC terminology, "rapidly rendered harmless" and "special care," in terms of a disposal management strategy.

The guidelines also require a review of alternatives to ocean disposal through a comparative assessment of human health and environmental risks, hazards (safety), economics, and exclusion of future uses of disposal areas. Furthermore, the guidelines recognize that, for dredged material, "sea disposal is often an acceptable disposal option" and encourages productive/beneficial uses such as marsh creation, beach nourishment, land reclamation, or construction material.

Future Meetings

Future meetings of the LDC and SG will address the overall structure of the annexes in regard to developing a waste management strategy that considers all disposal media. Consideration will be given to the need for the existing Annex I prohibited and Annex II special-care lists (black/gray lists) of substances proposed for ocean disposal. These lists are deemed quite arbitrary and do not necessarily lead to adequate protection of the ocean or alternative disposal environments.

ACKNOWLEDGMENT

This paper summarizes work carried out by the US delegation (USACE, EPA, NOAA, DOE, DOD, DOT, and State Department) to the London Dumping Convention (LDC VII, 1983; LDC VIII, 1984; LDC IX, 1985; and LDC X, 1986). The technical basis was largely dependent on research investigations conducted under the Dredged Material Research Program, Long-term Effects of Dredging Operations Program, Field Verification Program, Dredging Operations Technical Support Program, and field-reimbursable work funded by the US Army Corps of Engineers. Permission to publish this material was granted by the Chief of Engineers.

REFERENCE

International Maritime Organization. 1986 (Oct). "Report of the Tenth Consultative Meeting of Contracting Parties to the Convention on the Prevention of Marine Pollution of Dumping of Wastes and Other Matter," London, SEI.

APPENDIX A

The Guidelines are presented in their entirety in the following appendix and form the general technical guidance, application, and interpretation of the LDC Annexes as they apply to the ocean disposal of dredged material.

GUIDELINES FOR THE IMPLEMENTATION AND
UNIFORM INTERPRETATION OF ANNEX III
TO THE LONDON DUMPING CONVENTION

and

FOR THE APPLICATION OF THE ANNEXES TO THE DISPOSAL
OF DREDGED MATERIAL

Article IV(2): Any permit shall be issued only after careful consideration of all the factors set forth in Annex III, including prior studies of the characteristics of the dumping site, as set forth in Sections B and C of that Annex.

Annex III: Provisions to be considered in establishing criteria governing the issue of permits for the dumping of matter at sea, taking into account Article IV(2), include:

Interpretation:

Each authority or authorities designated in accordance with Article VI for the issue of general and special permits for the disposal of wastes and other matter at sea shall, when considering a permit application, carefully study all the factors set out in Annex III. This includes the establishment of procedures and criteria for:

1 deciding whether an application for sea disposal should be pursued in the light of the availability of land-based disposal or treatment methods;

2 selecting a sea disposal site, including the choice and collection of relevant scientific data to assess the potential hazards to human health, harm to living resources and marine life, damage to amenities, or interference with other legitimate uses of the sea.

A - CHARACTERISTICS AND COMPOSITION OF THE MATTER

1 INTRODUCTION

1.1 In accordance with Article IV(1)(a) of the Convention, Contracting Parties shall prohibit the dumping of dredged material containing substances listed in Annex I unless the dredged material can be exempted under paragraph 8 (rapidly rendered harmless) or paragraph 9 (trace contaminants) of Annex I.

1.2 Furthermore, in accordance with Article IV(1)(b) of the Convention, Contracting Parties shall issue special permits for the dumping of dredged material containing substances described in Annex II and, in accordance with Annex II, shall ensure that special care is taken in the disposal at sea of such dredged material.

1.3 In the case of dredged material not subject to the provisions of Articles IV(1)(a) and IV(1)(b), Contracting Parties are required under Article IV(1)(c) to issue a general permit prior to dumping.

1.4 Permits for the dumping of dredged material shall be issued in accordance with Article IV(2), which requires careful consideration of all the factors set forth in Annex III. In this regard, the Eighth Consultative Meeting, in adopting Guidelines for the Implementation and Uniform Interpretation of Annex III (resolution LDC.17(8)), resolved that Contracting Parties shall take full account of these Guidelines in considering the factors set forth in that Annex prior to the issue of any permit for the dumping of waste and other matter at sea.

1.5 With regard to the implementation of paragraphs 8 and 9 of Annex I to the Convention, the Fourth Consultative Meeting adopted Interim Guidelines (LDC IV/12, Annex 5) which provide advice concerning the conditions under which permits may be issued for dumping wastes containing Annex I substances, and concerning the evaluation of the terms "trace contaminants" and "rapidly rendered harmless."

1.6 Notwithstanding the general guidance referred to in paragraphs 1.4 and 1.5 above, subsequent deliberations by Contracting Parties have determined that the special characteristics of dredged material warrant separate guidelines to be used when assessing the suitability of dredged material for disposal at sea. Such guidelines would be used by regulatory authorities in the interpretation of paragraphs 8 and 9 of Annex I, and in the application of the considerations under Annex III. These Guidelines for the Application of the Annexes to the Disposal of Dredged Material have been prepared for this purpose and, more specifically, are intended to serve the following functions:

.1 to replace the Interim Guidelines for the implementation of paragraphs 8 and 9 of Annex I as they apply to dredged material; and

.2 to replace section A of the Guidelines for the Implementation and Uniform Interpretation of Annex III (resolution LDC.17(8)).

2 CONDITIONS UNDER WHICH PERMITS FOR DUMPING OF DREDGED MATERIAL MAY BE ISSUED

2.1 A Contracting Party may, after consideration of the factors contained in Annex III, issue a general permit for the dumping of dredged material if:

.1 although Annex I substances are present, they are either determined to be present as a "trace contaminant" or to be "rapidly rendered harmless"; and

.2 the dredged material contains less than significant amounts* of substances listed in part A of Annex II and meets the requirements of part C of Annex II.

2.2 If the conditions under 2.1.2 above are not met, a Contracting Party may issue a special permit provided the condition under 2.1.1 has been met. Such a special permit should either prescribe certain special care measures and/or give limiting conditions to diminish the pollution source.

2.3 The assessment procedures and tests described in the following sections are considered to apply equally to the interpretation of "harmlessness" (paragraph 8 of Annex I) and "trace contaminants" (paragraph 9 of Annex I) when applied in association with sections B and C of the Annex III guidelines.

3 ASSESSMENT OF THE CHARACTERISTICS AND COMPOSITION OF DREDGED MATERIAL

This section replaces the Guidelines for the Implementation and Uniform Interpretation of Annex III, part A, and provides an interpretation for the assessment of dredged material. It should be considered in conjunction with parts B and C of the Guidelines on Annex III.

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1 Total amount and average composition of matter dumped (e.g. per year).

2 Form, e.g., solid, sludge, liquid, or gaseous.

For all dredged material to be disposed of at sea, the following information should be obtained:

- gross wet tonnage per site (per unit time)
- method of dredging
- visual determination of sediment characteristics (clay-silt/sand/gravel/boulder)

* The following interpretations of "significant amounts" were agreed to by the Eighth Consultative Meeting:

Pesticides and their by-products not covered by Annex I and lead and lead compounds:	0.05% or more by weight
All other substances in Annex II, paragraph A:	0.1% or more by weight

In the absence of appreciable pollution sources, dredged material may be exempted from the testing referred to in these Guidelines in the following section if it meets one of the criteria listed below; in such cases the provisions of Annex III, sections B and C, should be taken into account:

.1 Dredged material is composed predominantly of sand, gravel or rock and the material is found in areas of high current or wave energy such as streams with large bed loads or coastal areas with shifting bars and channels;

.2 Dredged material is for beach nourishment or restoration and is composed predominantly of sand, gravel, or shell with particle sizes compatible with material on the receiving beaches; and

.3 In the absence of appreciable pollution sources, dredged material not exceeding 10,000 tonnes per year from small, isolated and single dredging operations, e.g. at marinas or small fishing harbors, may be exempted. Larger quantities may be exempted if the material proposed for disposal at sea is situated away from known existing and historical sources of pollution so as to provide reasonable assurance that such material has not been contaminated.

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3 Properties: physical (e.g. solubility and density), chemical and biochemical (e.g. oxygen demand, nutrients) and biological (e.g. presence of viruses, bacteria, yeasts, parasites).

For dredged material that does not meet the above exemptions, further information will be needed to fully assess the impact. Sufficient information may be available from existing sources, for example from field observations on the impact of similar material at similar sites or from previous test data on similar material tested not more than five years previously.

In the absence of this information, chemical characterization will be necessary as a first step to estimate gross loadings of contaminants. This should not mean that each dredged material should be subjected to exhaustive chemical analysis to establish the concentrations of a standard wide-ranging list of chemical elements or compounds; knowledge of local discharges or other sources of pollution, supported by a selective analysis, may often be used to assess the likelihood of contamination. Where such an assessment cannot be made, the levels of Annex I and II substances must be established as a minimum.

Where this information, coupled with knowledge of the receiving area, indicates that the material to be dumped is substantially similar in chemical and physical properties to the sediments at the proposed disposal site, testing described in the following section might not be necessary.

Where chemical analysis is appropriate, further information may also be useful in interpreting the results of chemical testing, such as:

- density;

- per cent solids (moisture content);
- grain size analysis (% sand, silt, clay); and
- total organic carbon (TOC).

In addition, there are several other parameters which may facilitate the interpretation of the behavior, fate, and effects of dredged material (e.g. sediment transport, pollutant transformation, sediment mitigative properties).

Sampling of sediments from the proposed dredging site should represent the vertical and horizontal distribution and variability of the material to be dredged. Samples should be spaced so as to identify and differentiate between non-contaminated and contaminated locations.

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4 Toxicity.

5 Persistence: physical, chemical, and biological.

6 Accumulation and biotransformation in biological materials or sediments.

The purpose of testing under this section is to establish whether the disposal at sea of dredged material containing Annex I and II substances might cause undesirable effects, especially the possibility of chronic or acute toxic effects on marine organisms or human health, whether or not arising from their bioaccumulation in marine organisms and especially in food species.

The following biological test procedures might not be necessary if the previous characterization of the material and of the receiving area allows an assessment of the environmental impact. If, however, the previous analysis of the material shows the presence of Annex I or Annex II substances in considerable quantities or of substances whose biological effects are not understood, and if there is concern for antagonistic or synergistic effects of more than one substance, or if there is any doubt as to the exact composition or properties of the material, it may be necessary to carry out suitable biological test procedures. These procedures should be carried out on the solid phase with bottom dwelling macrofauna and may include the following:

- acute toxicity tests;
- chronic toxicity tests capable of evaluating long-term sub-lethal effects, such as bioassays covering an entire life cycle; and
- tests to determine the potential for bioaccumulation of the substance of concern.

Substances in dredged material, when entering the marine environment, may undergo physical and chemical alteration that directly affects the release, retention, transformation, and/or toxicity of these substances. This shall be taken into particular account when carrying out the various tests mentioned above and when interpreting the results of these tests for actual or future dumping site conditions.

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7 Susceptibility to physical, chemical, and biochemical changes and interaction in the aquatic environment with other dissolved organic and inorganic materials.

Contaminants in dredged material, after dumping, may be altered by physical, chemical, and biochemical processes to more or to less harmful substances. The susceptibility of dredged material to such changes should be considered in the light of the eventual fate and effects of the dredged material. In this context, field verification of predicted effects is of considerable importance.

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8 Probability of production of taints or other changes reducing marketability of resources (fish, shellfish, etc.).

Proper dump site selection rather than a testing application is recommended. Site selection to minimize impact on commercial or recreational fishery areas is a major consideration in resource protection and is covered in greater detail in section C2 of Annex III.

4 DISPOSAL MANAGEMENT TECHNIQUES

4.1 Ultimately, the problems of contaminated dredged material disposal can be controlled effectively only by control of point source discharges to waters from which dredged material is taken. Until this objective is met, the problems of contaminated dredged material may be addressed by using disposal management techniques.

4.2 The term "disposal management techniques" refers to actions and processes through which the impact of Annex I or Annex II substances contained in dredged material may be reduced to, or controlled at, a level which does not constitute a hazard to human health, harm to living resources, damage to amenities, or interference with legitimate uses of the sea. In this context they may, in certain circumstances, constitute additional methods by which dredged material containing Annex I substances may be "rapidly rendered harmless" and which may constitute "special care" in the disposal of dredged material containing Annex II substances.

4.3 Relevant techniques include the utilization of natural physical, chemical and biological processes as they affect dredged material in the sea; for organic material these may include physical, chemical, or biochemical degradation and/or transformation that result in the material becoming non-persistent, non-toxic and/or non-biologically available. Beyond the considerations of Annex III, sections B and C, disposal management techniques may include burial on or in the seafloor followed by clean sediment capping, utilization of geochemical interactions and transformations of substances in dredged material when combined with seawater or bottom sediment, selection of special sites such as in abiotic zones, or methods of containing the spoil in a stable manner (including on artificial islands).

4.4 Utilization of such techniques must be carried out in full conformity with other Annex III considerations such as comparative assessment of alternative disposal options, and these guidelines should always be associated with post-disposal monitoring to assess the effectiveness of the technique and the need for any follow-up management action.

B - CHARACTERISTICS OF DUMPING SITE AND METHOD OF DEPOSIT

Matters relating to dump site selection criteria are addressed in greater detail in a study prepared by GESAMP* (Reports and Studies No. 16: Scientific Criteria for the Selection of Waste Disposal Sites at Sea, IMO 1982) which should be considered in conjunction with these guidelines.

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1 Location (e.g. co-ordinates of the dumping area, depth and distance from the coast), location in relation to other areas (e.g. amenity areas, spawning, nursery and fishing areas and exploitable resources).

Interpretation:

Basic site characterization information to be considered by national authorities at a very early stage of assessment of a new site should include the co-ordinates of the dumping area (latitude, longitude), as well as its location with regard to:

- distance to nearest coastline
- recreational areas
- spawning and nursery areas
- known migration routes of fish or marine mammals
- sport and commercial fishing areas
- areas of natural beauty or significant cultural or historical importance

* IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution.

- areas of special scientific or biological importance (marine sanctuaries)

- shipping lanes

- military exclusion zones

- engineering uses of seafloor (e.g. potential or ongoing seabed mining, undersea cables, desalination or energy conversion sites)

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2 Rate of disposal per specific period (e.g. quantity per day, per week, per month).

Interpretation:

Although the amounts of matter to be dumped (e.g. per year) are considered under paragraph A1 above, many operations, e.g. those related to dredging, are of shorter periods. In order to assess the capacity of the area for receiving a given type of material, the anticipated loading rates (e.g. per day) or in the case of existing sites, the actual loading rates (frequency of operations and quantities of wastes or other matter disposed of at each operation per time period) should be taken into consideration.

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3 Methods of packaging and containment, if any.

4 Initial dilution achieved by proposed method of release.

Interpretation:

The data to be considered under this item should include information on:

- type, size and form of packaging and containment units

- presence of any Annex I or Annex II substances as packaging material or in any matrix that might be used

- marking and labelling of packages

- disposal method (e.g. jettisoning over ship's side; discharge of liquids and sludges through pipes, pumping rates, number and location of discharge pipe outlets (under or above waterline, water depth, etc.)). In this connexion the length and speed of the vessel when discharging wastes or other matter should be used to establish the initial dilution

5 Dispersal characteristics (e.g. effects of currents, tides and wind on horizontal transport and vertical mixing).

6 Water characteristics (e.g. temperature, pH, salinity, stratification, oxygen indices of pollution - dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD) - nitrogen present in organic and mineral form including ammonia, suspended matter, other nutrients and productivity).

Interpretation:

For the evaluation of dispersal characteristics, data should be obtained on the following:

- water depths (maximum, minimum, mean)
- water stratification in various seasons and weather conditions (depth and seasonal variation of pycnocline)
- tidal period, orientation of tidal ellipse, velocities of minor and major axis
- mean surface drift (net): direction, velocity
- mean bottom drift (net): direction, velocity
- storm (wave)-induced bottom currents (velocities)
- wind and wave characteristics, average number of storm days per year
- concentration and composition of suspended solids

Where the chemical composition of the waste warrants, it may be appropriate to evaluate pH, suspended solids, persistent organic chemicals, metals, nutrients and microbiological components. BOD and COD or organic carbon determinations in the suspended or dissolved phase, together with oxygen measurements, may also be appropriate where organic wastes or nutrients are concerned.

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7 Bottom characteristics (e.g. topography, geochemical and geological characteristics and biological productivity).

Interpretation:

Maps and bathymetric charts should be consulted, and specific topographic features which may affect the dispersal of wastes (e.g. marine canyons) should be identified.

The geochemical observations of sediments in and around the disposal site should be related to the type of waste(s) involved. The range of chemical constituents should be the same as that provided for the characterization of the waste or other matter, with the minimum range of data set out in paragraph A1 above.

In areas where wastes may reach the bottom, sediment structure (i.e. the distribution of gravel, sand, silt and clay) as well as benthic and epibenthic community characteristics should be considered for the site area.

Mobility of sediments due to waves, tides or other currents should be considered in any waste disposal site assessments. The possibility of seismic activities in the area under consideration should be investigated, in particular when hazardous wastes in packaged form are concerned. The distribution of sediment types in an area provides basic information as to whether dumped solids with certain characteristics will accumulate at a site or be dispersed.

Sorption/desorption processes under the range of dump site redox and pH conditions, with particular reference to exchanges between dissolved and fine particulate phases, are relevant to the evaluation of the accumulative properties of the area for the components of the waste proposed for dumping and for their potential release to overlying waters.

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8 Existence and effects of other dumpings which have been made in the dumping area (e.g. heavy metal background reading and organic carbon content).

Interpretation:

The basic assessment to be carried out of a site, either a new or an existing one, shall include the consideration of possible effects that might arise by the increase of certain waste constituents or by interaction (e.g. synergystic effects) with other substances introduced in the area, either by other dumpings or by river input and discharges from coastal areas, by exploitation areas, and maritime transport as well as through the atmosphere. The existing stress on biological communities as a result of such activities should be evaluated before any new or additional disposal operations are established. The possible future uses of the sea area should be kept under consideration.

Information from baseline and monitoring studies at already established dumping sites will be important in this evaluation of any new dumping activity at the sand site or nearby.

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9 In issuing a permit for dumping, Contracting Parties should consider whether an adequate scientific basis exists for assessing the consequences of such dumping, as outlined in this Annex, taking into account seasonal variations.

Interpretation:

When a given location is first under consideration as a candidate disposal site, the existing data basis should be evaluated with a view to establishing whether the main characteristics are known in sufficient detail or accurately enough for reliable modelling of waste effects. Many parameters are so variable in space and time that a comprehensive series of observations have to be designed to quantify the key properties of an area over the various seasons.

If at any time, monitoring studies demonstrate that existing disposal sites do not satisfy these criteria, alternative disposal sites or methods should be considered.

C - GENERAL CONSIDERATIONS AND CONDITIONS

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1 Possible effects on amenities (e.g. presence of floating or stranded material, turbidity, objectionable odour, discolouration and foaming).

2 Possible effects on marine life, fish and shellfish culture, fish stocks and fisheries, seaweed harvesting and culture.

Interpretation:

Particular attention should be given to those waste constituents which float on the surface or which, in reaction with seawater, may lead to floating substances and which, because they are confined to a two-dimensional rather than a three-dimensional medium, disperse very slowly. The possibility of reaccumulation of such substances caused by the presence of surface convergences which may lead to interferences with amenities as well as with fisheries and shipping should be investigated.

Information on the nature and extent of commercial and recreational fishery resources and activities should be gathered.

Body burdens of persistent toxic substances (and, in the case of shellfish, pathogens) in selected marine life and, in particular, commercial food species from the dumping area should be established.

Certain grounds although not in use for fishing may be important to fish stocks as spawning, nursery or feeding areas, and the effects of sea disposal on these grounds should be considered.

The effects which waste disposal in certain areas could have on the habitats of rare, vulnerable or endangered species should be recognized.

Besides toxicological and bioaccumulation effects of waste constituents, other potential impacts on marine life, such as nutrient enrichment, oxygen depletion, turbidity, modification of the sediment composition and blanketing of the seafloor, should be addressed.

It should also be taken into account that disposal at sea of certain substances may disrupt the physiological processes used by fish for detection and may mask natural characteristics of seawater or tributary streams, thus confusing migratory species which consequently lose their direction, go unspawned or fail to find food.

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3 Possible effects on other uses of the sea (e.g. impairment of water quality for industrial use, underwater corrosion of structures, interference with ship operations from floating materials, interference with fishing or navigation through deposit of waste or solid objects on the seafloor and protection of areas of special importance for scientific or conservation purposes).

Interpretation:

Consideration of possible effects on the uses of the sea as outlined in paragraph C3 should include interferences with fishing, such as the damaging or fouling of fishing gear. Any possibility of excluding the future uses of the sea dumping area for other resources, such as water use for industrial purposes, navigation, erection of structures, mining, etc., should be taken fully into account.

Areas of special importance include those of interest for scientific research or conservation areas and distinctive habitats of limited distribution (such as seabird rookeries, kelp beds or coral reefs); information should also be provided on all distinctive habitats in the vicinity of the proposed site which might be affected by the material to be dumped. Attention should also be given to geological and physiographical formations of outstanding universal value from the point of view of science, conservation or natural beauty.

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4 The practical availability of alternative land-based methods of treatment, disposal or elimination, or of treatment to render the matter less harmful for dumping at sea.

Interpretation:

Before considering the dumping of matter at sea every effort should be made to determine the practical availability of alternative land-based methods of treatment, disposal or elimination, or of treatment to render the matter less harmful for dumping at sea.

The practical availability of other means of disposal should be considered in the light of a comparative assessment of:

- human health risks
- environmental costs
- hazards (including accidents) associated with treatment, packaging, transport and disposal
- economics (including energy costs)
- exclusion of future uses of disposal areas

for both sea disposal and the alternatives.

If the foregoing analysis shows the ocean alternative to be less preferable, a license for sea disposal should not be given.

In the special case of dredged materials, sea disposal is often an acceptable disposal option, though opportunities should be taken to encourage the productive use of dredged material for, for example, marsh creation, beach nourishment, land reclamation or use in aggregates. For contaminated dredged materials, consideration should be given to the use of special methods to mitigate their impact, in particular with respect to contaminant inputs. In extreme cases of pollution, containment methods (including land-based disposal) may be required, but very careful consideration should be given to the comparative assessment of the factors listed above before this option is pursued. Further advice on the management of contaminated dredged materials is given in the Guidelines for the Application of the Annexes to the Disposal of Dredged Material adopted by the Tenth Consultative Meeting by Resolution LDC 23(10).

REGIONAL DEMONSTRATION OF BENEFICIAL USES OF EXCAVATED MATERIAL IN THE CHESAPEAKE BAY

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ABSTRACT

The National Marine Fisheries Service (NMFS) and the Corps of Engineers have cooperatively developed and implemented regional demonstrations of beneficial uses of excavated material using two Baltimore District Federal maintenance dredging projects. At the Slaughter Creek, Dorchester County, Maryland, Federal project, the excavated material and the contractor-provided oyster shell cultch was used to rehabilitate an existing unproductive oyster bar. At the Twitch Cove, Smith Island, Somerset County, Maryland, Federal project, the excavated material and a wave-energy dissipating structure called a Longard tube were used to create a submersed aquatic eelgrass (*Zostera* sp.) bed in a moderately high-energy area. The Slaughter Creek and Twitch Cove projects were completed in July 1987. The submersed aquatic grass bed associated with the Twitch Cove project was transplanted in September 1987. The success of both projects will be monitored in fall 1987 and spring 1988.

INTRODUCTION

The Chesapeake Bay region has recently received national attention in the form of Federal funding for a multistate resource management program. The Corps of Engineers continues to participate with the environmental community in endorsing the objectives of the initiative and the legislative mandates of the Corps programs (Cole and Brainard 1978).

Background

Historically, the Baltimore District, Corps of Engineers, has made beneficial use of excavated material in a variety of applications, including beach nourishment, shore erosion protection and stabilization, wetland and bird habitat development, and sand dune creation (Earhart, in press). The applications of the concept have verified the advantages, which are cost-effectiveness, environmental enhancement, long-term placement site potential, reliable channel maintenance and project programming, and finally, public acceptance.

In January 1986, the National Marine Fisheries Service requested the Corps of Engineers to evaluate the potential for shellfish habitat development in the Chesapeake Bay using excavated material. As a result, an interagency working group was established in June 1986 to develop a proposal implementing the beneficial use concept as part of the Corps' maintenance dredging program. Members of this interagency working group are listed below.

a. National Marine Fisheries Service, Washington, D. C.

b. National Marine Fisheries Service, Oxford, Md.

c. Maryland Department of Natural Resources, Annapolis, Md.

d. Corps of Engineers

   (1) Water Resource Support Center, Fort Belvoir, Va.

   (2) North Atlantic Division, New York, N.Y.

   (3) Baltimore District, Baltimore, Md.

   (4) Norfolk District, Norfolk, Va.

e. Maryland Port Administration, Baltimore, Md.

f. Virginia Marine Resource Commission, Newport News, Va.

The current maintenance dredging program was reviewed, and a list of potential dredging projects was scrutinized for potential implementation. In January 1987, the proposal was endorsed by the Corps of Engineers and the National Marine Fisheries Service. The endorsement represented an opportunity to implement the beneficial use concept for application on a national level and to document the continued effort to environmentally enhance the Corps' maintenance dredging program.

Site Selection

The interagency working group selected two Federal maintenance dredging projects for the beneficial use demonstrations. The Slaughter Creek Federal channel is located in Dorchester County, Maryland (USAED, Baltimore 1980). The waterway separates Taylors Island, Maryland, from the mainland, which is approximately 20 miles southwest of Cambridge. The other site is located at the Federal channel at Twitch Cove, Smith Island, Somerset County, Maryland (Figure 1). Smith Island is approximately 20 miles west of Crisfield, Md.

SLAUGHTER CREEK PROJECT

The authorized project dimensions for the Slaughter Creek channel are 7 ft deep, 100 ft wide, and approximately 2,000 ft long (Figure 2). The channel was last dredged in 1981. The previously used placement option was a 10-acre upland site approximately 1 mile west of the channel.

The proposed beneficial use placement site is a 100-acre open-water site approximately 1 mile northeast of the channel. The area is a Maryland-charted

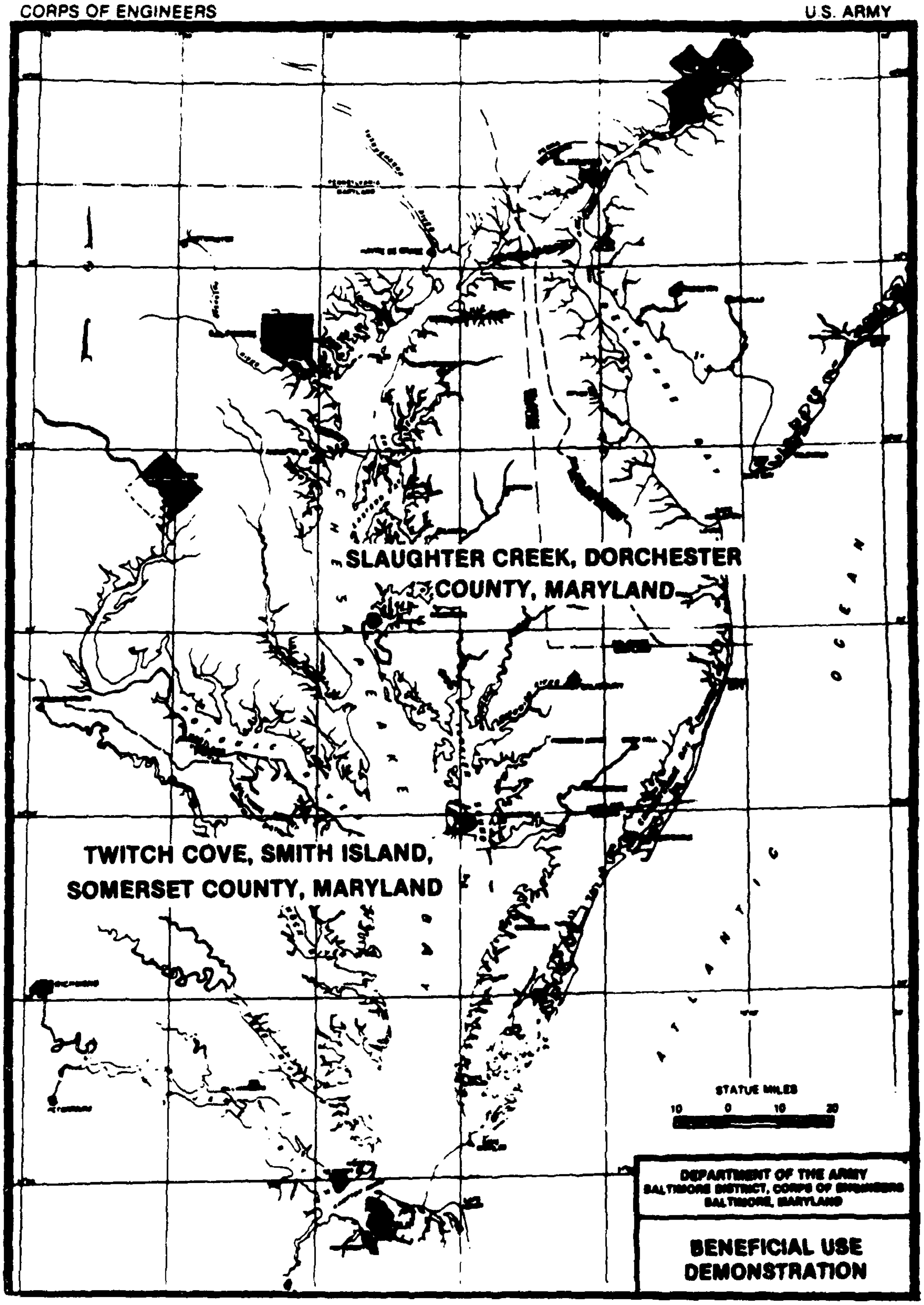

Figure 1. Chesapeake Bay location map

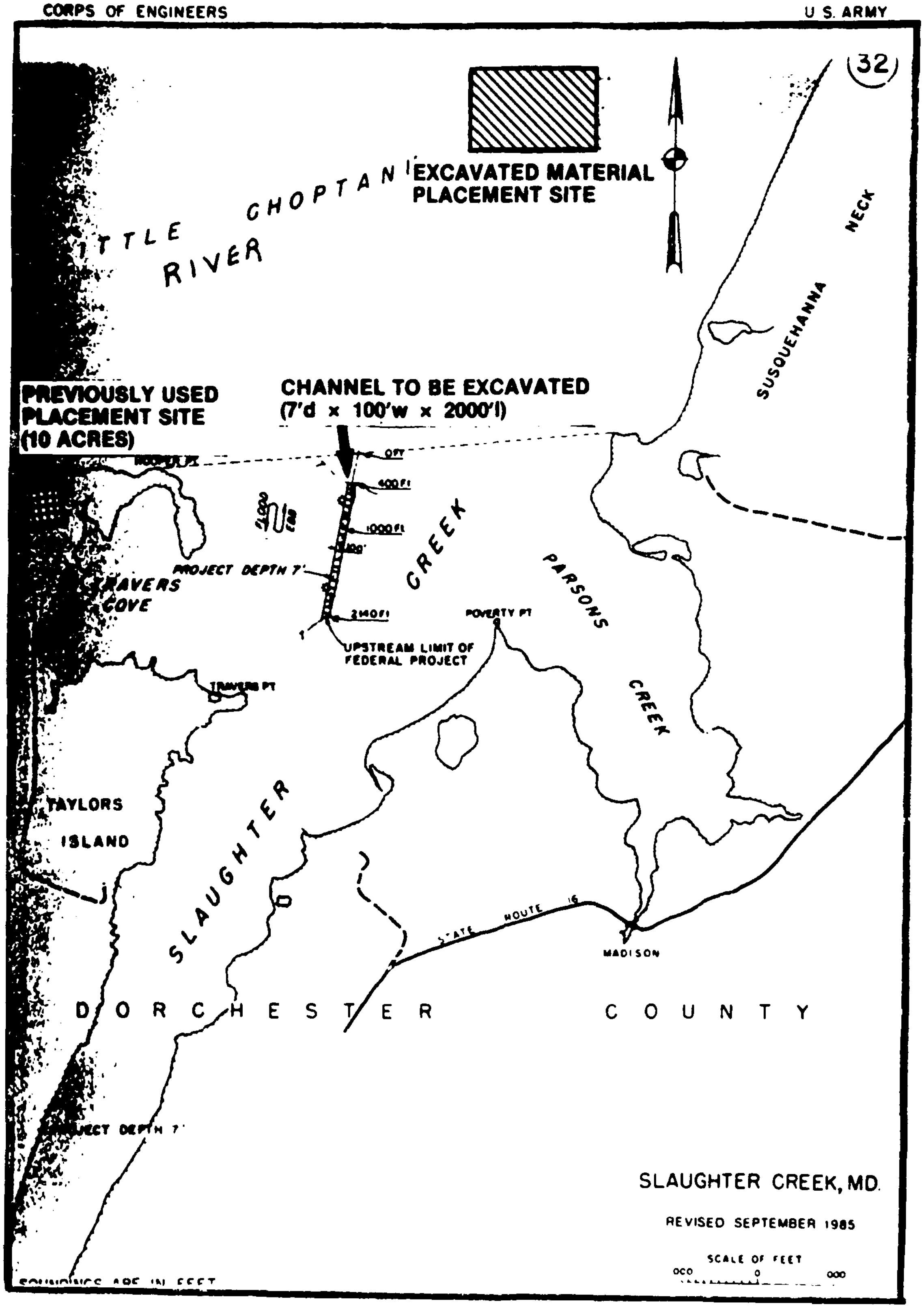

Figure 2. Slaughter Creek project map

public oyster bar (Maryland Department of Tidewater Fisheries 1983). However, the bar is unproductive due to unstable and unsuitable substrate conditions for oyster reproduction.

Approximately 16,863 yd^3 of material was removed and deposited in the open-water placement site. The channel sediments were composed of 60 percent fine sand and 40 percent silts (Figure 3).

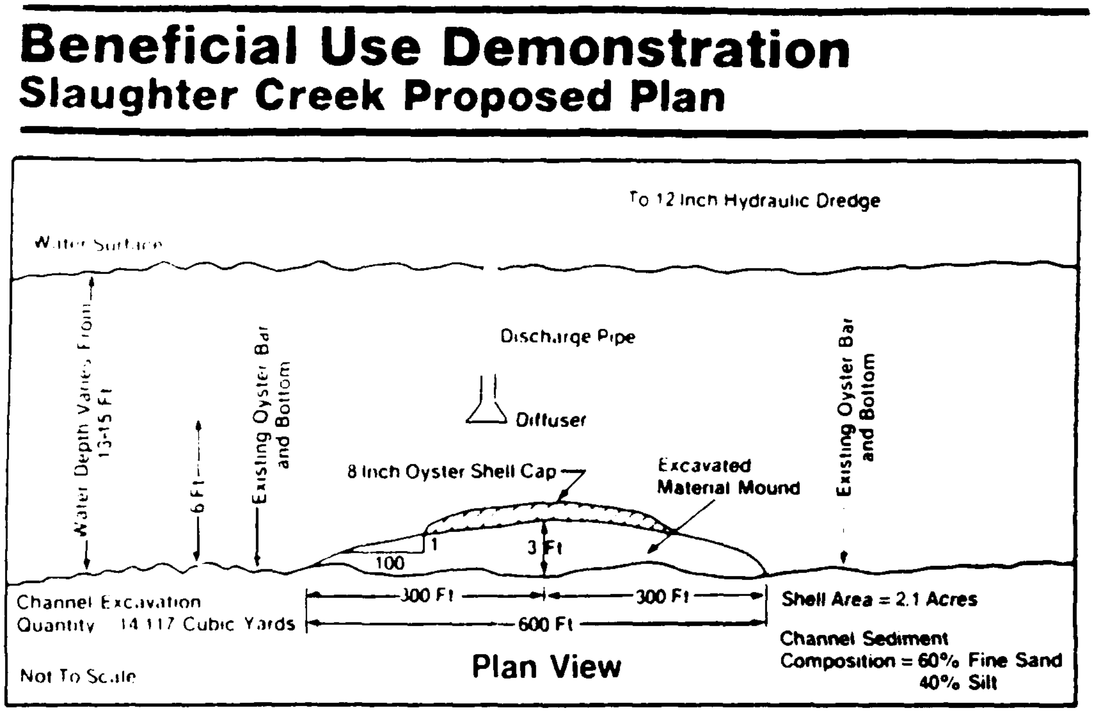

Figure 3. Slaughter Creek conceptual plan

The existing unsuitable bottom was stabilized with the excavated material. An 8-in. oyster shell cap was placed on top of the excavated material as cultch to encourage oyster larvae settlement. Upon completion of the project, a 2.1-acre unproductive charted oyster bar was rehabilitated and is expected to provide an acceptable bottom for the oyster spawning season beginning in late June 1987.

A monitoring plan has been developed to determine the amount of shell that is lost due to burial into the newly created bottom. This will be accomplished by analyzing hydrographic survey data, shell depth, exposed shell, and spat surveys in the fall of 1987 and spring of 1988. Construction was completed in June 1987.

One of the advantages of the beneficial use concept is the cost-effectiveness of the concept. A cost savings of 46 percent was documented at Slaughter Creek (Table 1).

TWITCH COVE PROJECT

The second site selected was the Federal project at Twitch Cove. The authorized channel is 7 ft deep, 60 ft wide, and approximately 5,000 ft long

TABLE 1. SLAUGHTER CREEK PROJECT ECONOMICS

Feature	Historical*	Current**	Savings
Placement	$67,452 ($4.00/yd^3)	$48,280 ($2.86/yd^3)	$19,172
Dike construction	$48,000	0	--
Shell cap	0	$21,435	$26,565
Mobilization/ demobilization	$49,200	$20,000	$29,200
Total	$164,652	$89,715	$74,937 (46%)

* Based on 1981 Slaughter Creek low bidder's price (updated to March 1987 costs).

** Based on April 1987 low bidder's price for the Slaughter Creek project.

(Figure 4). The previously used placement site was a 15-acre upland site northwest of the channel. The proposed placement site is located south and approximately 5,000 ft from the channel.

Historically, there has been an abundance of submersed aquatic grass *Zostera marina* (eelgrass) along the eastern coast of Smith Island (Orth et al. 1985). The placement site is currently one of the few areas along the coast that lacks eelgrass. One hypothesis for the lack of eelgrass in the placement site is that the wave energy may be too strong to allow the immature plants to become established and that the area may exceed the optimum depth required for the growth of eelgrass.

The conceptual plan was based on alleviating the conditions as previously hypothesized. A wave-dissipating structure called a Longard tube was filled with sand from a barge and strategically placed to break the predominant wave energies (Longard Corporation 1983) (Figure 5). The remaining excavated material was placed behind the wave-dampening structures to decrease existing water depths to encourage submersed aquatic grass stabilization.

Placement of the excavated material and filling of the tubes were completed in July 1987. The 3-acre area of *Z. marina* was transplanted in September 1987.

The Longard tubes and the transplants will be monitored twice during the growing season. Submersed aquatic vegetation density, survival, and general condition will be measured. A savings of $22,586, approximately 7 percent of the 1981 project costs, was documented for the Twitch Cove project (Table 2).

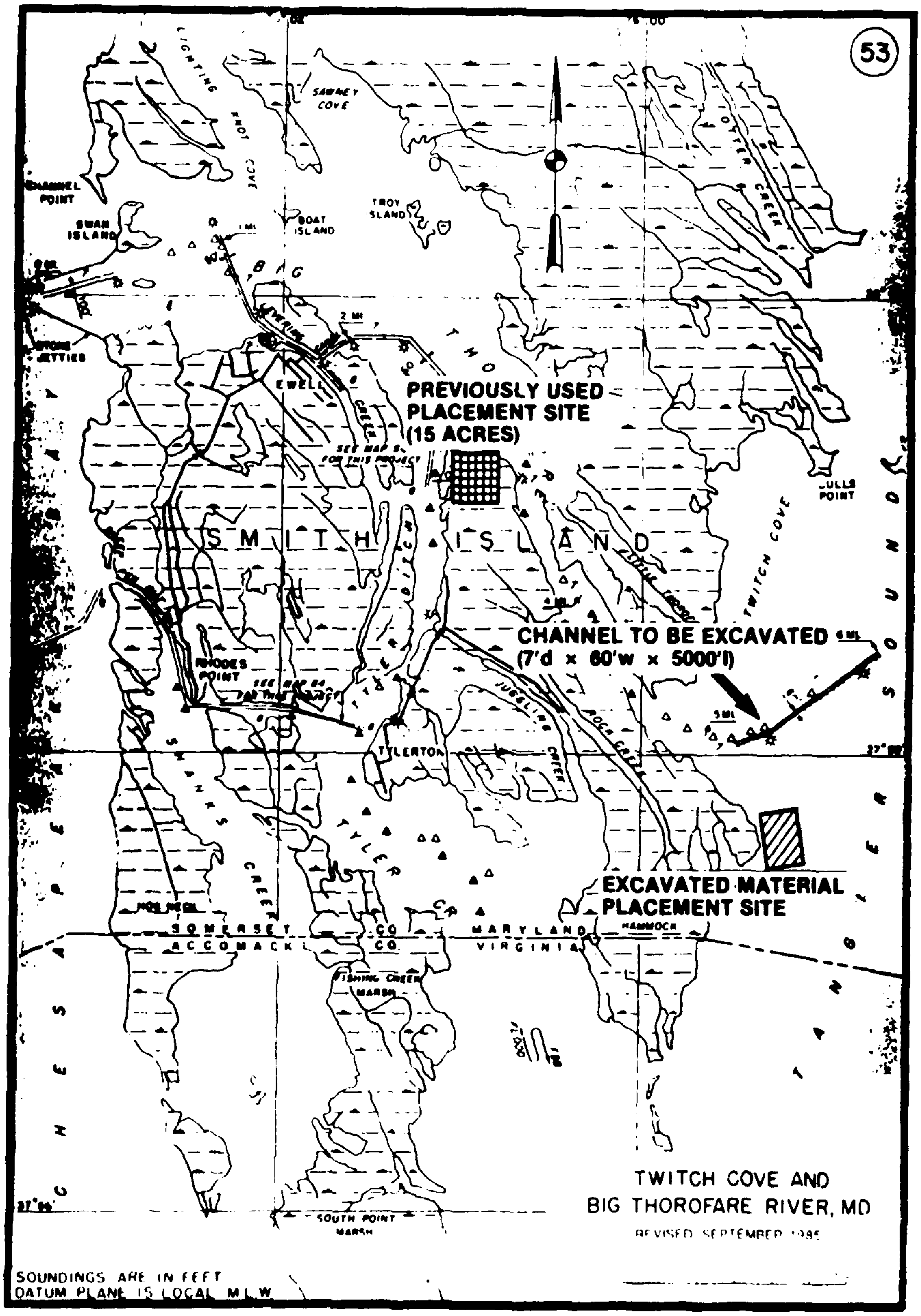

Figure 4. Twitch Cove project map

Beneficial Use Demonstration
Twitch Cove Proposed Plan

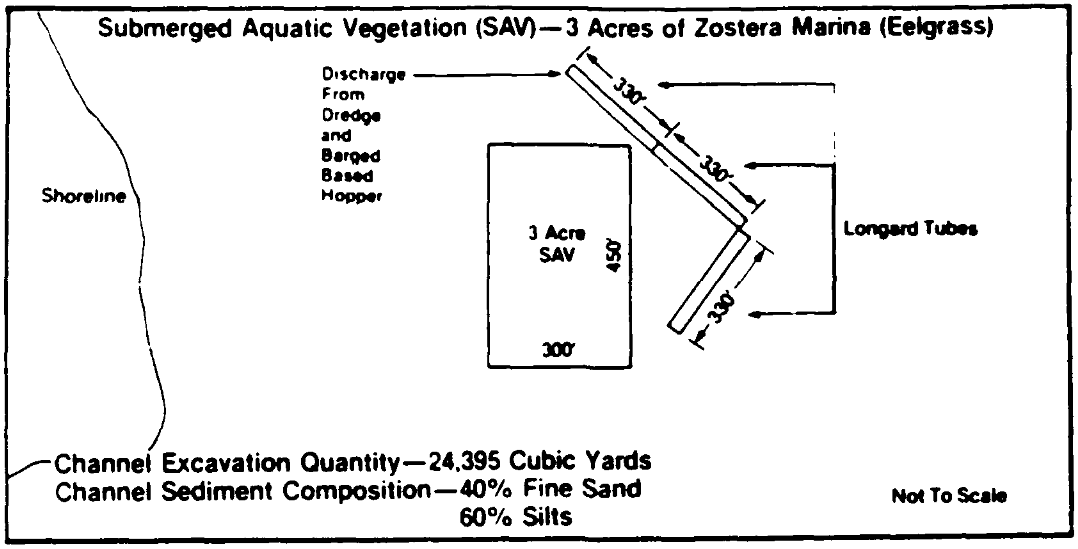

Figure 5. Twitch Cove conceptual plan

TABLE 2. TWITCH COVE PROJECT ECONOMICS

Feature	Historical*	Current**	Savings
Placement	\$83,919 (\$3.44/yd³)	\$64,680 (\$2.65/yd³)	
Plant modification	0	\$50,345	
Dike construction	\$100,000	0	
Longard tubes	0	\$23,580	
Transplants	0	\$57,900	
Subtotal	\$183,919	\$196,505	+\$12,586
Mobilization/ demobilization	\$120,000	\$84,828	\$35,172
Total	\$303,919	\$281,333	\$22,586 (7%)

* Based on 1981 Twitch Cove low bidder's price (updated to March 1987 costs).

** Based on May 1987 low bidder's price for the Twitch Cove project.

CONCLUSIONS

The beneficial use of excavated material is an innovative concept that is economically attractive, enhances the environment, and provides environmentally acceptable placement sites. The Baltimore District and the environmental community of the Chesapeake Bay will continue to pursue beneficial uses of excavated material.

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JAPANESE CLOSING REMARKS
13th US/JAPAN EXPERTS MEETING

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Bureau of Ports and Harbours
Ministry of Transport, Japanese Government
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I would like to say a few words as the Japanese Co-Chairman. First, I would like to express our gratitude to Co-Chairman COL Richard Rothblum, to Mr. Hamons, members of the Corps of Engineers, and those who coordinated and managed this US/Japan Experts Meeting so smoothly. I think the 13th US/Japan Experts Meeting has been very successful and fruitful. It has been an honor for me to serve as Co-Chairman.

I would like to express my personal thoughts briefly. It is regrettable that bottom sediments contain a multitude of toxic materials, including heavy metals, PCBs, and by-products of industry in many harbor areas, waterways, and lakes in both our countries. Many efforts have been funded to manage contaminated bottom sediments.

In Japan, the system that regulates dredging projects (including acts, regulations, budgeting, etc.) was established in 1972. During fiscal years 1972-1986, Japanese municipal governments completed or continued 37 projects involving contaminated bottom sediments, at a cost of more than $800 million (US). I have been personally involved with the Minamata project--the largest harbor area restoration project in Japan. This project is scheduled for completion in March 1990.

It will take over 10 years to complete the contaminated bottom sediment management program that has been outlined for the harbor areas, waterways, rivers, and lakes of Japan. A great deal of time, money, and effort will be expended.

I think that there are points of similarity and nonsimilarity between the contaminated bottom sediment management projects of the USA and Japan. A similar point is that a major portion of the effort has been directed toward convincing concerned organizations and area residents as to the value and safety of dredging projects. A point of nonsimilarity is represented by the environmental regulation systems of our countries, both for the purpose of observing the London Dumping Convention, as mentioned by Dr. Robert Engler.

In spite of the level of US and Japanese expertise, I think we must continue to pursue a highly advanced technology (including planning, design, execution, and monitoring) to manage contaminated bottom sediments successfully. In this sense, it is very important to continue the US/Japan Experts Meeting for the exchange of technical information. I have been pleased to learn that Co-Chairman COL Rothblum, Mr. Murden, and many other US engineers also share this opinion.

We shall hold the next meeting in November 1989 in Japan. I anticipate that many Japanese mayors would like to host the meeting in their city, so I shall choose carefully. In conclusion, I would hope that many of the engineers who attended the 13th US/Japan Experts Meeting will visit Japan in November 1989.

Thank you for your attention.