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US Army Corps of Engineers
Water Resources Support Center

Management of Bottom Sediments Containing Toxic Substances

Proceedings of the 7th U. S./Japan Experts Meeting

2-4 November 1981
New York City, USA

October 1983

COMPONENT PART NOTICE

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AD-P002 409	Summer Peak of Nutrient Concentrations in Lake Water.
AD-P002 410	1981 Status Report on the Environmental and Water Quality Operational Studies Program.
AD-P002 411	Marine Technology for Environmental Problems: Some Examples of Improved Systems on Workvessels.
AD-P002 412	Mount St. Helens Eruption, Corps of Engineers Restoration Efforts.
AD-P002 413	The Water Quality Preservation Measures in Lake Biwa, the Largest Lake in Japan.

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The 7th U. S./Japan Meeting on Management of Bottom Sediments Containing Toxic Substances was held 2-4 November 1981 in New York City. The meeting is held annually through an agreement with the U. S. Environmental Protection Agency 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 7th U. S./Japan Meeting on Management of Bottom Sediments Containing Toxic Substances was held 2-4 November 1981 in New York City. The meeting is held annually through an agreement with the U. S. Environmental Protection Agency (EPA) 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.

Topics of the presentations and discussions at the recent meeting have been more closely related to the Corps' dredging and regulatory missions than to EPA's mission. At the request of EPA, MG E. R. Heiberg III, Director of Civil Works, agreed for the Corps to become the lead agency for the meetings. MG Heiberg appointed COL Maximilian Imhoff, Commander and Director of the Water Resources Support Center (WRSC), as the U. S. Chairman.

Assistance in coordination of the organizational activities and publication of this report was provided by Mr. Thomas R. Patin, program assistant, and Mr. Charles C. Calhoun, Jr., Program Manager, Dredging Operations Technical Support Program (DOTS), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

ATTENDEES

7th ANNUAL MEETING
U. S./JAPAN EXPERTS MEETING

U. S. Delegation

COL Maximilian Imhoff, Cochairman	CE, Commander and Director, Water Resources Support Center (WRSC)
William Murden	CE, Chief, Dredging Division, WRSC
Herbert R. Haar	Board of Commissioners of the Port of New Orleans
Charles C. Calhoun	CE, Waterways Experiment Station
T. Allan Haliburton	Haliburton and Associates
Robert M. Engler	CE, Waterways Experiment Station
Thomas R. Patin	CE, Waterways Experiment Station
David Mathis	CE, Dredging Division, WRSC
Dennis Suskowski	CE, New York District
Italo G. Carcich	State of New York
Jim Tofflemire	State of New York
Ron Vann	CE, Norfolk District
Willis Pequegnat	Texas A&M University
Ken Hall	CE, Waterways Experiment Station
Jack Bechly	CE, Portland District

Japanese Delegation

Rikuro Takata, Cochairman	Bureau of Ports and Harbours Ministry of Transport (MOT)
Hiroaki Togashi	Dredging and Reclamation Engineering Association
Kiichi Kikegawa	Dredging and Reclamation Engineering Association
Masakuni Nakamura	Bottom Sediment Management Association
Masao Shimoda	Bottom Sediment Management Association
Hiroshi Kubo	Bottom Sediment Management Association
Hiromi Koba	Dredging and Reclamation Engineering Association
Toyoaki Shiba	Dredging and Reclamation Engineering Association
Tadashi Otsuki	Dredging and Reclamation Engineering Association
Mitsumasa Okada	Environment Agency
Tatsuo Yoshida	Bottom Sediment Management Association
Ichiro Ofuji	Workvessel Association
Naoshi Ishimatsu	Workvessel Association

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AGENDA

7th U.S./JAPAN EXPERTS MEETING ON MANAGEMENT
OF BOTTOM SEDIMENTS CONTAINING
TOXIC SUBSTANCES

World Trade Center
New York City

2-4 November 1981

Cochairmen

Mr. Rikuro Takata

Director, Environmental Protection Division
Bureau of Ports and Harbours, Ministry of Transport

COL Maximilian Imhoff

U. S. Army Corps of Engineers, Water Resources Support Center

Monday, November 2, 1981

0800	Bus departs for World Trade Center
0830-0900	Opening session
0900-0930	Rikuro Takata, "Prospect of Sea Bottom Management in Ports and Harbors and Sea Water Areas in Japan," Ministry of Transport, Japan
0930-1000	Herbert R. Haar, "Rescuing the Ports," Board of Commissioners of the Port of New Orleans, USA
1000-1030	Kanenobu Hagiwara and Masamichi Shirahase, "Water Pollution Control Projects in Japanese Rivers and Lakes," Ministry of Construction, Japan
1030-1100	T. Allan Haliburton, "Fabric Reinforced Dike Design and Construction," Haliburton and Associates, USA
1100-1300	Luncheon
1300-1330	Hiroaki Togashi, "Sand Overlaying for Sea Bottom Sediment Improvement by Conveyor Barge," Dredging and Reclamation Engineering Association, Japan

1330-1400	Kiichi Kikegawa, "Sand Overlaying for Sea Bottom Sediment Improvement by Sand Spreader," Dredging and Reclamation Engineering Association, Japan
1400-1430	V. L. Andreliunas and Dick Semonian, "Studies on Capping of Contaminated Dredged Material in New England Division," Corps of Engineers, USA
1430-1500	Dennis Suskowski, "Studies on Capping of Comtaminated Dredged Material Conducted by New York District," Corps of Engineers, USA
1500-1530	Masakuni Nakamura, "Experience on the Stabilization of Sediments," Bottom Sediment Management Association, Japan
1530-1600	Italo G. Carcich and Jim Tofflemire, "PCB Cleanup Activities on the Upper Hudson River," State of New York, USA
1600-1630	Masao Shimoda, "On the Calcination of Sediment for an Artificial Aggregate," Bottom Sediment Management Association, Japan
1630	Bus returns to Milford Plaza Hotel
1800	Bus departs for Seaman's Institute
1830-2030	U. S. Reception for Japanese delegation
2030	Bus departs for hotel

Tuesday, November 3, 1981

0800	Bus departs for World Trade Center
0830-0900	Hiroshi Kubo, "Several Solidifying Works of Sediment," Bottom Sediment Management Association, Japan
0900-0930	Ron Vann, "Kepone Removal from the James River," Norfolk District, Corps of Engineers, USA
0930-1000	Hiromi Koba and Toyoaki Shiba, "Test Dredging of Bottom Sediments in Osaka Bay," Dredging and Reclamation Engineering Association, Japan
1000-1030	Willis Pequegnat, "Biological Assessment Studies for Predictions of Cause and Effect Relationships," Texas A&M University, USA
1030-1100	Tadashi Otsuki, "Purification of Water and Sediments Using Organisms (Living Filter) - Removal of Suspended Sediment and Nutrients," Dredging and Reclamation Engineering Association, Japan

1100-1130	Mitsumasa Okada, "The Effect of Nutrient Release from Sediment on the Formation of Water Blooms," Environment Agency, Japan
1130-1200	Tatsuo Yoshida, "On the Summer Peak of Nutrient Concentrations in Lake Water, Bottom Sediment Management Association, Japan
1200-1230	Ken Hall, "Overview of the Corps Environmental and Water Quality Operational Studies," Waterways Experiment Station, Corps of Engineers, USA
1230-1630	Harbor Tour (Luncheon to be served on board)
1630	Bus departs for hotel

Wednesday, November 4, 1981

0800	Bus departs for World Trade Center
0830-0900	Ichiro Ofuji and Naoshi Ishimatsu, "Marine Technology for Environmental Problems - Some Examples of Improved Equipment on Workvessels," Workvessel Association, Japan
0900-0945	Jack Bechly, "Navigation Impacts of Mt. St. Helens Eruption," Portland District, Corps of Engineers, USA
0945-1200	Closing session

JOINT COMMUNIQUE

The 7th U. S./Japan Experts Meeting on Management of Bottom Sediments Containing Toxic Substances was held by the Japanese (Rikuro Takata, Director, Environmental Protection Division, Bureau of Ports and Harbours, Ministry of Transport) and the United States (COL Maximilian Imhoff, Commander/Director, Water Resources Support Center, U. S. Army Corps of Engineers) Co-chairmen November 2-4, 1981, at New York, N. Y., U. S. A. The purpose of the conference was to exchange information in both regulatory and technical areas relevant to bottom sediments management and to explore areas where joint effort in the dredging and marine technology fields would be fruitful.

Japanese and United States experts presented papers on several technical and managerial subjects including: prospects of sea bottom management and water pollution control administration in Japan, four studies of subaqueous sand overlaying and capping of contaminated dredged material deposits, experience on the stabilization of sediments, PCB cleanup activities on the upper Hudson River, Kepone removal from the James River, an overview of efforts by port and harbor associations to resolve regulatory problems confronting their industry, fabric-reinforced dike design and construction, summer peak of nutrient concentrations in lake water and effects of sediment nutrient release on water bloom formations, feasibility of sediment calcination for artificial aggregates, several solidifying works of sediments, test dredging of bottom sediments in Osaka Bay, purification of water and sediments using organisms, management tools for assessing dredged material impacts, improved marine technology for environmental problems, navigation impacts of the Mt. St. Helens eruption, an overview of the Corps' environmental and water quality operational studies, and advances in dredging technology to include new equipment and operational techniques.

The attendees represented a broad spectrum of engineering and scientific disciplines. Technical papers were presented by representatives of the Federal Government of Japan and the United States, from States, universities, Port Authority, engineering firms, and from other industrial interests.

There was general agreement that this conference has been highly fruitful in meeting its major goal: to exchange the most recent information in techniques management and the environmental effects of sediment material containing toxics and other pollutants. Consistent with the provisions of the Memorandum of Understanding, the next meeting should be held in Japan and the dates will be decided jointly by the Co-chairmen.

Director, Environmental Protection Division, Bureau of Ports and Harbours, Ministry of Transport

Rikuro Takata
November 4, 1981

Commander/Director, Water Resources Support Center, U. S. Army Corps of Engineers

COL Maximilian Imhoff
November 4, 1981

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

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

Multiply	By	To Obtain
acres	4046.873	square meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons per day per square foot	40.75	cubic decimeters per day per square meter
gallons (U. S. liquid)	3.785412	cubic decimeters
horsepower (550 foot-pounds per second)	745.6999	watts
inches	25.4	millimeters
miles (U. S. statute)	1.609347	kilometers
million gallons per day	1.54723	cubic feet per second
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6894.757	pascals
pounds (mass)	0.4535924	kilograms
tons (2,000 lb, mass)	907.1847	kilograms

AD P002392

PROSPECT OF SEA BOTTOM MANAGEMENT IN PORTS AND HARBORS AND SEA WATER AREAS IN JAPAN

Rikuro Takata
Director,
Environmental Protection Division
Ports and Harbors Bureau
Ministry of Transport
Kasumigaseki 2-1-3, Chiyoda-ku
Tokyo, Japan, 100

ABSTRACT

The Bureau of Ports and Harbors, Ministry of Transport, has undertaken two projects that relate to sea bottom management. The Marine Environment Improvement Pilot Project is an experiment to clean organic bottom sediment accumulated in the closed inland bays and inland waters, and the Port Pollution Control Works is a project to clean polluted bottoms in the port areas. This paper introduces the prospect of these two projects in relation to the 6th Five-Year Plan for Port Improvement Program (period from 1981 to 1985).

INTRODUCTION

Since the 1960's, Japan's economy has experienced a rapid growth that lacked environmental protection and sufficient measures for prevention of pollution. Because of this, environmental pollution has occurred, causing grave social concern. In the 1970's, various laws were revised and enacted, including the revision of Basic Law for Environmental Pollution Control; our system of environmental measures has also been organized.

For ports and harbors, a section of the Port and Harbor Law and Public Water Area Reclamation Law was revised in 1973 and judicial measures were established for the environmental protection of ports and harbors.

Presently, sea bottom management is undertaken as a part of the

Improvement Works of Port Facilities (with government financing such as Marine Environment protection pilot work of Tokyo Bay, Ise Bay, and Seto Inland Sea) and the Port Pollution Control Works in port areas.

The former is carried out as experimental work for studying and developing the efficient and economic methods and grasping the improvement effect of water quality by sea bottom management for improving enclosed environments such as inland bays and inland waters. The latter carries out dredging and sand overlaying of the sea bottom in ports and harbors where the livelihood of the population in the area is affected by the deteriorated water quality and bad smells caused by organic bottom sediment or harmful substances.

MARINE ENVIRONMENT IMPROVEMENT PILOT PROJECT

The Marine Environment Improvement Pilot Project is to carry out sea bottom management by the Port and Harbor Bureau of the Transportation Ministry on especially polluted waters as a model case to assess the effect of the management on the enclosed inland bay and inland waters and to establish the method of work.

The work, now at the Practical Design Study stage, is being carried out on Tokyo Bay, Seto Inland Sea, and Ise Bay to study a wide range of actual pollution conditions; to study environmental improvement assessment, test work, and field investigation of the effect; and to study the work method.

The future program of the Marine Environment Improvement Pilot Project is discussed below.

Need for Sea Bottom Management

Environmental Problems on Inland Bays and Inland Seas

Figure 1 shows the pollution load history in the Seto Inland Sea, and Table 1 shows the pollution load history in Tokyo Bay. Both indices show rapid increases in the 1960's. In 1970, a water pollution prevention law was enacted leading to the establishment of effluent standards at factories and businesses; further standards were created in many places by local regulations.

In the Seto Inland Sea, Ise Bay, and Tokyo Bay, total restriction of COD was enforced. As a result, the inflow load of COD in Tokyo Bay and Seto Inland Sea has decreased to the level of around 1955 (Figure 1, Table 1).

TABLE 1. COD INFLOW LOAD IN TOKYO BAY

Year	1955	1971	1976
COD, t/day	500	1,200	300

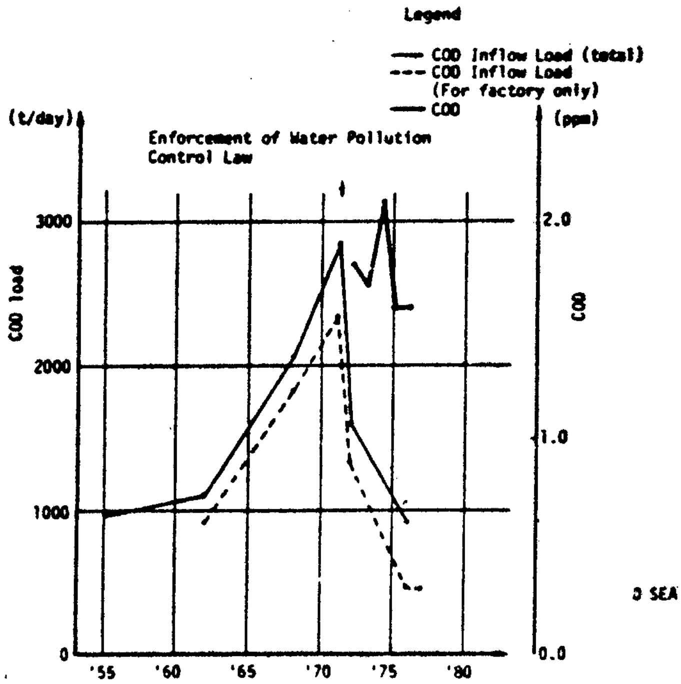


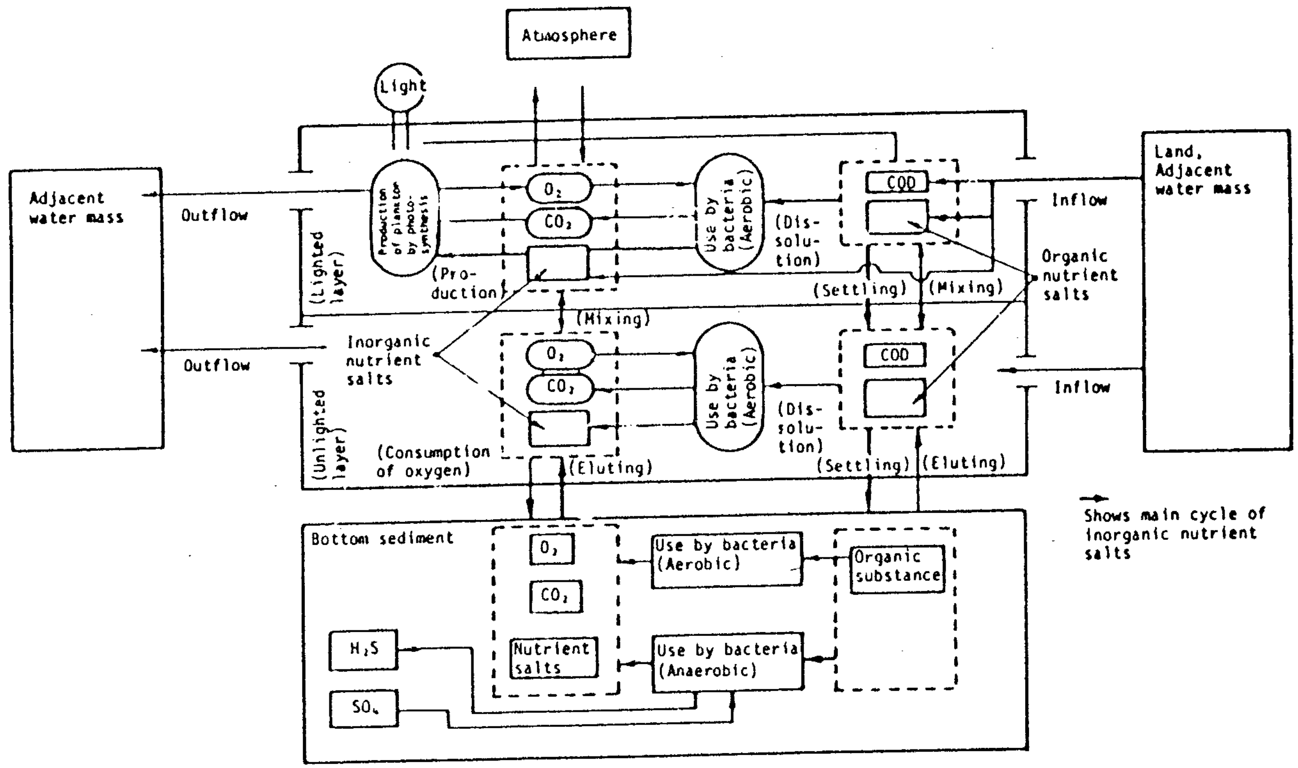
Figure 1. Yearly changes of COD inflow load into Seto Inland Sea

Although the inflow load of COD has decreased remarkably, water quality has not improved as expected and stays at the same level as '75 (Figure 1). One of the reasons may be the elution of nutrient salts from the bottom sediment deposited in the past. The mechanism of circulation of substances (mechanism of eutrophication) that causes ill effects on the environment of the sea needs to be studied.

Mechanism of Eutrophication

Figure 2 shows a model of the circulation of substances in seawater. Inflow from the land and elution of the sea bottom are the sources of inorganic nutrient salts that generate red tide and eutrophication.

In Tokyo Bay, Seto Inland Sea, and Ise Bay, polluting substances discharged over a long period of time have widely accumulated on the sea bottom, creating a loss of oxygen in water. This loss is due to the dissolution of organic substances in bottom sediment and the elution of large amounts of nutrient salts from bottom sediment and production of the large amount of organic substances in the bay. Therein lies one of the reasons why water quality does not improve despite the reduction of inflow load of COD. In such waters, to improve the marine environment, it is necessary to stop the cycle of sea pollution by managing the sea bottom together with reducing the inflow load of COD, N, and P.



(Source) Study material of 2nd District Port Construction Bureau

Figure 2. Cycle of substances and model of eutrophication

This is substantiated by the fact that the water quality of part of the Seto Inland Sea (Osaka Bay, the sea of Harima, Hiroshima Bay, and the sea of Suoo and Beppu Bay) is poor due to organic bottom sediment.

Environmental Improvement by Sea Bottom Management

The effect of sea bottom management field-testing work is shown from the results of a study in Mikawa Bay.

By removing the bottom sediment of an area 100 m × 100 m × 10 cm thick, remarkable improvements have been observed on the eluted amount of nutrient salts and benthos. This study has proved that sea bottom management is an effective means to improve the marine environment (Figure 3).

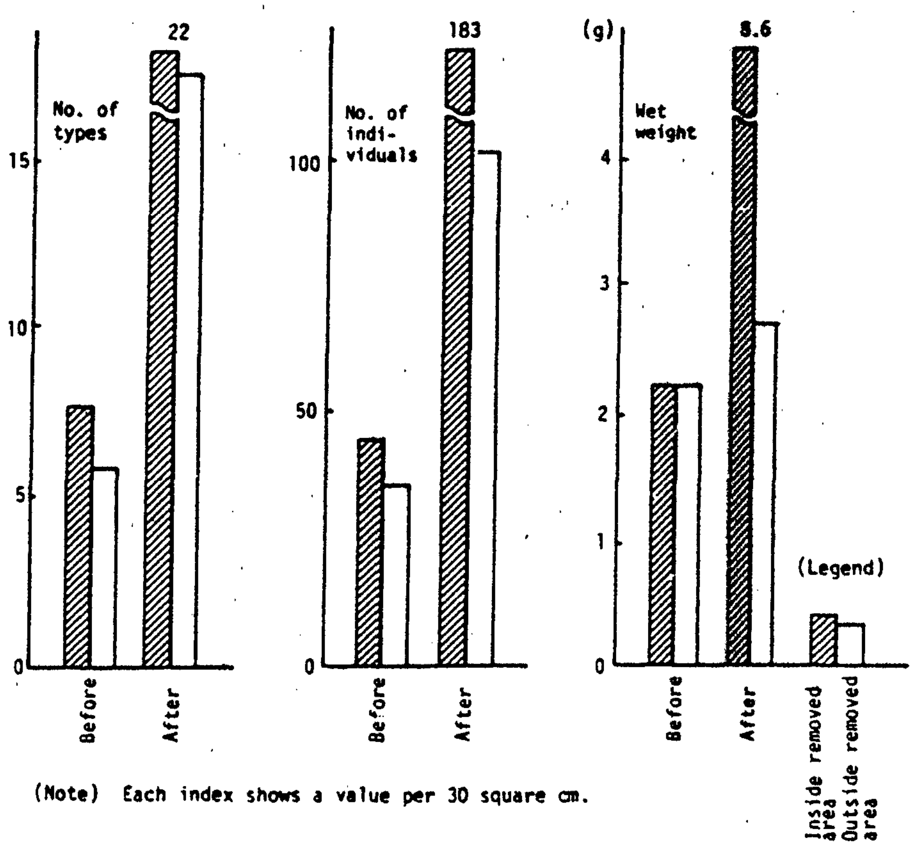


Figure 3. Improvement effects of living things on the sea bottom

By using the reduction rate of nutrient salts (phosphorus) elution, the effect of removal of more than 30 mg/g(COD) of the bottom sediment in the Mikawa Bay is calculated to be equivalent to 33% of T-P flowed in from the rivers.

Purpose of Marine Environment Improvement Pilot Project

In order to remove a large deposit of sludge accumulated widely over an enclosed inland bay and inland waters:

1) A sea bottom management program must be established to effectively improve the marine environment.

2) Dredging and overlaying must be conducted in waters where there is heavy ship traffic and where good fishing ground is located.

3) A thorough study must be made on the method of disposing the dredged material that contains a large amount of sludge.

For this reason, before undertaking the actual sea bottom management work, pilot work must be done and the effect and method of sea bottom management must be established. In this connection, the Marine Environment Improvement Pilot Project is carried out in areas where the sea bottom is heavily polluted. At the stage of Practical Design Study of the pilot work, actual conditions of pollution and factors of the cycle of substances are obtained and the effect of water quality improvement is studied by simulation of these figures. A preliminary study is also undertaken on the method of work.

Pilot work is carried out on a broader range after results of the Practical Design Study are obtained. The effect of improvement of water quality is confirmed in the field and the method of sea bottom management suited to the subject waters is established.

Outline of Marine Environment Improvement Pilot Project

In the Marine Environment Improvement Pilot Project the environmental improvement effects by sea bottom management are established and the sea bottom management work method, studies, test work, and technical development are carried out considering the characteristics of each subject water with the system shown in Figure 4 as the standard.

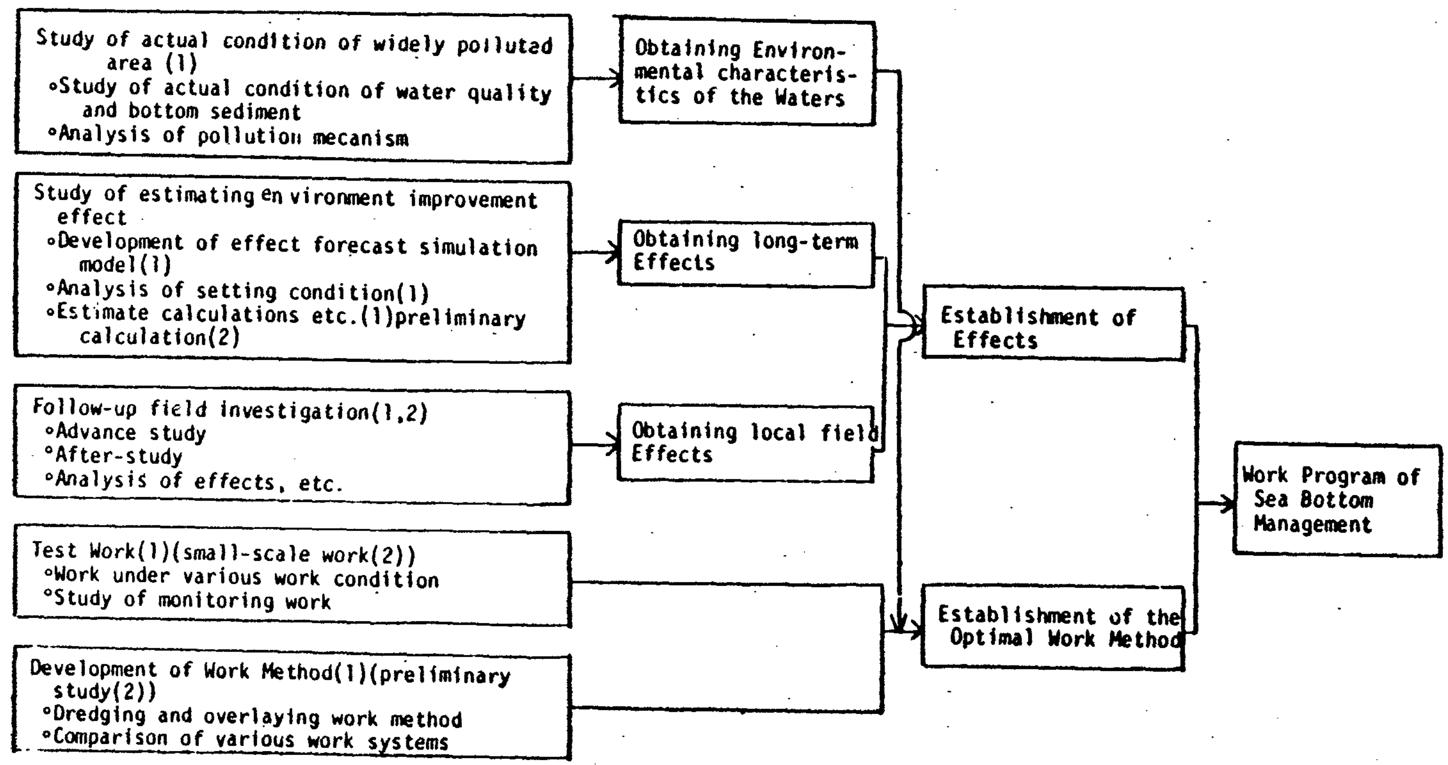
Subject waters for the Marine Environment Improvement Pilot Project included the Seto Inland Waters (Osaka Bay, Hiroshima Bay, and Suoo Sea), Ise Bay, and Tokyo Bay. Table 2 shows characteristics of the subject waters, and Table 3 outlines the work.

The Pilot Project will be conducted for 4-5 years after making the Practical Design Study in each waters and establishing the effects of sea bottom management and the work method in the inland bays and waters. Table 4 and Figure 5 show the work program for Tokyo Bay.

PORT POLLUTION CONTROL WORKS

Outline of the System

The Port Pollution Control Works carries out dredging of bottom sediment



Remarks: 1: Practical Design Study
2: Marine Environment Improvement Pilot Project

Figure 4. System of Marine Environment Improvement Pilot Project

TABLE 2. ENVIRONMENTAL CHARACTERISTICS OF THE SUBJECT WATERS OF MARINE ENVIRONMENT IMPROVEMENT PILOT PROJECT

Environment Items	Tokyo Bay	Osaka Bay	Hiroshima Bay	Suoo Sea	Ise Bay (Mikawa Bay)
Amount of sludge 10000m (more than 30mg/g)	2,100	7,000	12,000	82	1,960
10000m (more than 20mg/g)	8,800	64,000	110,500	1,000	6,230
Polluted Area Km (more than 30mg/g)	100	350	400	16.4	99.3
(more than 20mg/g)	200	800	900	170	189.3
Average Sludge Thickness in cm	30	80	120	50-70	15-20
Max. Sludge Thickness	50	200	about 200	40	60
Average Water Depth of polluted Area m (20mg/g)	20	21	28	13	25(10)
(30mg/g) m	32	40	51	45	17-18
Sea Bottom COD max. mg/g	61.2	50	47	about 30	37.2
Water Area Km2	1,000	1,529	946	2,400	510
Amount of Seawater Km^3	16.0	41.8	24.2	38.4	5.5
Average Water Depth m	17	27.5	25.6	16	9.2
Inflow Land Water Volume m^3/day	2.73 × 10	4.3 × 10	1.1 × 10	2.2 × 10	8.3 × 10
Seawater Replacement Volume Km^3/day	9.96	1.30	2.23	--	1.6
COD Inflow Load Volume t/day	145.3	315.5	82.5	70	64
COD Elution Load Volume t/day	537.6	105.4	72.2	876	198
COD max. elution Unit mg/m · day	354	148	97	155	240
Internal Production Unit t/day	6,040	2,736	1,412	1,530	2,190
COD Internal Production Unit mg/m · day	--	1.79	1.49	--	200
Rate of Achieving Environmental Standards; COD (%)	61	76% in all Seto Inland Sea			53
Newly Created Deposit cm/year	2	1.0	1.5	--	1.0

Characteristics of Waters		Tokyo Bay	Ise Bay	Seto Inland Sea
Bottom Sediment	Degree of Pollution	large	medium	medium
	Pollution Distribution	concentrated in the center of the Bay	distributed widely	concentrated locally
	Amount of Sludge	medium	small	large
	Characteristics of Sea Bottom Pollution	Sludge Depositing speed large	--	Dynamic movement of bottom mud large
Topography	Shape of Bay	simple	medium	complex
	Water Depth	medium	shallow	varied depending on location
Marine Hydraulics	Flow Condition	simple	medium	complex
	Enclosed	large	medium	complex
Seawater Pollution	COD Pollution	half achieved	half achieved	partly achieved
	Land Inflow Load	large	medium	large
	Frequency of red tide	medium	medium	large
Living Environment	Marine Lives	poor	medium	rich
Fishing	Fishing	few	many	many
	Fish Farming	few	medium	many

(Blank columns in the table show figures not available)

TABLE 3. CHARACTERISTICS OF SUBJECT WATERS AND OUTLINE OF PILOT PROJECT

Seawaters	Characteristics of Waters	Objectives of Work	Outline of Work
Tokyo Bay	•Extreme pollution of water quality and sea bottom •Only one mouth of bay and extremely stagnant waters •Sludge is accumulated in the center of bay rather than on coastal areas •Great inflow load	•Develop effective work method in heavily polluted waters	•Testing work of dredging •Highly efficient dredging test and testing for practical application of disposal method •Analysis and survey of inflow load performance •Study of actual condition of pollution
Seto Inland Sea: Osaka Bay	•2 bay mouth, seawater is renewable in the center of bay •Sludge is more heavily accumulated on the northeast coast	•Determine the reduction effect of elution of polluted substances by dredging •Develop dredging method	•Testing work of dredging •Follow-up study of dredging effects •Development of water quality improvement forecast simulation model •Study of actual condition of pollution
Seto Inland Sea: Hiroshima Bay	•Sludge is heavily accumulated	•Determine the reduction effect of elution of polluted substances by overlaying •Develop overlaying method	•Testing work of overlaying •Follow-up study of overlaying effects •Development of water quality improvement forecast simulation model •Study of actual condition of pollution
Seto Inland Sea: Suoo Sea	•Sludge is thinly accumulated in wide range •Sludge is easily movable	•Develop a method utilizing dynamic nature of sludge	•Testing work by trench work method •Follow-up study of effects of trench work method •Analysis of sludge movement •Study of actual condition of pollution
Ise Bay	•Marine lives are active •Shallow waters	•Determine the effect of sea bottom sediment management on marine lives •Develop a work method which will not adversely affect marine lives	•Testing work of dredging •Follow-up study of effects of recovery of marine lives •Study of actual condition of pollution

TABLE 4. ITEMS OF STUDY

Items	Practical Design Study ('81-'84)	Marine Environment Improvement Pilot Project ('85-'88)
Study of Actual Pollution of Wide Areas	°Study of actual pollution of wide area (water, bottom sediment, deposit, etc.) °Analysis of pollution mechanism °Analysis of environmental characteristics	
Forecast of Water Quality Improvement	°Field survey and analysis deposit performance °Development of deposit forecast model °Simulation of environmental improvement effect forecast	°Simulation of long-term and wide-range effect forecast in heavily polluted waters
Follow-up Study of Effects	°Field study and analysis in relation to deposited sludge in the work area °Field study and analysis of improvement effects such as quality of waters immediately above and lives in the work area	°Field study and analysis of long-term and wide-range effects of recovery of self-purification by sea bottom
Test Work	°Dredging work °Study of work environmental effects	°Dredging work °Overlaying work
Study of Work Method Development	°Dredging and sludge disposal system °High-efficiently dredging and disposal method	°Study of work environmental effects °Study of a model for dredging and sludge disposal system

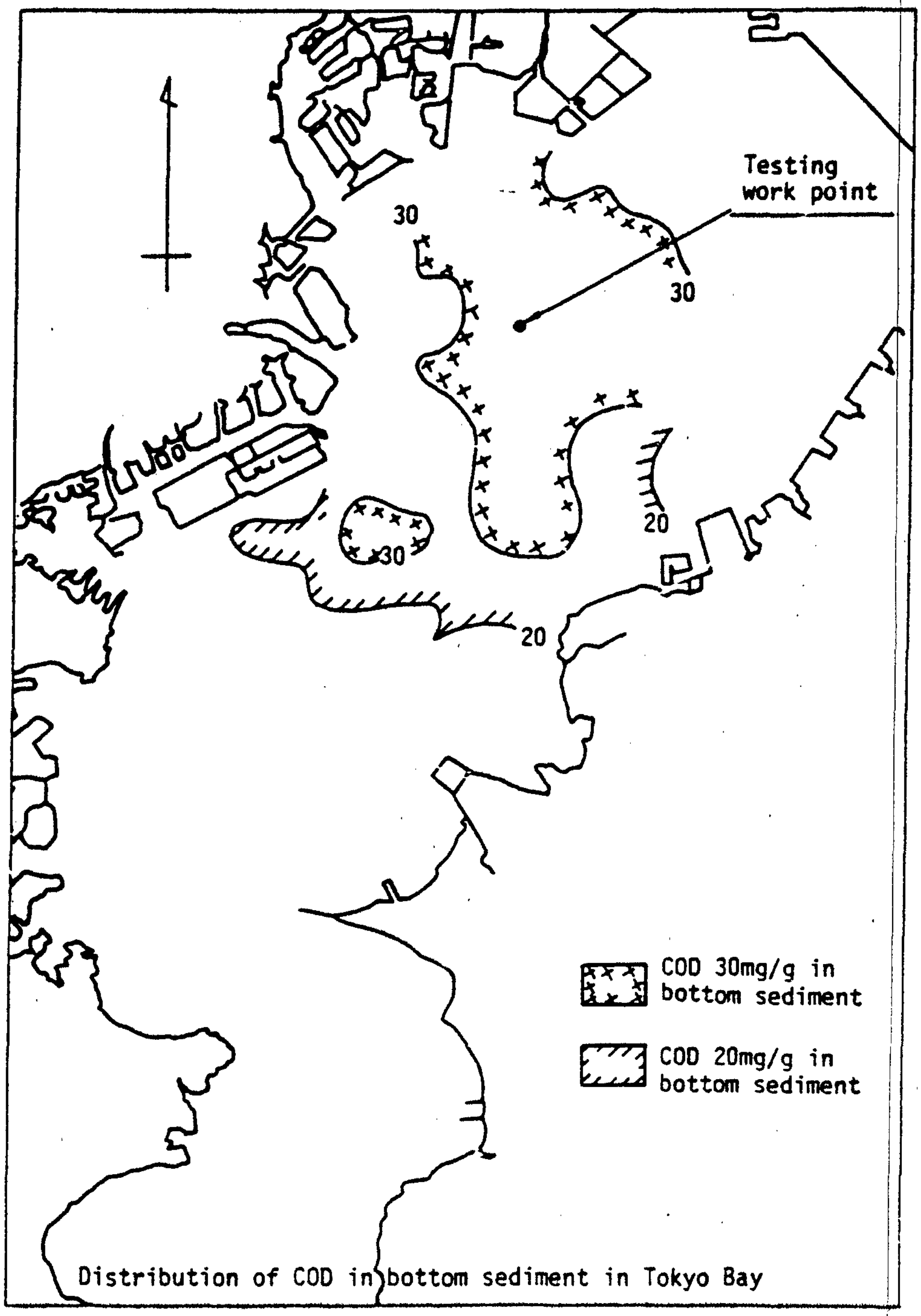


Figure 5. Location map of test work

and overlaying of earth or installation of water line and other port and harbor pollution control facilities where sludge and other pollutants are deposited or where water is polluted in ports and harbors. The work is 50 percent subsidized by the government fund and as sub-government work pursuant to Art. 3 of the Law Concerning Special Government Financial Measures for Pollution Control Project and Art. 43 of the Port and Harbor Law.

Work related to the disposal of bottom sediment is carried out in accordance with the former law. In order to qualify under the law, an environmental pollution control program, pursuant to Art. 19, para. 2, of the Basic Law for Environmental Pollution Control, is prepared as designated by the Minister of Home Affairs in consultation with the minister in charge and the Minister of Environmental Agency, pursuant to Art. 3, para. 3, of the Law Concerning Special Government Financial Measures for Pollution Control Project. The designation is made for each single year.

In cases where businesses caused the pollutions, Art. 4 of the Law concerning Entrepreneurs' Bearing of the Cost of Public Pollution Control Works requires the business to withstand all or part of the cost required for the work depending on the extent of the cause acknowledged as pollutant.

The Port Pollution Control Works has been carried out as part of the Improvement Works of Port Facilities since '72.

Work Program for 1981

Table 5 shows the work cost and amount of dredged soil of the Port Pollution Control Works for 1981 now under way.

TABLE 5. WORK PROGRAM OF PORT POLLUTION CONTROL WORKS IN 1981

Name of Port	Cost of Work (million yen) (Government Expense)	Quantity ($1000m^3$)
Tokyo	1,220 (610)	174.9
Yokohama	138 (68)	82.8
Nagoya*	411 (74.089)	(16.2 $1000m^2$)
Tsu-Matsuzaka	600 (300)	101.5
Osaka	727 (363.5)	195.5
Himeji	320 (160)	30.7
Amagasaki-Nishinomiya-Ashiya	224 (112)	52.9
Higashiharima	30 (15)	11
Omuta*	120 (12.426)	(21.6 $1000m^2$)
Minamata	4,026 (919.585)	266.7
TOTAL	7,814 (2,634.6)	916 (37.8)

* The amount of dredged soil at Nagoya and Omuta shows areas of soil overlay.

Future Program of the Work

Table 6 shows an overall program of Port Pollution Control Works (bottom sediment disposal); work completed by '80; program of '81-85; program after '86; and polluted substances, removal standards, etc.

TABLE 6. PROGRAM FOR PORT POLLUTION CONTROL WORKS

Name of port	Areas	Governing body	Type of work	Overall program			Quantity of work carried out by '80		Five-Year Plan (81-85)	
				Quantity	Cost of work	Period of work	Quantity	Cost of work	Quantity	Cost of work
				($1000m^3$)	(1000 yen)		($1000m^3$)	(1000 yen)	($1000m^3$)	(1000 yen)
Otaru	Ironai	Otarushi	Dredging	20.0	212930	82 - 85	--	--	20.0	212930
Rumoi	Yukuko	Rumoishi	Dredging	15.0	79600	84 - 65	--	--	15.0	79600
Tokyo	Koto	Tokyoto	Dredging	1232.6	5847100	72 - 85	754.8	2319100	477.8	3528000
Tokyo	Shibaura	Tokyoto	Dredging	1132.5	4221270	72 - 87	829.8	3206270	17.2	58000
Tokyo	Konan	Tokyoto	Dredging	261.3	781000	72 - 87	77.1	124000	--	--
Yokohama	Ookagawa	Yokohamashi	Dredging	275.1	401170	73 - 87	189.6	276170	54.5	84000
Yokohama	Katabiragawa	Yokohamashi	Dredging	646.2	1073730	73 - 87	431.3	716730	170.5	286000
Yokohama	Ebisu, Osato	Yokohamashi	Dredging	702.4	988100	73 - 87	401.8	537100	124.7	187000
Shimizu	Konai	Shizuokaken	Dredging	120.0	970000	83 - 84	--	--	120.0	970000
Nagoya	Konai (2)	Nagoyako-kanrikumiai	Dredging	57.7	1156500	83 - 86	0.6	13000	47.3	948000
Nagoya	Konai (2)	Nagoyako-kanrikumiai	Overlaying	(32.3) 8.9	468000	80 - 86	(5.9) 1.6	86000	(20.0) 5.5	289000
Nagoya	Oegawa	Nagoyako-kanrikumiai	Dredging	128.9	947500	83 - 86	3.7	27321	85.6	629000
Nagoya	Oegawa	Nagoyako-kanrikumiai	Overlaying	(221.1) 98.7	1964000	79 - 86	(23.4) 10.5	208211	(185.5) 82.8	1648000
Tsu-Matsuzaka	Konai	Mieken	Dredging	472.0	2489922	79 - 83	155.7	619922	316.3	1870000
Kinuura	Hekinan	Aichiken	Dredging	27.3	82000	82 - 83	--	--	27.3	82000
Wakayama-Shimotsu	Naiko	Wakayamaken	Dredging	100.0	250000	83 - 84	--	--	100.0	250000

(Continued)

TABLE 6. (Continued)

Name of port	Plan after 1986		Polluted Substance	Removal Standard	Pollution Control Program, etc.	Cost borne by business	
	Quantity	Cost of work				No. of business	Share of cost (%)
	(1000m³)	(1000 yen)					
Osaka	170.0	1,340,700	Organic Matter	I. L. 15%	Osaka Area Pollution Control Program	--	--
Himeji (Yaka)	20.0	220,000	Organic Matter	I. L. 10%, COD 20 mg/g, Sulfide 0.8 mg/g	South of Harima Area Pollution Control Program	--	--
Himeji (Shikama)	16.6	104,000	Organic Matter	I. L. 15%, COD 30 mg/g, Sulfide 1.2 mg/g	South of Harima Area Pollution Control Program	--	--
Himeji (Aboshi)	111.5	566,000	Organic Matter	I. L. 15%, COD 30 mg/g, Sulfide 1.2 mg/g	South of Harima Area Pollution Control Program	--	--
Amagasaki-Nishinomiya-Ashiya	12.0	59,000	Organic Matter	I. L. 15%, COD 30 mg/g, Sulfide 1.2 mg/g	East of Hyogo Prefecture Area Pollution Control Program	--	--
Amagasaki-Nishinomiya-Ashiya	323.0	1,351,000	Organic Matter	I. L. 15%, COD 30 mg/g, Sulfide 1.2 mg/g	East of Hyogo Prefecture Pollution Control Program	--	--
Higashiharima	15.6	14,000	Organic Matter	I. L. 15%, COD 30 mg/g, Sulfide 1.2 mg/g	South of Harima Area Pollution Control Program	--	--
Kure	--	--	Organic Matter	I. L. 24%, COD 50 mg/g, Sulfide 1.0 mg/g	Hiroshima-Kure Area Pollution Control Program	1	Undecided
Otake	--	--	Organic Matter	I. L. 20%	Otake Area Pollution Control Program	6	Undecided
Otake	--	--	Organic Matter	I. L. 20%	Otake Area Pollution Control Program	6	Undecided
Takamatsu	--	--	PCB, Organic Matter	PCB 10 ppm	Kagawa Area Pollution Control Program	4	Undecided
Matsuyama (Naiko)	--	--	Organic Matter	Undecided	Designated by the Ministry of Home Affairs	--	--
Matsuyama (Wake)	--	--	Organic Matter	Undecided	Designated by the Ministry of Home Affairs	--	--
Iwakuni	--	--	Organic Matter	I. L. 15%	Iwakuni Area Pollution Control Program	5	Undecided

(Continued)

TABLE 6. (Continued)

Name of port	Areas	Governing body	Type of work	Overall program Quantity	Overall program Cost of work	Overall program Period of work	Quantity of work carried out by '80 Quantity	Quantity of work carried out by '80 Cost of work	Five-Year Plan (81-85) Quantity	Five-Year Plan (81-85) Cost of work
				($1000m^3$)	(1000 yen)		($1000m^3$)	(1000 yen)	($1000m^3$)	(1000 yen)
Osaka	Konai	Osakashi	Dredging	2562.0	9787500	73 - 88	1415.9	4816800	976.1	3630000
Himeji	Yaka	Hyogoken	Dredging	162.0	1600000	74 - 90	77.2	820000	64.8	560000
Himeji	Shikama	Hyogoken	Dredging	172.0	1110000	79 - 90	9.4	86000	146.0	920000
Himeji	Aboshi	Hyogoken	Dredging	434.0	2800000	79 - 90	36.7	334000	285.8	1900000
Amagasaki-Nishinomiya-Ashiya	Nishinomiya	Hyogoken	Dredging	40.0	180000	80 - 90	3.0	11000	25.0	110000
Amagasaki-Nishinomiya-Ashiya	Amagasaki	Hyogoken	Dredging	697.0	2700000	77 - 90	229.0	739000	145.0	610000
Higashiharima	Beppu	Hyogoken	Dredging	41.4	180000	78 - 90	7.8	80000	18.0	86000
Kure	Hiro	Kureshi	Dredging	240.0	2973000	84 - 85	--	--	240.0	2973000
Otake	Kojima	Hiroshimaken	Dredging	225.0	1485000	83	--	--	225.0	1485000
Otake	Kojima	Hiroshimaken	Overlaying	$1000m^2$ (278.0)	583000	83	--	--	278.0	583000
Takamatsu	Senbagawa	Kagawaken	Dredging	34.4	640000	83 - 84	--	--	34.4	640000
Matsuyama	Naiko	Ehimeken	Dredging	60.0	260000	84	--	--	60.0	260000
Matsuyama	Wake	Ehimeken	Dredging	17.5	80000	85	--	--	17.5	80000
Iwakuni	Muronoki	Yamaguchiken	Dredging	300.0	500000	82 - 84	--	--	300.0	500000

(Continued)

TABLE 6. (Continued)

Name of port	Areas	Governing body	Type of work	Overall program Quantity	Overall program Cost of work	Overall program Period of work	Quantity of work carried out by '80 Quantity	Quantity of work carried out by '80 Cost of work	Five-Year Plan (81-85) Quantity	Five-Year Plan (81-85) Cost of work
				($1000m^3$)	(1000 yen)		($1000m^3$)	(1000 yen)	($1000m^3$)	(1000 yen)
Ube	Honko	Yamaguchiken	Dredging	492.0	800000	83 - 84	--	--	492.0	800000
Omuta	Omuta	Fukuokaken	Overlaying Dredging	100.0	2361180	76 - 81 (73 - 75)	78.4	2241180	21.6	120000
Minamata	Hyakken	Kumamotoken	Overlaying Dredging	1663.0	21520983	74 - 85	[illegible]	[illegible]	778.5	11750000
	TOTAL		Overlaying	12331.0	66117305		5507.9	24497396	5384.3	35488530
			Overlaying	485.6	5376180		90.5	2535391	387.9	2640000

(Continued)

TABLE 6. (Continued)

Name of port	Plan after 1986		Polluted Substance	Removal Standard	Pollution Control Program, etc.	Cost borne by business	
	Quantity	Cost of work				No. of business	Share of cost (%)
	($1000m^3$)	(1000 yen)					
Otaru	--	--	Organic Matter	I. L. 10%	Designated by the Ministry of Home Affairs	--	--
Rumoi	--	--	Organic Matter	I. L. 15%	Designated by the Ministry of Home Affairs	--	--
Tokyo (Koto)	--	--	Organic Matter	I. L., COD, Sulfide Total Estimate Method; 6 points	Tokyo Area Pollution Control Program	--	--
Tokyo (Shibaura)	285.5	957,000	Organic Matter	I. L., COD, Sulfide Total Estimate Method; 6 points	Tokyo Area Pollution Control Program	--	--
Tokyo (Konan)	184.2	657,000	Organic Matter	I. L., COD, Sulfide Total Estimate Method; 6 points	Tokyo Area Pollution Control Program	--	--
Yokohama (Ookagawa)	31.0	41,000	Organic Matter	I. L., COD, Sulfide Total Estimate Method; 6 points	Kanagawa Area Pollution Control Program	--	--
Yokohama (Katabiragawa)	44.4	71,000	Organic Matter	I. L., COD, Sulfide Total Estimate Method; 6 points	Kanagawa Area Pollution Control Program	--	--
Yokohama (Ebisu)	175.9	264,000	Organic Matter	I. L., COD, Sulfide Total Estimate Method; 6 points	Kanagawa Area Pollution Control Program	--	--
Shimizu	--	--	Organic Matter	I. L. 15% or COD 15 mg/g	Shizuoka Shimizu Area Pollution Control Program	--	--
Nagoya	9.8	195,000	Hg	Hg 24 ppm	Nagoya, etc., Area Pollution Control Program	2	60.34
Nagoya (Konai (2))	(6.4) 1.8	93,000	Hg	Hg 25 ppm	Nagoya, etc., Area Pollution Control Program	2	60.34
Nagoya (Oegawa)	39.6	291,179	Hg, PCB	Hg 25 ppm, PCB 10 ppm	Nagoya, etc., Area Pollution Control Program	7	65.85
Nagoya (Oegawa)	(12.2) 5.4	107,789	Hg, PCB	Hg 25 ppm, PCB 10 ppm	Nagoya, etc., Area Pollution Control Program	7	65.85
Tsu-Matsuzaka	--	--	Organic Matter	Sulfide 1 mg/g	Designated by the Ministry of Home Affairs	--	--
Kinuura	--	--	Organic Matter	Undecided	Kinuura Nishimikawa Area Pollution Control Program	--	--
Wakayama-Shimotsu	--	--	Organic Matter	I. L. 15%	Wakayama Area Pollution Control Program	--	--

(Continued)

TABLE 6. (Concluded)

Name of port	Plan after 1986 Quantity	Plan after 1986 Cost of work	Polluted Substance	Removal Standard	Pollution Control Program, etc.	Cost borne by business No. of business	Cost borne by business Share of cost (%)
	(1000m^3)	(1000 yen)					
Ube	--	--	Organic Matter	I. L. 15%	Shimonoseki-Ube Area Pollution Control Program	7	Undecided
Omuta	--	--	Hg, CD	Hg 25 ppm, Cd 200 ppm	Omuta Area Pollution Control Program	6	79.29
Minamata	--	--	Hg	Hg 25 ppm	Designated by the Ministry of Home Affairs	1	65,0025
TOTAL	1439.1 7.2	6,131,379 (Dredging) 200,789 (Overlaying)					

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RESCUING THE PORTS

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ABSTRACT

The environmental movement in the United States of the early and mid-seventies began exacting its toll on the ports of the country in the late seventies. This toll is in the form of time delays in obtaining dredging and dredged material disposal permits, denial of permits, delayed capital investment improvements, increased investment and operation and maintenance costs, and lost revenues. To counter these impacts and to seek state-of-the-art practices in dredging and dredged material disposal activities, both the American Association of Port Authorities and the International Association of Ports and Harbors established ad hoc dredging committees. Since late 1979 these two organizations separately and jointly have pursued similar goals to obtain political recognition and acquire influence to alter United States legislation and international convention. Decisions governing ports and port operations engaged in international trade must be made in the overall public interest and welfare and not excessively hampered by environmental considerations alone. Achieving organizational goals will require continued effort, organizational funding, and exploitation of opportunities to tell the story.

INTRODUCTION

Dredging and disposal of dredged material are essential operations in maintaining the navigability and economic vitality of ports throughout the world. In the United States, more than 350 million cubic yards* of dredged material per year is dredged from more than 100 ports serving the nation.

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

More often than not, viable disposal options are limited, and ocean disposal of this material becomes the most economical alternative, the least damaging to the environment, and the only practical method of disposal.

One example of the importance of ocean disposal of dredged material to ports and the national economy--and one with which I am most closely associated--is the situation in the Lower Mississippi River. Maintenance of the deep-draft navigation channels in 1978 at the Mississippi River-Gulf Outlet accounted for 6.1 million cubic yards of dredged material disposed of in the ocean. Waterborne commerce in the stretch of river from Baton Rouge to below New Orleans, a distance of slightly more than 200 miles, totaled 572 million tons in 1978, making this one of the largest port areas in the world. Ocean disposal of dredged material is the only feasible method of keeping this vital shipping area open.

DISPOSAL OPERATIONS AND ASSESSING THE ENVIRONMENT

In recent years, however, ocean disposal operations have come under close environmental scrutiny. Many ports throughout the world, and particularly those in the United States, have experienced increased difficulty in obtaining the necessary government permits to accomplish the dredging required for normal operation and maintenance activities as well as capital improvements. Periodic maintenance dredging is essential for operations at seaports. Delays in performing this maintenance often mean lost revenues, increased shipping costs, and lessened port efficiency. These impacts affect the economic vitality of a port.

Environmental Legislation

The ports of the United States began feeling the pressures generated by new environmental laws during the early and mid 70's. Mandates of the National Environmental Policy Act of 1969; the Federal Water Pollution Control Act of 1972; the Marine Protection, Research, and Sanctuaries Act of 1972; and other federal laws impacted expansively on the scope and complexity of the federal regulatory program over port and channel construction and operation and maintenance activities. The Administrator of the Environmental Protection Agency (EPA), in conjunction with the Secretary of the Army, was required to develop regulations controlling dredging and filling activities in waters of the United States and adjacent wetlands and controlling disposal of dredged material in ocean waters (ocean dumping). These activities require evaluation and assessment of probable impacts on the marine environment, wildlife habitats, and, in general, the overall environment, including the well-being of man.

Chemical analyses of materials to be dredged was required after the regulations were promulgated in 1974 and 1975. Soon afterward, water column chemistry was additionally required to prepare an assessment. The degree of testing accuracy was greatly increased when EPA published its "Quality Criteria for Water" in July of 1976. Costs and time required to obtain permit approval were increased considerably.

On January 11, 1977, the United States Environmental Protection Agency revised the "Ocean Dumping" regulations and criteria, requiring additional testing of materials to be dredged. An interim test procedure called "bioassay" was included. In a bioassay, marine organisms such as juvenile shrimps, clams, worms, and fishes are exposed to sediments and water taken from the site to be dredged. Organism survival is evaluated after 96 hr. After 10 days, the tissues of certain surviving organisms are analyzed for chemical content to provide an indication of potential for bioaccumulation. On September 7, 1977, this bioassay test procedure became mandatory in evaluating ocean disposal of dredged material.

A Case Study--Port of Lake Charles and Calcasieu River

A classic example of lengthy delays caused by this new regulation was soon to unfold. On November 22, 1977, the U. S. Army Corps of Engineers notified Region VI, U. S. Environmental Protection Agency, of the intent to perform maintenance dredging of the Gulf approach channel to the Calcasieu River and its inland reach.

Considerable discussion developed over the need for bioassays because of exclusions provided for in the regulations. On February 15, 1978, EPA refused approval of the permit until receipt of bioassay results. Bioassays were then run by a contractor, but results indicated a potential for acute toxicity for marine organisms in direct contact with the sediments. The EPA again disapproved the disposal operations, and, thus, the dredging, on July 3, 1978.

The "Ocean Dumping" regulations provide that, if the material proposed for dumping does not meet the criteria, the District Engineer may determine that no economically feasible alternative method or site is available and so notifies EPA's Regional Administrator. The District Engineer submitted a report of these findings to the Chief of Engineers on October 11, 1978, and requested that he certify these facts to the Secretary of the Army and request that the Secretary seek a waiver of the criteria from the Administrator. Additional supportive information was provided to the Office of the Chief of Engineers, and the Secretary of the Army subsequently requested the waiver from the Administrator, EPA, on February 7, 1979. Again, additional information was requested by EPA (this was the first waiver request which they had received). On April 18, 1979, EPA granted a partial waiver to Mile 10 for maintenance dredging. Eighteen months elapsed from the time of the original request to granting of the partial waiver.

(Incidentially, it was not until January 7, 1981, that the Administrator of the EPA informed the Secretary of the Army that he granted unconditional approval for the disposal of the maintenance dredging material into the ocean. In rendering his determination, he found that such dumping would not cause undue degradation to the marine environment. A period of over three years had elapsed!)

In summary, it is most interesting to note that, if this problem had not been resolved and alternative disposal sites had been required, the annual maintenance dredging costs would have escalated from $1.1 million to $62.9 million versus annual project benefits of $21.0 million. It would have also involved thousands of acres of new dredged material disposal areas.

ORGANIZING FOR SURVIVAL

American Association of Port Authorities

In response to such ever-increasing problems of delays and escalating costs and to continue efforts of those proposing more stringent, if not always applicable, testing procedures, the American Association of Port Authorities (AAPA) established an Ad Hoc Committee on Dredging in June, 1979. Its establishment was recognition that the then existing AAPA Committee structures and ensuing resolutions were ineffective in moderating the trend toward increasing environmental restrictions on dredging activities. Early on, goals were established. These goals included the identification and documentation of those laws, rules, regulations, agencies, procedures, and agreements creating dredging problems. Targeted for study were concerns over mitigation, compensation, endangered species, bioassay test criteria, local costs, permit delays, and interagency agreements. Additionally, the Committee was charged with developing recommended revisions to existing regulations and procedures that would provide needed relief as well as the necessary documentation to support those revisions. Finally, the new Committee was instructed to develop a strategy to be used to achieve adoption and implementation of these revisions and to compile data on key legislators, committees, boards, and administrators to whom these revisions must be officially transmitted.

International Association of Ports and Harbors

In early 1980, a similar committee to coordinate on the international scene was established by the International Association of Ports and Harbors (IAPH).

At the IAPH Executive Board Meeting in Brisbane, Australia, in April, 1980, there was considerable discussion of the problems the United States ports had been encountering in their attempts in recent years to dredge their facilities. The Board recognized that those difficulties stemmed in a large measure from the United States being party to the "Convention on the Prevention of Marine Pollution by the Dumping of Wastes and Other Matter," negotiated in London in November of 1972, and more commonly called the "London Dumping Convention" (LDC). Further, the Board agreed that it would benefit the IAPH membership to develop a better understanding of port dredging practices and the relationship of those practices to the terms of the LDC.

The missions of the International Ad Hoc Dredging Committee were:

1. To review, report, advise, and submit recommendations on major matters relating to seaport and inland port dredging and dredging equipment;

2. To meet with and coordinate with the LDC and the Inter-Governmental Maritime Consultative Organization (IMCO), the latter being the organization designated to serve as the Secretariat to the LDC;

3. To develop a program on disposal of dredged material problem areas for inland ports;

4. To publish an inventory of dredging equipment owned by dredging companies worldwide, including a special section on new, innovative equipment;

5. To collect and publish information on the state of the art;

6. To publish a brochure on sources of information and assistance on dredging techniques and types of equipment best suited for given situations.

WORKING TOWARD THE GOALS

These two committees, the Ad Hoc Dredging Committee of the IAPH and the Ad Hoc Dredging Committee of the AAPA, have pushed forward in their efforts to resolve regulatory problems confronting the industry and to seek, as well, solutions that are environmentally and economically sound. (The AAPA Committee was redesignated as the Special Dredging Task Force of Committee II: Channels and Harbors, in September of 1980 after a decision by the AAPA Coordinating Committee to establish a Special Projects Fund. The Special Projects Fund is established and maintained by voluntary participation--funds being solicited from AAPA members and other individuals or entities with similar interests. Funds thus received will be used solely for technical and legal assistance for the ongoing work of the Special Dredging Task Force.)

Three meetings were held by the AAPA Ad Hoc Dredging Committee during calendar year 1980. These were on March 19, 1980, at Washington, D. C.; on August 25, 1980, at New Orleans, Louisiana; and on October 20, 1980, at Norfolk, Virginia. In the course of these meetings, and in other frequent contacts among Committee members, work in connection with the following Committee objectives and subjects was conducted:

On March 14, 1980, AAPA representatives appeared before the House Committee on Merchant Marine and Fisheries to deliver a supporting statement on H. R. 6361, entitled "A Bill to Amend the Marine Protection, Research and Sanctuaries Act of 1972 In Order to Suspend Temporarily the Use of Bioaccumulation and Biomagnification Testings in the Evaluation of Applications Relating to Ocean Dumping of Dredged Material, and for Other Purposes." The testimony document for this hearing was forty-seven pages long and included fifty pages of enclosures.

As a result of this hearing, action was taken to develop proposed amendments to the Marine Protection, Research, and Sanctuaries Act of 1972. These amendments, which would resolve many dredging problems, were provided to several U. S. Representatives who promised to co-sponsor the necessary legislation.

Through a meeting on March 19, 1980, with White House authorities of the Carter Administration, the Committee and the AAPA at large derived substantial benefits and positive direction. The meeting included AAPA leadership members and was held to provide an opportunity for discussing dredging problems. The group, including myself as the AAPA Special Dredging Task Force Chairman, met with Mr. William G. Simpson, Deputy Assistant to the President; and Mr. David M. Rubenstein, an Assistant to Mr. Stuart E. Eizenstat, Assistant to the President for Domestic Affairs and Policy. Our appeal for support in dredging activities was delivered. We were cautioned that budgets were being cut. Mr. Simpson later advised us that we needed to make stronger and more frequent representations to Congress and involved government agencies.

The members of the AAPA Special Dredging Task Force believed that the AAPA could provide influence on ocean dumping controls if the AAPA became involved in the United States EPA-chaired Committee on Ocean Dumping, a Subcommittee of the U. S. State Department Shipping Coordinating Committee. This Subcommittee was formed in 1976 to provide an opportunity for public and government interagency comments and advice on United States policy relating to the London Ocean Dumping Convention. As Chairman of AAPA's newly organized Dredging Committee, I requested in June, 1979, that the EPA appoint me as a member of the Committee on Ocean Dumping, also frequently referred to as the "Advisory Committee on Ocean Dumping." The appointment was finalized on August 15, 1979.

During 1980, it became apparent that the EPA-chaired Committee on Ocean Dumping was dominated by the outlook of the parent agency and sometimes unfounded concerns of environmental organizations and, thus, would not provide the vehicle to influence ocean dumping criteria so as to enhance dredging programs clearly in the national interest. A direct appeal to the London Convention appeared to be the only hope. This was achieved through the cooperation and assistance of Mr. Anthony J. Tozzoli, Port Authority of New York and New Jersey, who is a Vice President of the International Association of Ports and Harbors and, at the time, was also Chairman of that organization's Dredging Committee. Through him it was possible to arrange for the AAPA Dredging Task Force Chairman, who is also a member of the IAPH Dredging Committee, to head an IAPH delegation with observer status at the 1980 Fifth Consultative Meeting of the Contracting Parties to the London Dumping Convention held in London, September 22-25, 1980. This convention is the major global treaty governing the ocean dumping of wastes, including dredged materials. It should be noted that as a signatory to this convention, the United States is bound by the international rules and criteria in promulgation of national laws and regulations.

In appearing before the London Convention, the Chairman of our Dredging Task Force presented a position paper directing the attention of the Contracting Parties to possible interpretations of the terms of the LDC and their subsequent application to ocean disposal operations of dredged material. Application of differing interpretation could result in an absolute prohibition of ocean dumping of dredged material--even when there may be no feasible or practical alternative means of disposal, and even when the disposal might be safely carried out if special care is taken. This, it was pointed out, could threaten world ports with closures resulting in devastating economic impacts upon the flow of international commerce. IAPH urged the Contracting Parties to consider these possible effects upon port operations. The IAPH also proposed a study on the dredged material issue with a view toward adopting whatever changes are needed in the LDC to ensure that there will be no unintended or unnecessary interference with essential port operations.

The concerns expressed by the IAPH delegation at the Fifth Consultative Meeting were well received. The Contracting Parties recognized the significance of the technical issues raised by the IAPH, namely, the use of "special care" in the ocean dumping of dredged material. The consultative parties directed that these issues be considered by the Ad Hoc Scientific Group of the Convention at its next intersessional meeting of May, 1981, and to report to the Convention at the Sixth Consultative Meeting to be held in London in October, 1981. The Contracting Parties also agreed to consider during the intersessional period administrative/legal issues raised by IAPH as they relate to the application of the Convention and to submit any comments at the Sixth Consultative Meeting of the LDC.

IAPH employed a technical consultant in the environmental field, Dr. Willis W. Pequegnat, an oceanographer for Texas A & M University, to develop on a priority basis a technical paper for presentation to the international Ad Hoc Scientific Group. The paper focused upon the "special care" measures raised by the IAPH delegation during the Fifth Consultative Meeting. Dr. Pequegnat advanced the basic premise that ways must be found to permit ports and harbors to continue the dredging of new and existing waterways to ensure the safe passage of commercial shipping. He outlined a number of techniques (clean material capping, borrow pit disposal, split-side disposal, deep ocean disposal, hypersaline basin disposal, submarine canyon disposal, and erection of offshore islands) for the disposal in the marine environment of dredged material containing Annex I substances under the London Dumping Convention.

Ad Hoc Scientific Group Report on Dredged Material (Paraphrased)

As a result of the Ad Hoc Scientific Group's considering the IAPH document at its intersessional meeting in May of this year in Halifax, Canada, the Group rendered a report to the Convention.

There was general agreement that, while many of the special measures showed promise for future use, there is at present very little information on the extent to which the techniques will be successful in practice. The

Ad Hoc Scientific Group, therefore, agreed that dredged material (spoil) disposal operations involving special care techniques should be conducted as field research studies to gather experience with a view to allowing "special care" measures to be used on a routine basis.

> The Ad Hoc Scientific Group agreed that existing regulations or the interpretation of the terms "trace contaminants" or "rapidly rendered harmless" in respect to Annex I contamination of dredged spoil could be interpreted to allow national authorities to evaluate research results and utilize, as appropriate, "special care" measures in the disposal of dredged spoil. These measures should ensure that disposal was conducted in a manner which would avoid undesirable effects, especially the possibility of acute or chronic toxic effects on marine organisms or human health whether or not arising from bioaccumulation in marine organisms, and especially in food species.
>
> The Ad Hoc Scientific Group, therefore, recommended to the Consultative Meeting that Contracting Parties should take note of the possibility of using "special care" methods as suggested by the IAPH where disposal of dredged spoil contaminated by Annex I substances is being considered. The Group also recommended that Contracting Parties should be invited to submit details of any experience gained, with respect to using these methods, to future meetings of the Ad Hoc Scientific Group.

The significance of the issues raised is highlighted not only by the attention that will be given by the Contracting Parties, but also by the inquiry received from Mr. P. A. Haywood, Secretary of the OSLO Commission (which administers the OSLO Convention, governing the ocean dumping of wastes, including dredged material, in the North Sea). Mr. Haywood attended the Fifth Consultative Meeting in London as an observer for the OSLO Commission and has expressed great interest in the IAPH position. He has asked that the IAPH furnish him a copy of any statements which have been prepared addressing these concerns, as well as any studies which may be available (or which may be prepared) by the IAPH concerning the ocean dumping of dredged material.

At the Sixth Consultative Meeting in London, IAPH additionally invited the Contracting Parties to express their views upon the applicability of the "emergency" provisions of the Convention to the disposal of dredged material containing Annex I substances which may not be within the "trace contaminant" and "rapidly rendered harmless" exception provisions to Annex I materials. On the issue of "special care" measures, we received support from the Contracting parties by the acceptance of the recommendations of the Ad Hoc Scientific Group. At the same time, the IAPH confirmed its continuing interest in the consideration of "special care" measures at future meetings of Contracting Parties and the Ad Hoc Scientific Group and extended a continuing offer of technical expertise in matters relating to dredged material. With regard to utilizing the "emergency" provisions of the Convention, the delegates expressed a decided preference for using one of the "special care" techniques proposed by the IAPH rather than consider the matter under the "emergency" clause.

Also, while in London for the Consultative Meeting, members of the IAPH delegation met with members of the International Association of Dredging Contractors to initiate a cooperative joint effort in the previously mentioned dredge equipment survey and capabilities studies.

Continued cooperation between the AAPA Dredging Task Force and the IAPH Ad Hoc Dredging Committee is mutually beneficial and will serve to intensify the efforts of both associations. Our Dredging Task Force cooperated with the IAPH Committee in developing questionnaires for all ports, worldwide. These questionnaires were designed to determine the effect of national and international legal and regulatory controls on dredging efficiency. The final report, "A Survey of World Port Practices in the Ocean Disposal of Dredged Material as Related to The London Dumping Convention," was published in April, 1981.

In the past presidential election year, advantage was taken to influence the platform of the Republican Party by drafting a "plank" for a dredging position. This position emphasized the problems inherent in current laws and regulations and the need to include economic factors as a prime consideration in the implementation of such laws and regulations. The plank emphasized that ports of this country were experiencing increased difficulties and delays--in some cases outright denials--in obtaining critically needed dredging permits necessary to provide adequate channels and harbors. We are hopeful that presentation and recognition of our plank will gain support and ultimately result in a critical reappraisal of and reforms in the permitting and environmental approaches that federal regulatory agencies have pursued with regard to dredging and disposal activities.

The Port Authority of New York and New Jersey provided an organizational model for pursuing a reasonable balance between economic and environmental values in the disposal of dredged material in their "Save Our Port" activities and promotion. This program, largely through the energy of the New Jersey Alliance for Action, an effective business and labor organization, brought a groundswell of concern for the port's dredging problem and its effect on the community. This concern and the attendant activity resulted in needed permit approvals from Washington. This model can serve other ports in trouble; however, we hope to resolve or ameliorate the problem before this is necessary.

Experience has shown that an inordinate proportion of delays in granting dredging permits stems from a lack or delay in the "Interagency Coordination Act of 1981" which would expedite agency action (particularly in the area of environmental review) and would require action by each agency in a reasonable period of time. This draft will be utilized to obtain input and review by AAPA Standing Committees before approaching a Congressional delegation to sponsor the legislation. Introduction and enactment of such a law will do much to enhance the necessary ongoing dredging programs to maintain and improve channels and harbors.

On December 24, 1980, the United States Environmental Protection Agency published in the Federal Register as final rule-making the Section 404(b)(1) Guidelines for Specification of Disposal Sites and Dredged or Fill Material under Section 404 of the Clean Water Act. These guidelines failed to incorporate AAPA views which had been submitted earlier. The guidelines continue to contain provision for prohibiting a discharge of dredged material or fill material without regard to the total impact on the overall public interest. The 404(b)(1) testing requirements were also published in the 24th of December issue of the Federal Register. This rule-making required all comments to be submitted on or before February 6, 1981. Our Dredging Task Force Committee, in coordination with the AAPA Environmental Affairs Committee, did prepare and submit AAPA comments.

On the basis of a projected work program for eighteen months, the Task Force Chairman submitted to AAPA in the fall of 1980 an annual budget of approximately $155,000 to fund technical and legal assistance to the Task Force. The membership at large approved AAPA offices in Washington to raise these funds by an appeal for donations and for AAPA offices to administer the funds for the Task Force as required. Over $200,000 to date has been made available for this work. IAPH Headquarters in Tokyo is now in the process of soliciting funds from their multination membership to further this program.

Summarizing 1981 to date, the Committee has continued to emphasize direct liaison with concerned members of the Congress and officials of the United States Army Corps of Engineers as well as other federal and state agencies and officials with an interest in or control of dredging laws and regulations. We are actively seeking the opportunity for any forum at which we can present our problems and suggest the changes in procedures and testing that are necessary. We have been successful in publishing our position in magazines read by the dredging, business, and port industries and have been able to attend and participate in meetings and conventions representing elements in a position to influence our objectives.

We look forward to an even more productive year in 1982.

DESIGN AND CONSTRUCTION OF FABRIC-REINFORCED DREDGED MATERIAL RETAINING DIKES

by

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INTRODUCTION

During the last decade, environmental and land-use constraints have resulted in more emphasis on confined dredged material disposal, as opposed to unconfined disposal on land or in shallow water, especially when fine-grained maintenance dredged material and any contaminated dredged material is disposed. As a result, considerable effort has been directed toward proper management of confined dredged material disposal areas, including design, construction, operation, and maintenance of such facilities; dewatering, reclamation, and reuse of uncontaminated dredged material; and similar activities [1]. In the U. S., the majority of research and development concerning proper confined disposal area operation and management was accomplished by the U. S. Army Corps of Engineers during 1973-1978, under the Dredged Material Research Program (DMRP). Information developed under the DMRP was then implemented by Corps of Engineer operating elements and other agencies, with consultive assistance from the Corps' Dredging Operations Technical Support (DOTS) Program. Methods and procedures described in this paper were developed by the author while on special assignment to the DMRP, and field verification of the concepts was conducted with DOTS Program support.

Before any dredged material may be confined, some sort of confinement system must be constructed. Whether confinement is on land or in shallow water, earth embankments or retaining dikes are normally the most cost-effective method of retaining the dredged material. Assuming no foundation problems, costs of obtaining a cubic yard of confined disposal area storage capacity by perimeter diking in the southeastern U. S. are on the order of $0.25-$0.35 (1979 dollars), with similar costs incurred to provide additional future capacity by perimeter dike raising [2]. However, in many coastal onshore or shallow offshore locations, extremely soft, weak foundation soils may be present, and considerable difficulty, and thus expense, may be incurred in construction of satisfactory retaining dikes to desired containment elevations. In the past, construction of retaining dikes on poor foundation, with consequent periodic failure and escape of dredged material, was regarded as an undesirable event, but one simply inherent in soft-ground construction of retaining dikes. However, in recent years with stricter constraints on escape of confined dredged material, especially when contaminated sediments are involved, it is quite often necessary to provide a positive assurance of constructability for retaining dikes on extremely soft foundation, so that positive containment of dredged material can be achieved. Use of engineering fabric, a permeable artificial fiber textile product (also called geotechnical fabric, geotextile, and filter cloth), placed between the soft foundation and the retaining dike, has been found to facilitate successful dike construction in spite of unsatisfactory foundation conditions.

USE OF ENGINEERING FABRIC IN RETAINING DIKE CONSTRUCTION ON SOFT FOUNDATION

Conventional Retaining Dike Construction Alternatives

Normal dredged material retaining dike construction procedures are simple and well defined, consisting of:

a. Clearing and other site preparation along the proposed alignment,

b. Sequential placement of fill material in thin lifts followed by compaction or semi-compaction, and

c. Upon reaching design height, final shaping and placement of slope protection, if necessary.

For stable foundation conditions, no problems are encountered with such construction methods. However, when soft/weak foundation conditions exist, the dike may fail during or after construction by horizontal splitting, rotational slope/foundation failure, or excessive settlement.

For such adverse foundation conditions, alternative construction procedures must be used. Conventional alternatives used for embankment construction on soft foundation include preloading/staged construction, construction with lightweight fill materials, construction of floating sections with stability berms, excavated and replaced embankment sections, and displacement embankment sections [3]. Advantages and disadvantages of these various soft ground construction alternatives are listed in Table 1. In general, engineering fabric-reinforced retaining dike construction will be more cost-effective than any Table 1 alternative except preloading/staged construction, and that option is usually operationally impractical because of disposal-related time constraints.

Fabric-Reinforced Retaining Dike Design Concepts and Analysis

Earthfill embankments on soft foundation are susceptible to failure from horizontal splitting/spreading, rotational slope/foundation failure, and excessive foundation displacement. Engineering fabric used as reinforcement must resist these various actuating forces to achieve satisfactory performance. The key to successful fabric-reinforced construction is development of moderate to high fabric tensile stresses at low fabric strains. Fabric tensile forces resist failure actuating forces, and fabric tensile modulus controls vertical and horizontal displacements of the reinforced embankment. Additional considerations include development of sufficient soil-fabric friction to transfer embankment loads to the fabric as tensile forces, and use of construction procedures which will develop fabric tensile forces at small strains.

Potential fabric-reinforced embankment failure modes are illustrated in Figure 1. Analytical procedures for determining required fabric strength and tensile modulus make use of conventional geotechnical engineering relationships for soil mass behavior, which include expressions for fabric strength, and will be summarized in subsequent sections. More detail on analytical procedures is available elsewhere [4]. In analysis of a fabric-reinforced embankment, it is assumed that embankment height, embankment fill material, and foundation strength are known, and that embankment side slopes may be adjusted as necessary to provide proper

TABLE 1. ALTERNATIVES TO USE OF ENGINEERING FABRIC FOR EMBANKMENT CONSTRUCTION ON SOFT FOUNDATION

Conventional Alternative	Advantages	Disadvantages
Preloading/staged construction	Simple concept, low cost	Potential equipment mobility problems, time required for foundation consolidation
Use of lightweight fill	Simple concept, conventional construction methods can be used	Cost of fill, possible equipment mobility problems and degradation of fill material
Floating section with berms	Simple concept, easy to design	Difficult to construct, potential equipment mobility problems, may end up as a displacement section
Excavated and replaced foundation	Simple concept, conventional construction methods can be used	Excavation/replacement costs acceptable only for thin layers of soft foundation soil
Displacement section	Simple concept, no worries about foundation failure	Excessive fill may be required, shape of section may be difficult to control

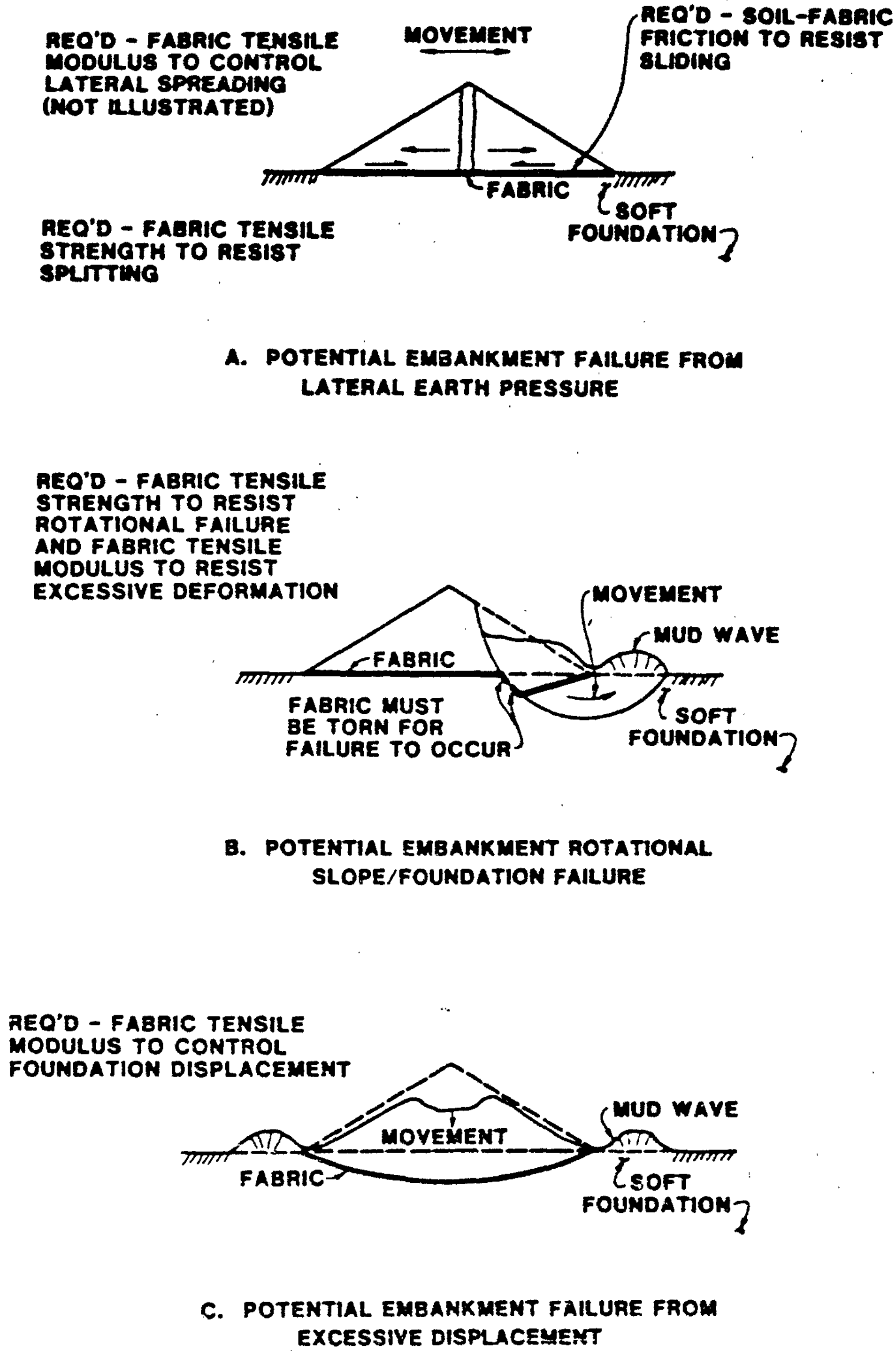


Figure 1. Potential Failure Modes for Fabric-Reinforced Retaining Dikes on Soft Foundation

stability. In general, fairly flat embankment slopes (6h on 1v or greater) will be necessary on extremely soft foundation soils.

Embankment Splitting/Spreading

Fabric-reinforced embankment splitting-type failures, as illustrated in Figure 1a, may occur by fabric tensile failure, by fill material sliding off the fabric surface, and/or by excessive fabric elongation.

In order to resist tensile failure, fabric tensile strength in the direction normal to the embankment alignment must exceed the maximum lateral earth pressure by an appropriate factor of safety, as given in Equation 1:

$$T_F = FS\ (P_A) = FS\ (0.5\ \gamma_m H^2 K_A) \tag{1}$$

where

T_F = Minimum fabric tensile strength,
FS = Desired factor of safety,
P_A = Lateral earth pressure per unit length of embankment,
γ_m = Moist unit weight of embankment fill,
H = Embankment height, and
K_A = Fill material coefficient of active lateral earth pressure.

In order to transfer lateral earth pressure to the fabric and prevent the embankment sliding horizontally off the fabric, the minimum angle of soil-fabric friction is given by:

$$\phi_{SF} = \tan^{-1}\ [2(FS)P_A)/\gamma_m X H^2)] \tag{2}$$

where

ϕ_{SF} = Minimum angle of soil-fabric friction,

X = Slope parameter (i.e., for 5h on 1v slope, X = 5), and other symbols are as defined previously.

If the required soil-fabric friction angle exceeds 30°, embankment side slopes should be flattened, as most engineering fabrics suitable for use as embankment reinforcement possess a value of soil-fabric friction approximately equal to 30° if loose, sand-sized fill material is used [5].

Lateral spreading of the embankment may be held to an average of approximately 5% by selecting a fabric with minimum tensile modulus (secant through the 5% strain value) of 10 times the minimum required fabric tensile strength or:

$$E_F = 10T_F \tag{3}$$

where

E_F = Minimum fabric tensile modulus.

Slope Stability Analysis

Rotational slope failure potential may be evaluated using any conventional limit equilibrium slope stability analysis method and adding the strength of the fabric layer to the resisting forces opposing rotational sliding, as the fabric must be physically torn for the embankment to slide (Figure 1b). Because fabric has no flexural strength, it is assumed to deform so as to lie on the incipient slip circle and be placed in tension.

Stability analyses should initially be performed for the no-fabric condition and a critical slip circle and minimum factor of safety obtained. Once the critical slip circle is determined, the resisting moment from shear strength developed along the critical slip circle necessary to provide the desired factor of safety can be computed. If the factor of safety without fabric is inadequate, additional resisting moment can be computed and the minimum required fabric tensile strength T_{FR} can be determined by dividing the extra resisting moment required by the critical slip circle radius. This procedure was verified by Risseeuw [6], and is illustrated in Figure 2.

Excessive Center Line Displacement

Excessive center line displacement of fabric-reinforced embankments can be controlled by use of fabric with minimum required tensile strength and modulus determined previously and use of an outward-inward fill placement scheme, to be described subsequently.

Selection of Proper Engineering Fabric

The minimum value of fabric tensile strength necessary for satisfactory performance is the larger of T_F and T_{FR} computed previously while the minimum fabric tensile secant modulus is E_F, computed previously. These values, along with the minimum value of soil-fabric friction ϕ_{SF} should be used to select an appropriate fabric. It should be noted that both fabric tensile strength and tensile modulus are normally expressed in units of force/width, with the thickness dimension neglected. Further, results of grab strength tests (ASTM D-1682) should not be used as a measure of fabric tensile strength. Appropriate test procedures for determining fabric tensile strength, tensile modulus, and angle of soil-fabric friction have been developed by the author and are available [7].

In addition to the tensile strength, tensile modulus, and soil-fabric friction requirements for the particular embankment configuration desired, fabric should be chosen with appropriate survivability and field workability properties, considering site conditions, type of embankment fill to be used, and available construction equipment, following available criteria [4]. Selection of fabric with proper field workability (fabric ability to support required construction operations) is of

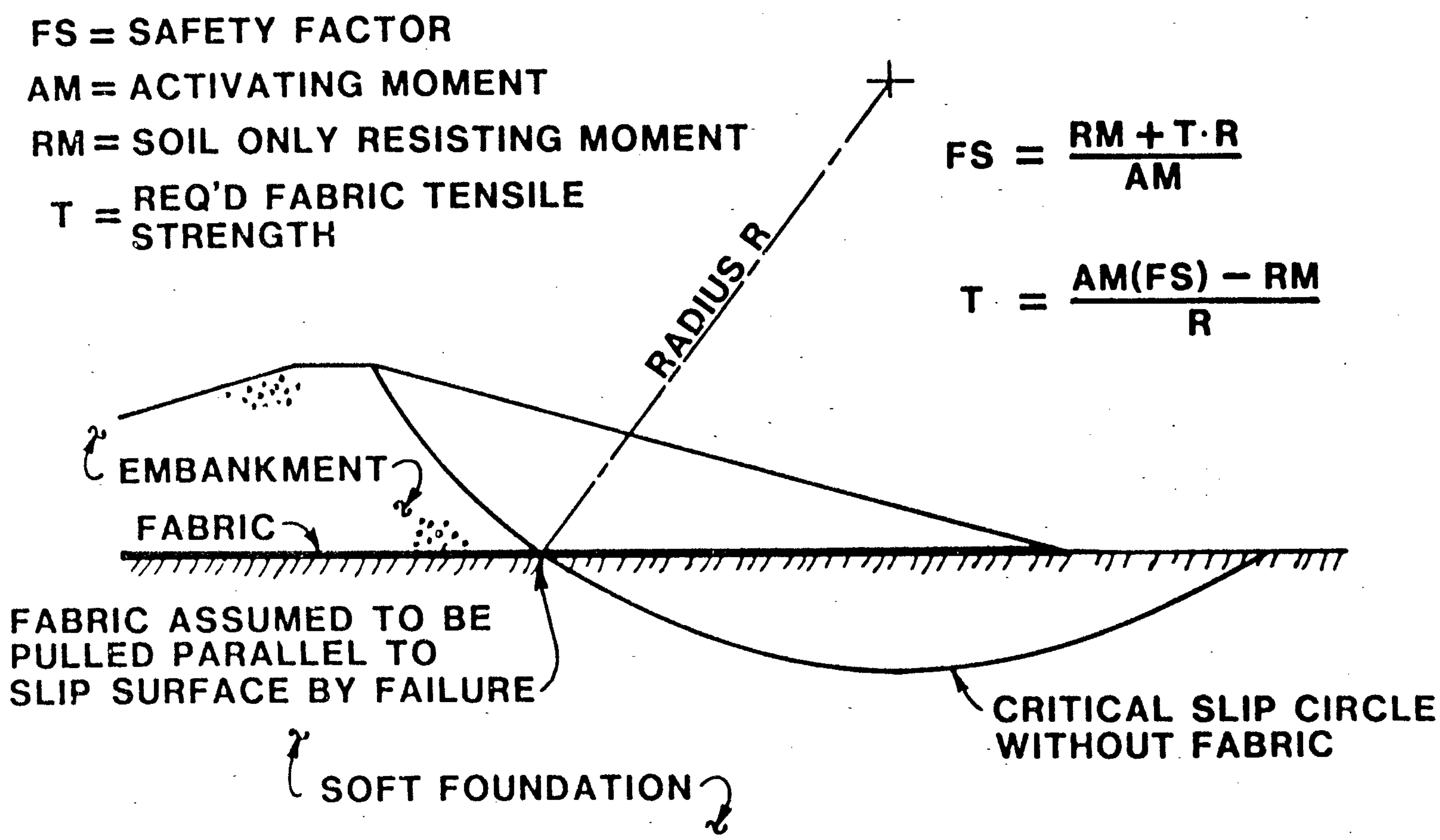


Figure 2. Concept Used for Determining Fabric Tensile Strength Necessary to Prevent Slope Failure

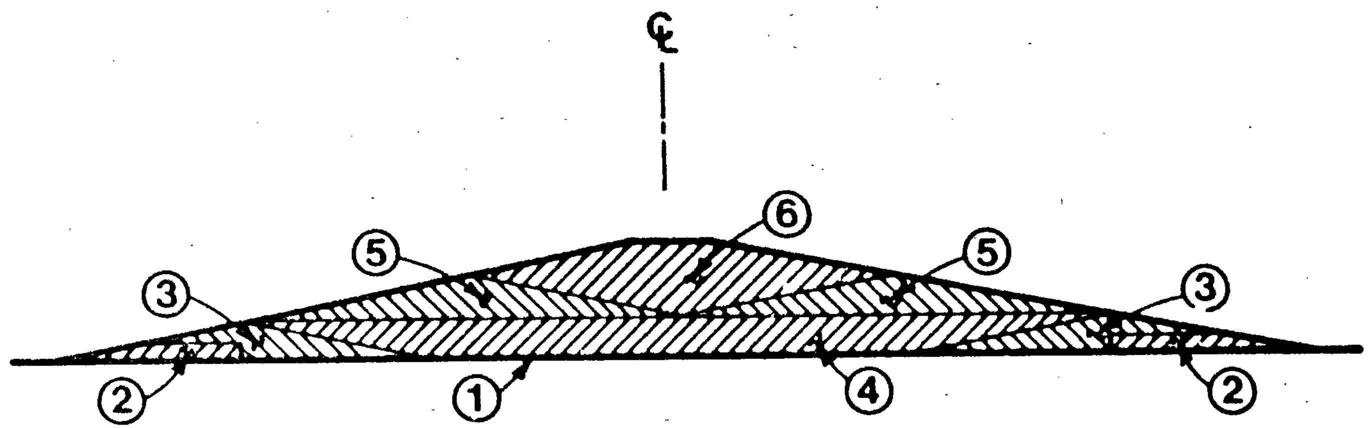
extreme importance if men and/or equipment cannot maintain mobility along the proposed alignment.

FABRIC-REINFORCED EMBANKMENT CONSTRUCTION PROCEDURES

The importance of specifying proper construction procedures for building fabric-reinforced embankments on soft foundation cannot be overemphasized, as the desired fabric behavior cannot be obtained without specific sequential construction operations. The most important construction consideration is to use an outward-inward sequential fill placement procedure, as shown in Figure 3. This sequence is necessary to provide fabric anchorage at the embankment toes prior to placement of center fill, and is exactly opposite the conventional procedure used for no-fabric embankment construction on soft foundation.

Further, successful embankment construction is contingent upon use of construction equipment which will not fail the fabric and foundation during initial material placement. The author's personal preference is to use small wide-track dozers with maximum 2.5- to 3.0-psi ground pressure during fill spreading operations. If desirable, fabric-reinforced haul roads can be constructed along each outside toe for hauling fill to the working face and, if properly designed and constructed, can carry fully loaded 12- to 15-cu-yd tandem-axle dump trucks. If extremely soft foundation conditions exist, insufficient to support the contractor's workmen, construction may be facilitated by "working on the mud wave," a construction procedure which uses fill placement techniques to develop, trap, and push a small surface mud wave forward under the fabric, facilitating fabric placement and stretching operations. This procedure is described in detail elsewhere [4, 8].

In general, fabric is placed with the warp or machine direction transverse to the embankment alignment, in continuous toe-to-toe strips. Adjacent fill direction edges should be sewn together with high-strength polypropylene or polyester thread, with a seam strength at least equal to the fill direction tensile strength of the fabric. Locked-type stitching should be used or else all seams should be double-sewn. Fabric overlapping is definitely not recommended as an alternative to sewing.



SEQUENCE OF CONSTRUCTION

1. LAY FABRIC IN CONTINUOUS TRANSVERSE STRIPS, SEW STRIPS TOGETHER.
2. END DUMP ACCESS ROADS.
3. CONSTRUCT OUTSIDE SECTIONS TO ANCHOR FABRIC
4. CONSTRUCT INTERIOR SECTION TO "SET" FABRIC.
5. CONSTRUCT INTERMEDIATE SECTIONS TO TENSION FABRIC.
6. CONSTRUCT FINAL CENTER SECTION.

Figure 3. Method of Sequential Fill Placement for Construction of Fabric-Reinforced Retaining Dikes on Soft Foundation

Construction of a "working table" on which to place fabric is usually an unnecessary and unwarranted expense. Selection of fabric with proper survivability and workability properties for direct placement on the foundation is normally a more cost-effective alternative, and will provide similar performance. More detail concerning appropriate construction procedures is available elsewhere [4].

FIELD VERIFICATION OF FABRIC-REINFORCED RETAINING DIKE DESIGN AND CONSTRUCTION CONCEPTS

The design and construction concepts described previously were verified by field construction of a fabric-reinforced dredged material retaining dike for the U. S. Army Engineer District, Mobile, at Pinto Pass, Mobile Harbor, Alabama. The project was part of retaining dike construction necessary for development of the Pinto Island Disposal Area to contain maintenance dredging from Mobile Harbor. Concepts were verified by construction of an 830-ft-long embankment test section, located as shown in Figure 4. Foundation conditions along the proposed dike alignment consisted of very soft clays and silty clays with moderate organic content and high plasticity, having undrained shear strengths of approximately 50 psf at the surface, increasing to approximately 150 psf 40 ft below the surface, where dense sand was encountered. Approximately 50% of the proposed test section alignment was in the intertidal zone. A typical cross section of the embankment, showing the settlement plates installed at each 100-ft station, is shown in Figure 5. In addition to the settlement plates, eight Casagrande piezometers were installed at various depths from 10 ft below the surface to 40 ft below the surface to monitor foundation pore pressures.

Construction was initiated using low-ground-pressure dozer equipment for material spreading and 12-cu-yd, tandem-axle dump trucks for fill material transport, following the outward-inward material placement sequence shown in Figure 3. Fine, poorly graded sand available from Mobile Harbor new-work dredging activities was used as embankment fill. Initially, a working table was constructed over the existing root mat prior to fabric placement, but this operation was found to be unneeded and to constitute an unnecessary expense; thus, the fabric was placed

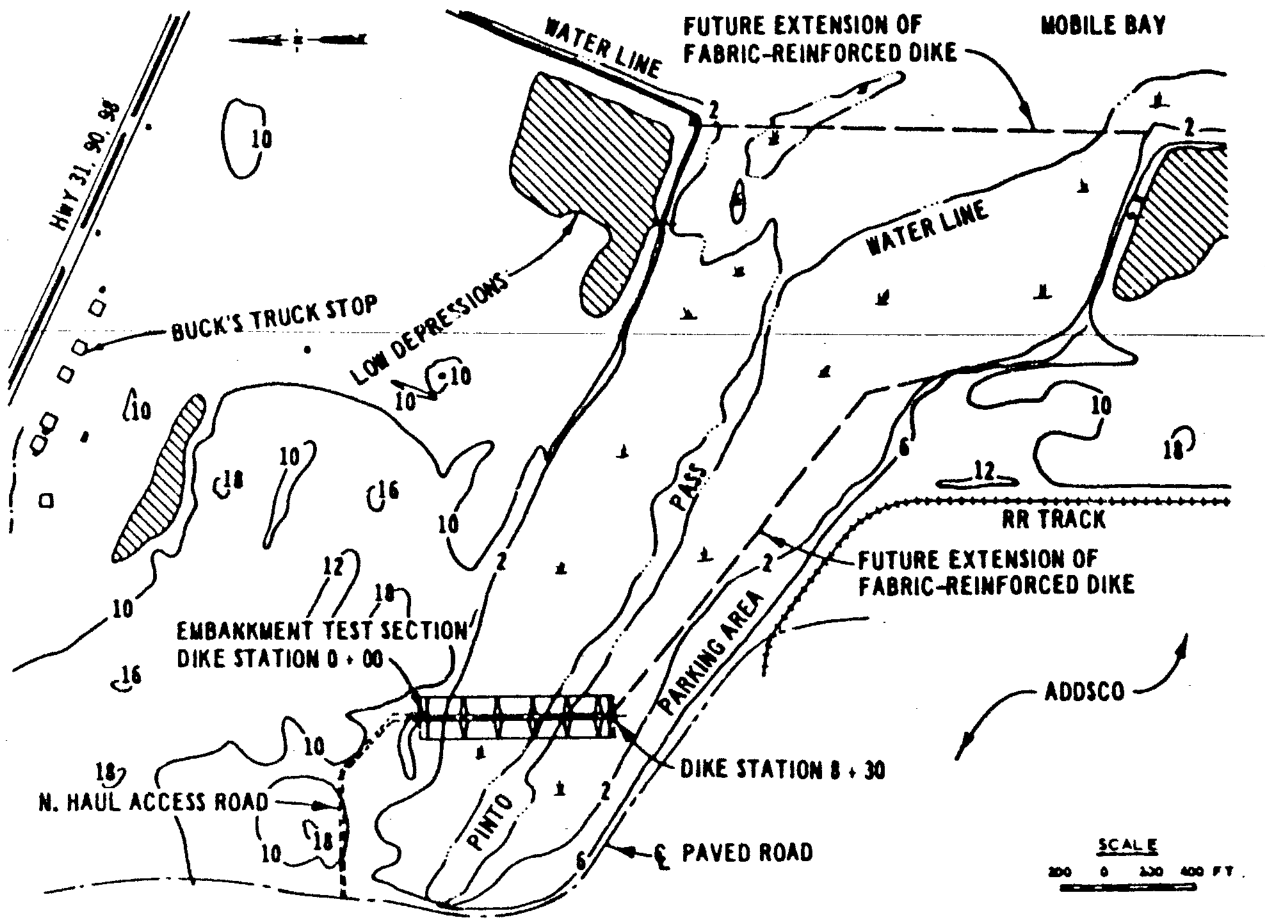


Figure 4. Location of Fabric-Reinforced Retaining Dike Test Section, Mobile Harbor, Alabama

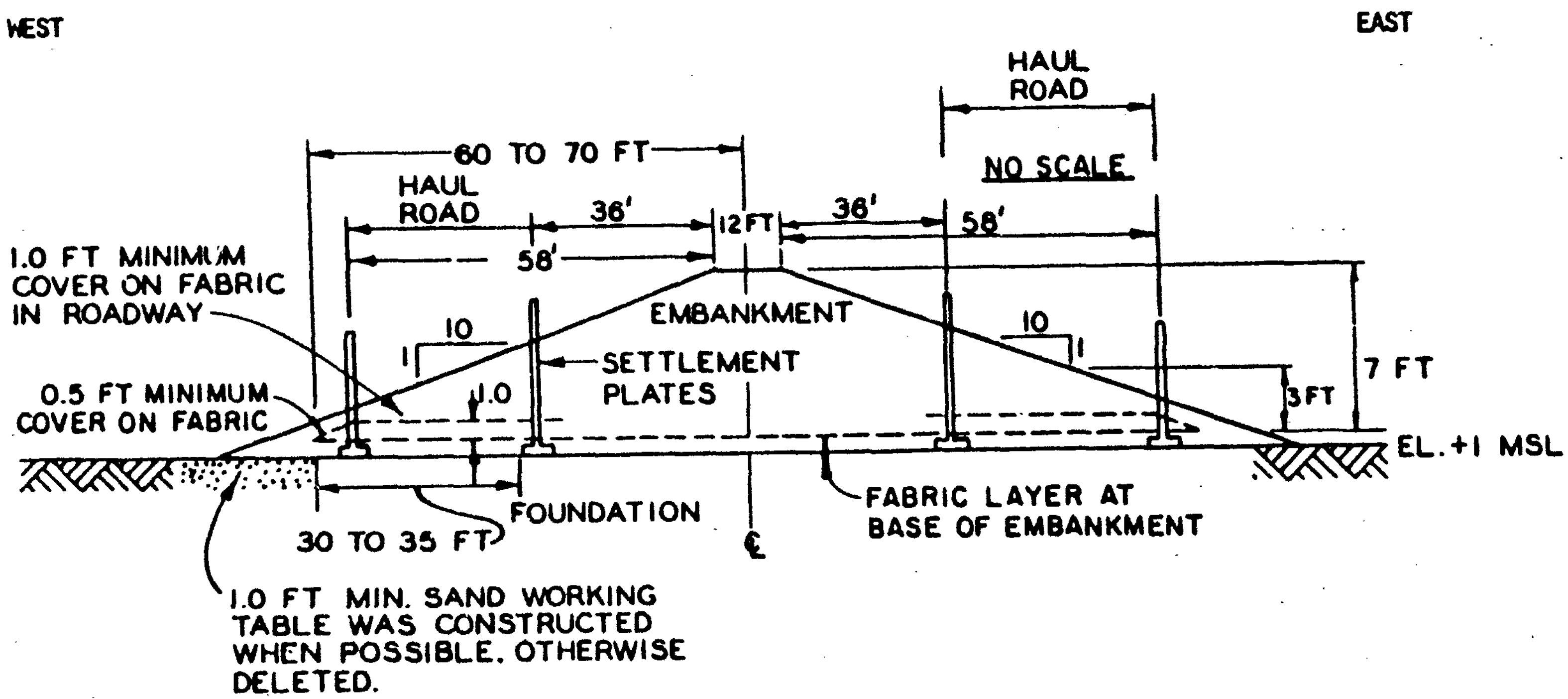


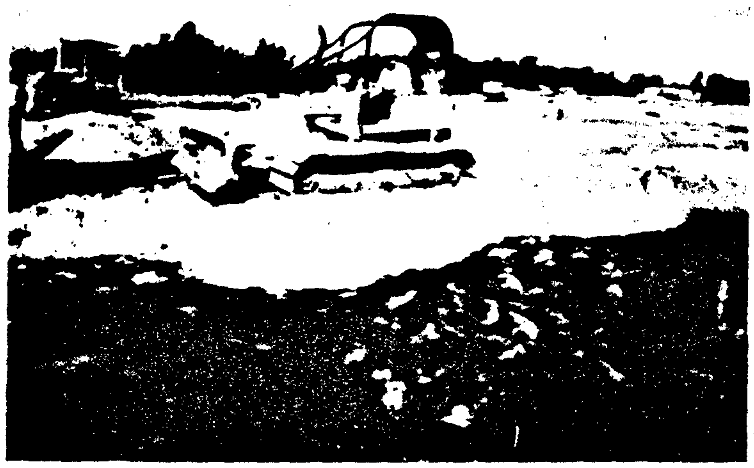
Figure 5. Typical Design Cross Section for Pinto Pass Fabric-Reinforced Dike

directly on the alignment for the remaining construction. Typical photographs of ongoing construction activities and the completed embankment are shown in Figure 6. More detail on actual construction operations is available elsewhere [8].

Typical foundation and settlement displacement behavior of the fabric-reinforced embankment is shown in Figure 7 for Stations 5+00 and 6+00 in the center of the Pinto Pass channel. At these locations, construction operations caused a shallow surface mud wave to develop, raising the fabric above the original ground elevation at the time embankment fill was applied. The "as-installed" fabric position immediately after placement of initial embankment fill and the after-foundation settlement position of the fabric are shown at these two sections in Figure 7. As may be noted from the figure, maximum consolidation settlements on the order of approximately 1.5 ft were noted. Original construction produced (essentially) a zero effective stress condition in the foundation, with excess pore pressures approximately equal to the weight of embankment fill. Approximately 7 months was necessary for 90%+ foundation consolidation to occur, and measured consolidation settlements were approximately 20% of theoretically predicted values. Because the surface mud wave that developed during construction raised the fabric above the original ground elevations, the final fabric location after foundation consolidation was at or only slightly below the original ground surface, resulting in construction with minimum foundation displacement. In addition, the embankment underwent approximately 4 ft of lateral spreading as a result of fabric elongation necessary to develop tensile stresses necessary to resist unbalanced retaining dike lateral earth pressures.

Total project cost of the 800-ft test section was $154,000, including construction of fabric-reinforced roads to the adjacent borrow area. A benefit-cost ratio of approximately 2.3 was determined for the fabric-reinforced construction, compared to foundation displacement construction, the alternative normally used by the U. S. Army Engineer District, Mobile, for building retaining dikes on soft ground.

A. View of Test Section Location, View Looking West to East, Tracks Made by Amphibious Vehicle



b. Embankment Fill Being Placed Over Fabric Reinforcement

Figure 6. Photographs of Pinto Pass Fabric-Reinforced Dike Test Section (Continued)

c. New Transverse Strip of Fabric Reinforcement Being Sewn in Place at Working Face

d. Completed Dike, View Looking North to South; Note Excess Foundation Pore Pressure Seeping from Dike Side Slopes

Figure 6. (Concluded)

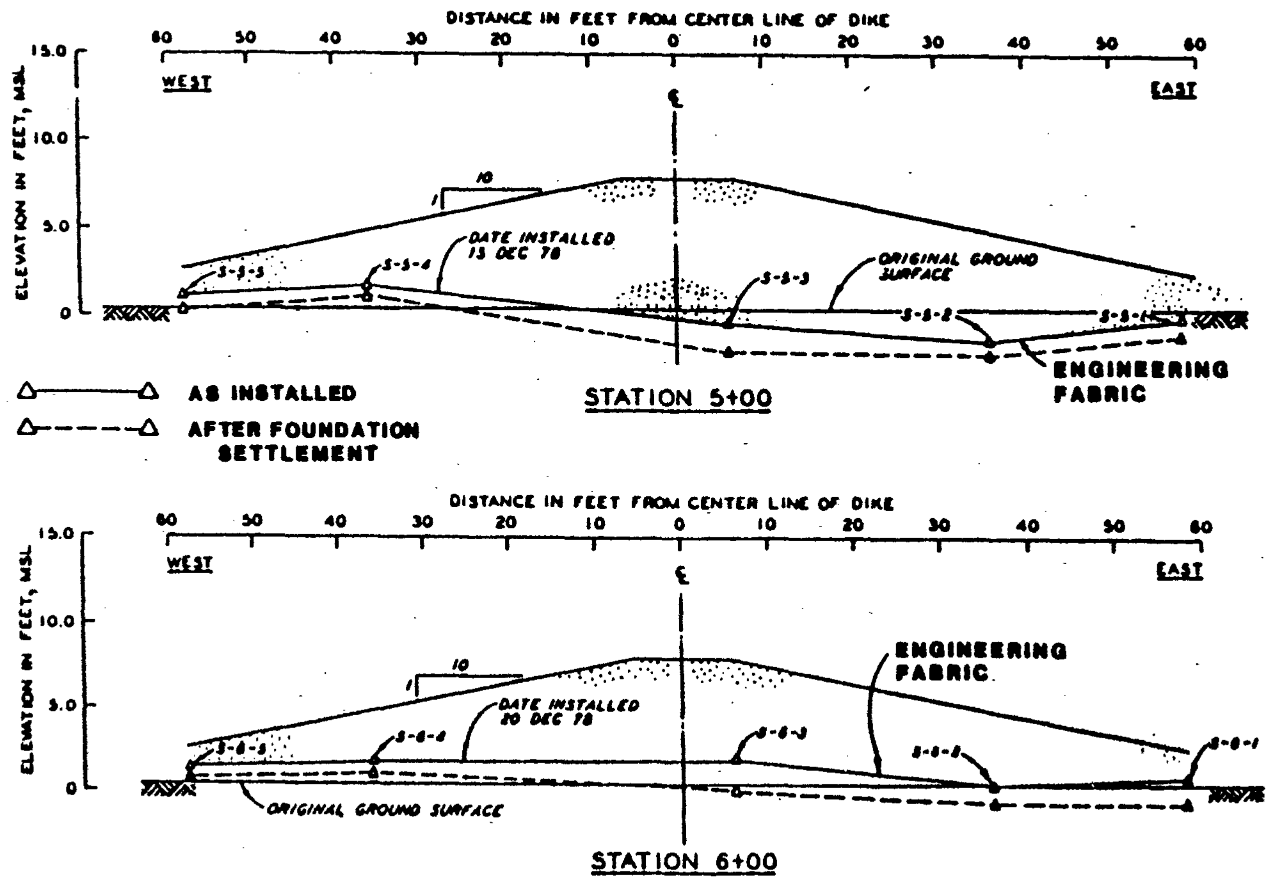


Figure 7. Measured Maximum Displacement and Consolidation Settlements for the Pinto Pass Retaining Dike

CONCLUSION

The design and construction concepts postulated for fabric-reinforced retaining dike construction were successfully verified under field conditions, and the method was found to a technically feasible, operationally practical, and cost-effective method of constructing retaining dikes on an extremely soft foundation when positive assurance of constructability is required.

Development of an overall management plan, including location and design of dredged material retaining structures, is currently under way for the Pinto Island Disposal Area, and it is anticipated that fabric-reinforced construction will be used for at least another 4,000 lin fit of retaining dike at this location. A similar fabric-reinforced dike test section is currently being designed for placement on very soft (undewatered) fine-grained dredged material in the Craney Island Disposal Area of the U. S. Army Engineer District, Norfolk. Several other Corps of Engineer operating elements are actively considering fabric-reinforced retaining dikes as an alternative to their current dike construction procedures.

Use of the analysis technique, design methods, fabric selection criteria, and construction procedures summarized herein should allow qualified engineers and contractors to build successful fabric-reinforced retaining dikes for positive containment of disposed dredged material. In considering use of fabric-reinforced dike construction alternatives, favorable benefit-cost ratios will normally accure where existing foundation soil strengths are low and when positive assurance of rapid construction is required.

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SAND OVERLAYING FOR SEA BOTTOM SEDIMENT IMPROVEMENT BY CONVEYOR BARGE

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ABSTRACT

As a feasibility survey for a pilot project for prevention of water pollution of the Seto Inland Sea, the 3rd District Port Construction Bureau of the Ministry of Transport conducted a series of sand overlaying tests of sludge in an area off Kure in the Hiroshima Bay in October 1979.

INTRODUCTION

Sand overlaying tests were intended to prevent harmful components from dissolving out of the bottom sediment and into the seawater by laying 50 cm of sand over the bottom sediment using a conveyor barge.

The testing procedure and the test results are reported herein.

CONVEYOR BARGE

As illustrated in Figure 1, the conveyor barge has hoppers of a capacity of about 110m^3 arranged in two rows totaling 18 hoppers and also two lines of belt conveyors 1,200mm wide running beneath each row of hoppers at a maximum speed of 125m/min. It thus has a capacity of discharging 2,000m^3 of sand in 1 hour and is different in performance from the conventional bottom door type dumping barges in that the discharging capacity is adjustable over a wide range up to 2,000m^3/hr. Without such a feature, this method of sand overlaying would have been impossible.

This conveyor barge had a telescopic tremie tube provided at the bow, and the length of the telescopic tube was adjusted according to the height of the sea bottom so that the sand discharged from the tube would not disturb and spread the sludge as it hit the seawater.

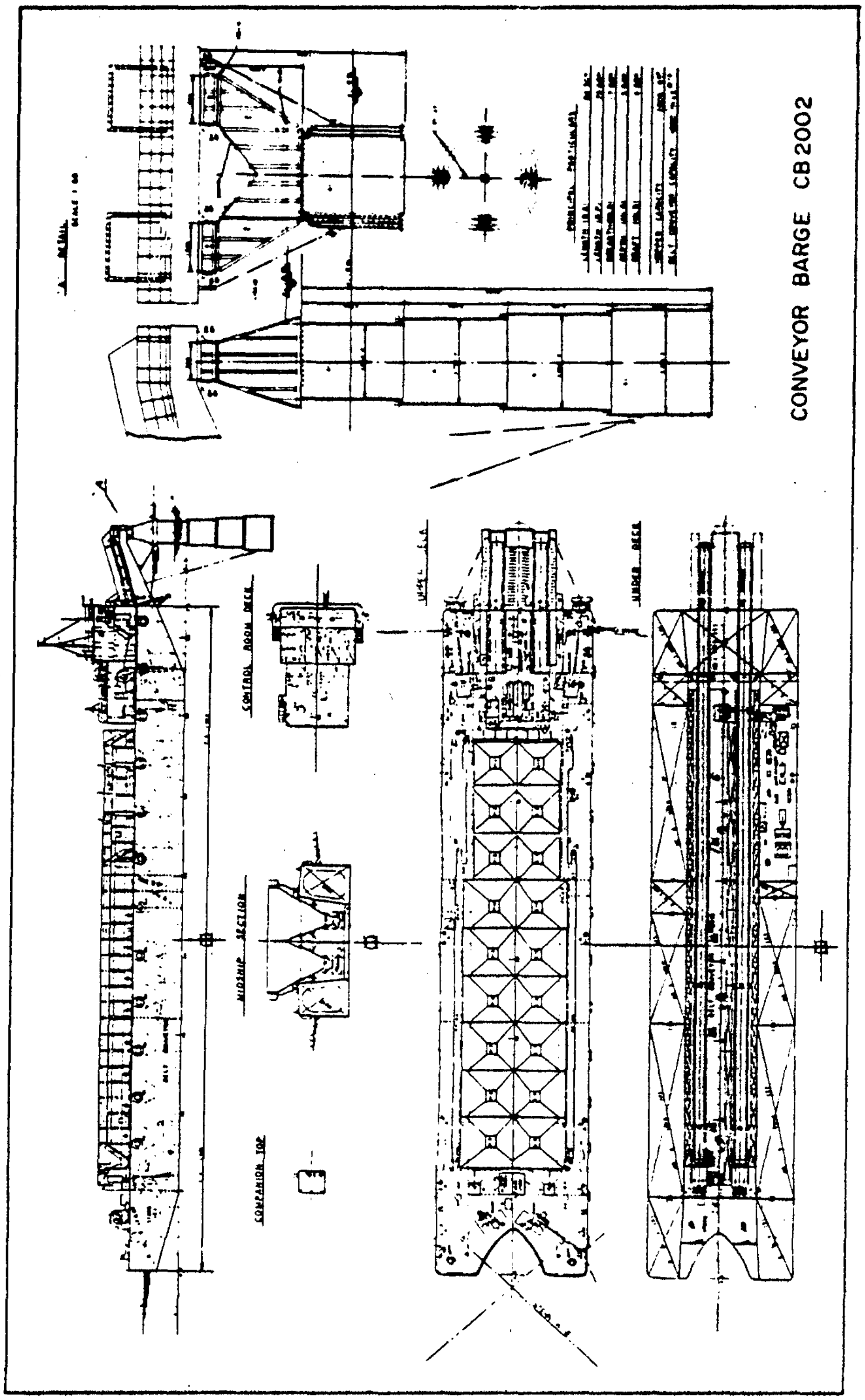


Figure 1. Conveyor barge

Originally, the conveyor barge was designed mainly for reclamation by spreading, sand replacement work for revetment, improvement of sediment by thin layer discharge, improvement of fishing fields by sand laying, and transporting of sand, etc.

TEST SITE

The sand overlaying area was located between Etajima and Kure Port in the Hiroshima Bay about 1km off Etajima Town (about 30 minutes by ferry from Kure Port) and formed a rectangular of 120m north to south and 160m east to west.

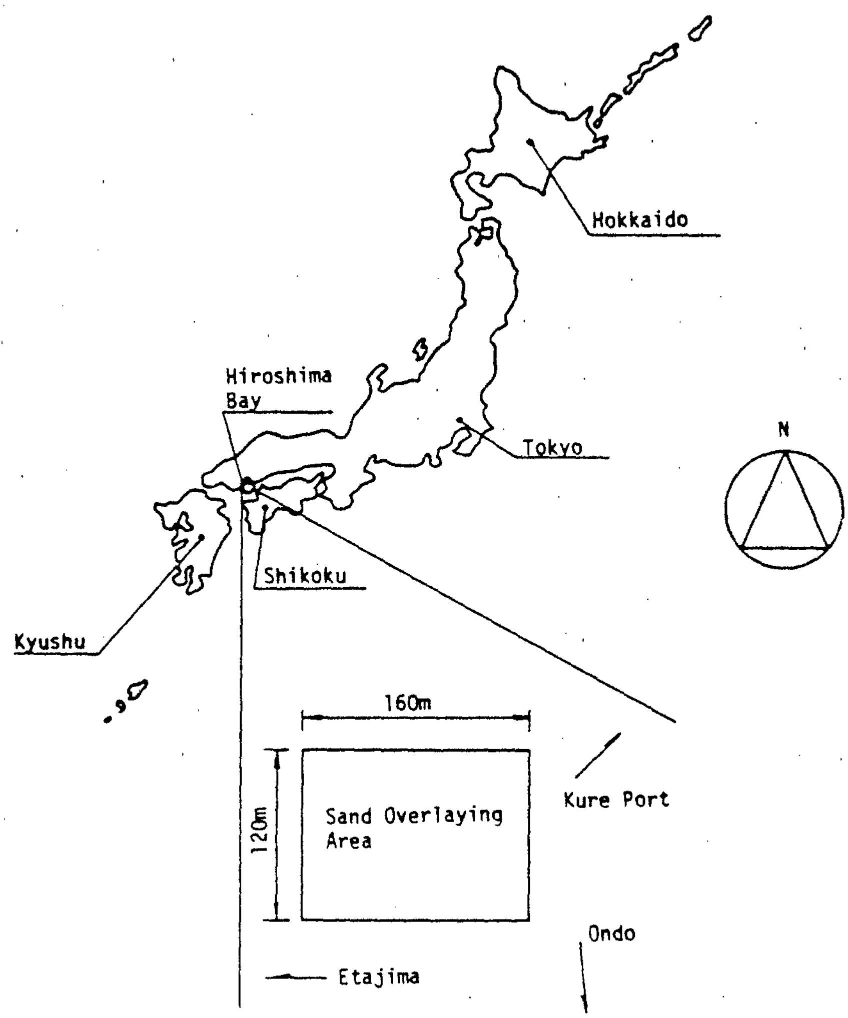


Figure 2. Test site

THICKNESS AND VOLUME OF DESIGNED OVERLAY

With sand overlaid evenly in the design thickness of 50cm, the volume of overlaying sand was planned as shown below:

Overlaying sand volume = Area × (Design thickness + Maximum difference in unevenness × 1/2)

where, Design thickness = 0.5m;

Maximum difference in unevenness = 0.3m (empirical value); and

Area = 120m × 160m

Thus, Overlaying sand volume = 120m × 160m × (0.5m + 0.3m × 1/2) = 12,480m^3

TEST OF ADAPTABILITY OF OVERLAYING MATERIAL

The overlaying material was sea sand from Tadanoumi in Hiroshima prefecture, and it was tested physically, chemically, and biologically and for harmful materials; as a result of these tests, it was found to be suitable. With an average specific gravity of 2.62 and silt content of 0.6 - 1.5%, it was shell mixed, odorless, slightly yellowish, and weak alkaline sand.

WORK METHOD

The work method is shown below in Figure 3.

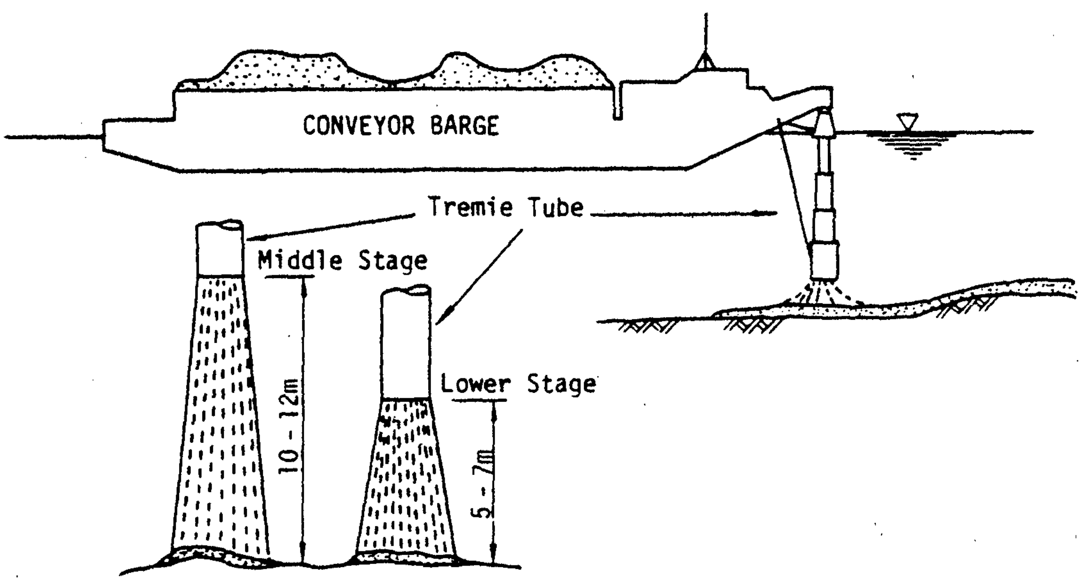


Figure 3. Sand discharge by conveyor barge

Spread of the overlaying material was made in four cases (Cases 1, 2, 3 and 4) combining the spread times (1st and 2nd layers), the spread volume (13m^3/min and 6.5m^3/min), the swing speed (5m/min), and the falling position (middle and lower stages). For particulars, see Figure 4 and Table 1.

Each case had a test area and a work area, and the overlay found to be good in the test area was then carried out in the work area.

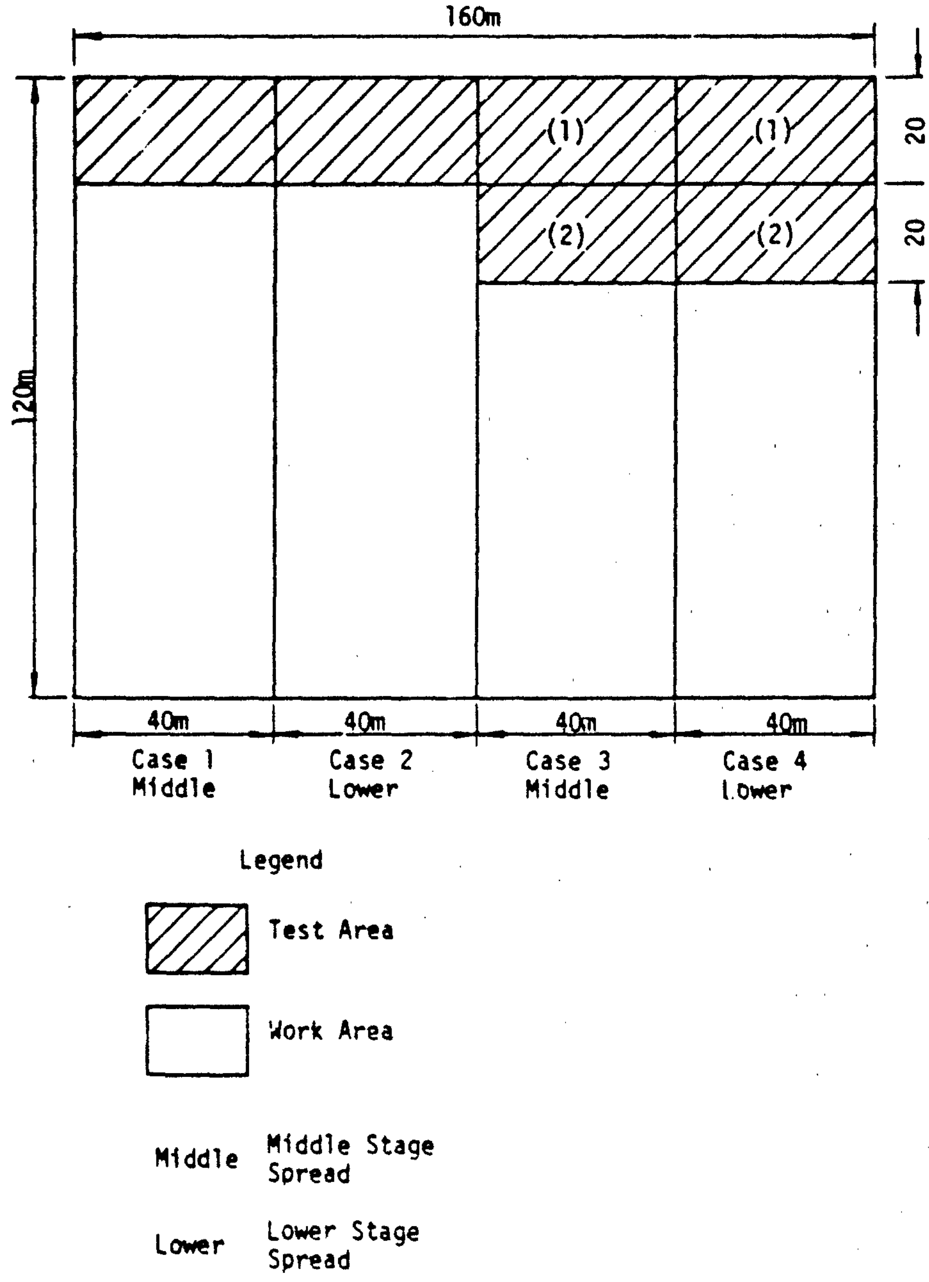


Figure 4. Sand overlaying area

TABLE 1. SPREAD METHOD

Cases	Classification	① Spread Volume	② Spread Time	①·②=③ Spread per Swing	④ Swings per Hour	③×④ Spread per Hour	Swing Method	Details of Spread
		m^3/min.	min.	m^3	Time/HR	m^3/HR		
1,2	Test and Work	13	8	104	2	208	Half swing	Sand equivalent to a 50cm overlay scattered once.
3,4	Test (1)	6.5	8	52	2	104	Half swing	Sand equivalent to a 25cm overlay scattered twice (2nd scattering giving a final overlay of 50cm).
	Test (2)	6.5	16	104	2	208	Full swing	Sand equivalent to a 25cm overlay scattered twice successively to give a final overlay of 50cm in the 2nd scattering.
	Work	6.5	16	104	2	208	Full swing	Method similar to that in Test (2).

(Note) Spread volume: When sand of a volume of 4m wide, 40m long, and 0.65m thick (or $104m^3$) is scattered in 8 minutes, the overlay is $13m^3$/min, or in 16 minutes, $6.5m^3$/min.

Spread time: With a swing speed of 5m/min, it takes 16 minutes by full swing, or 8 minutes by half swing.

Swings per hour: With swing time being constant at 16 minutes and the retrogression and other time being nearly 14 minutes, thus 1 cycle being 30 minutes, the swings are twice an hour.

SWING METHOD

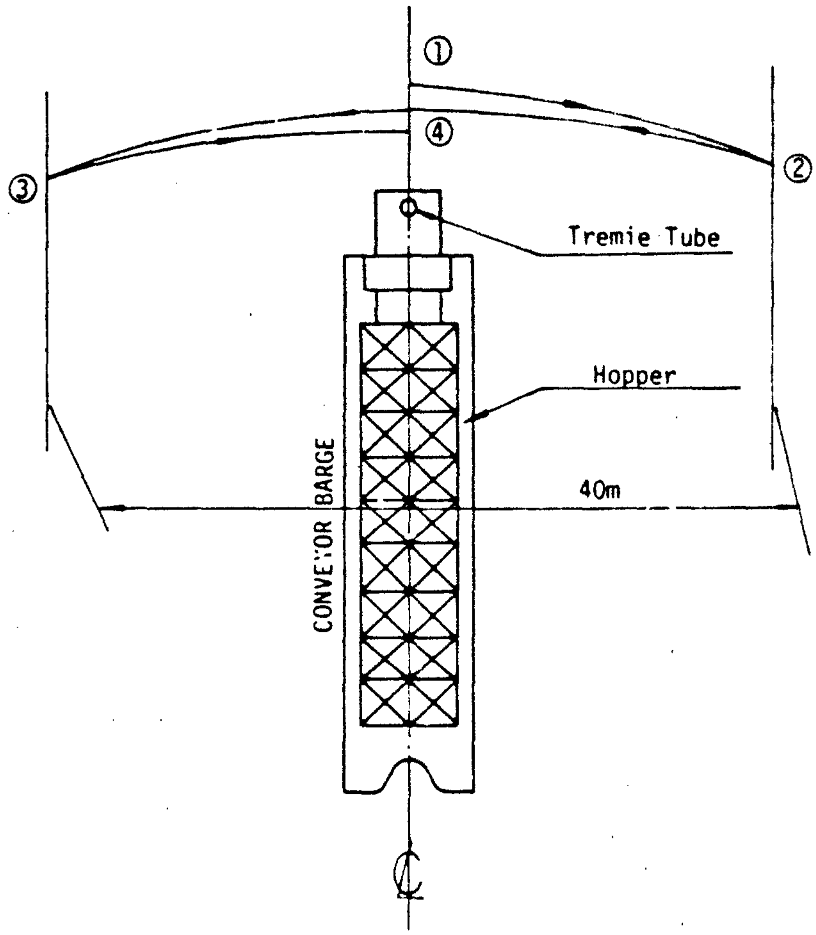


Figure 5. Swing method

Referring to Figure 5, points ① and ④ are positioned on the center line of the spread width (40m), and ② and ③ are on the extreme lines of swing on the right and left hand sides, respectively. In overlaying, the center of the tremie tube starts from point ① and completes a cycle of swing at point ④ . That is, whenever a swing cycle is completed, the tremie tube is returned to the center. Then, the barge moves back, and when the position is determined, the tremie tube makes the next swing cycle. About 14 minutes is required for the backward movement.

FULL SWING AND HALF SWING

Under a full swing, the tremie tube spreads sand successively from point ① to point ④. Under a half swing, the tremie tube swings from point ① to point ② without spreading sand, spreads sand from point ② to point ③ and swings back to point ④ without spreading sand.

SURVEYS AND RESULTS OF SPREAD

After overlaying sand by the conveyor barge, data were collected and analyzed to see if the overlaying material was penetrating into the bottom sediment; if the sand was laid evenly over the sludge sediment; if the planned thickness of overlay was secured; if there was any expansion of the sand spread, diffusion of turbidity, stirring up of sludge, or unevenness in the overlay; and what effect the current would have on diffusion of turbidity. Further, the conditions after overlaying were photographed by a submarine TV camera. The following items are discussed in this section:

(1) Survey of penetration

(2) Survey of stirring up of sludge

(3) Survey of settlement

(4) Survey of laps

(5) Survey of unevenness

(6) Survey of current

(7) Video picture taking

Survey of Penetration

A diagram of the penetration survey is given in Figure 6.

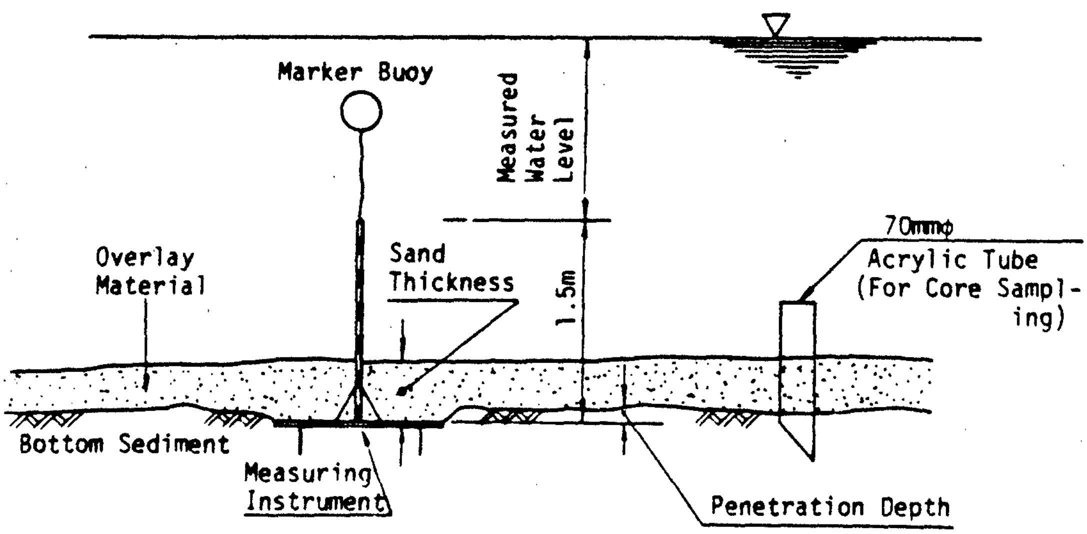


Figure 6. Penetration survey

Penetration was examined, in a manner similar to using a settlement plate carried out on land, by checking the height of a measuring instrument (weighing about 60kg) at the time of installation and by checking the settlement plate after overlaying. The results are shown in Table 2

The acrylic tube shown in Figure 6 was used to confirm the sand thickness by core sampling. The results are shown in Figure 7, and a histogram of the sand thickness in each case is shown in Graph 1.

TABLE 2. PENETRATION DEPTH

Cases	Depth
1	20
2	23
3	16
4	16

(Unit: cm)

Unit: cm (10m Mesh)

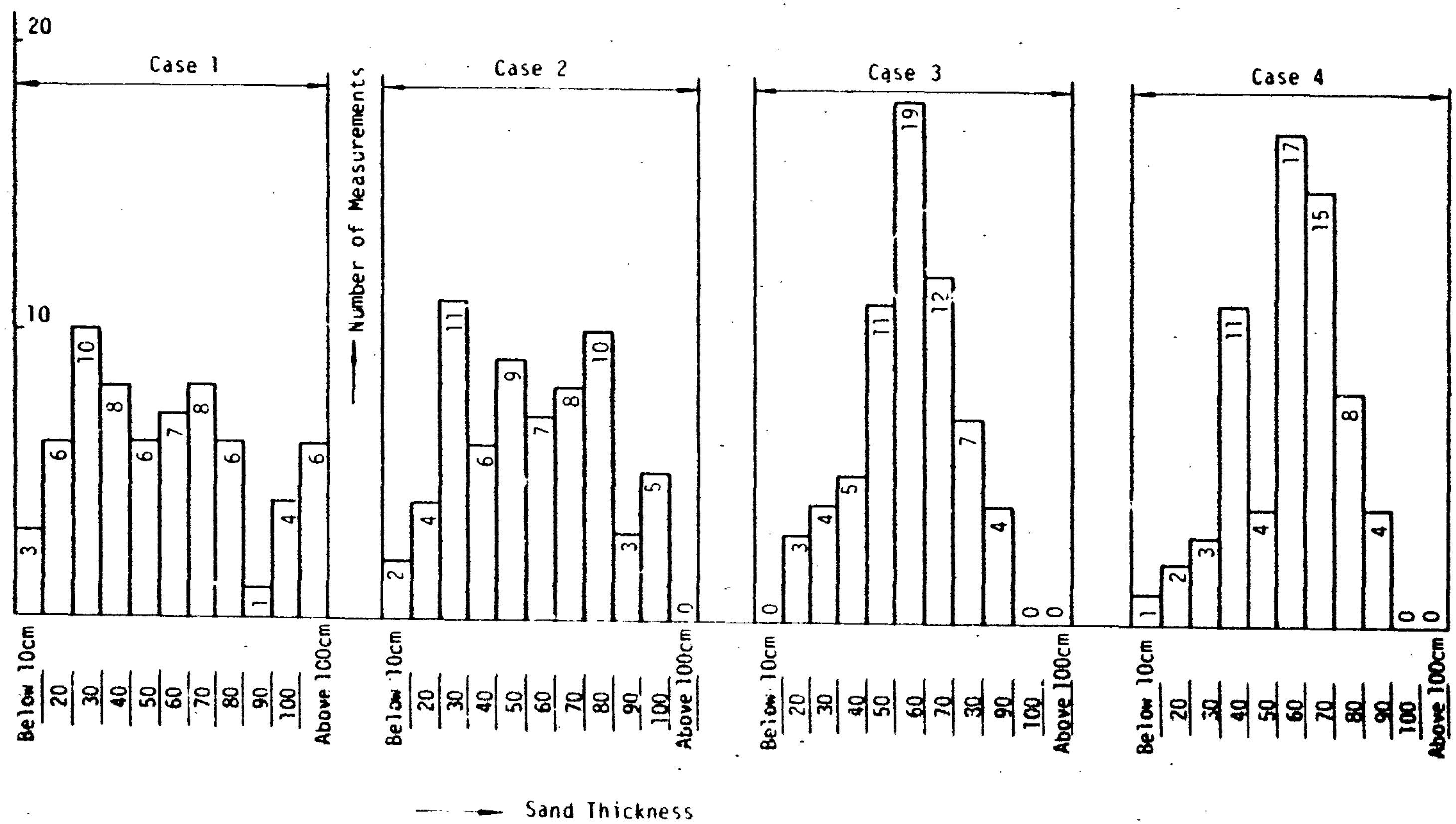
40m — 40m — 40m — 40m; 120m

45	60	35	23	15	45	34	60	80	63	48	52	40	65	77	50	35
80	59	61	27	75	8	30	45	45	40	50	25	60	70	88	40	60
45	20	35	17	60	22	21	75	80	50	45	55	60	60	74	50	40
15	60	75	50	100	55	40	75	60	70	55	60	80	80	56	65	20
15	70	60	35	65	65	40	90	60	75	65	75	60	60	78	65	40
5	29	30	25	30	25	25	100	35	59	65	90	90	65	74	64	5
30	80	110	110	5	50	63	65	35	62	55	70	75	65	70	85	70
30	70	90	75	50	66	[illegible]	66	30	60	65	65	70	45	52	58	50
70	125	110	100	100	75	77	50	30	51	62	62	70	33	32	32	20
70	120	135	65	95	85	75	85	45	50	60	85	85	55	52	68	25
65	55	35	10	80	65	100	80	20	55	60	60	60	60	60	55	35
35	40	45	25	25	20	60	50	30	40	50	50	75	53	55	68	35
40	40	45	20	55	25	70	50	20	45	20	45	55	25	70	26	40

Vertical grid lines: H-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17

Horizontal grid lines: V-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13

Figure 7. Sand thickness measurement

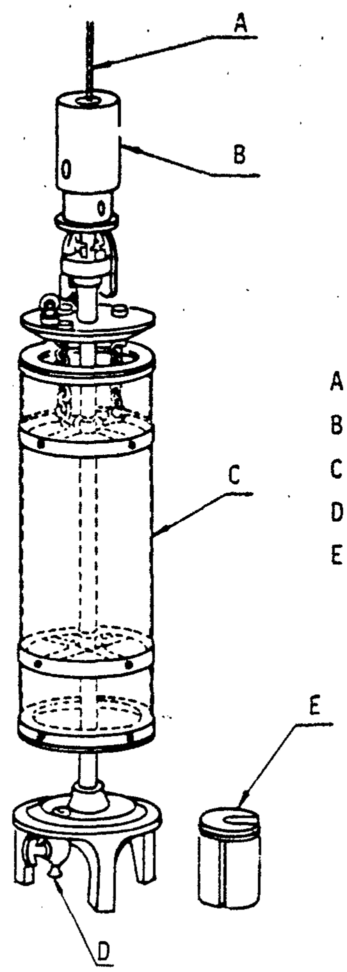


Graph 1. Histograms of sand thickness

Survey of Stirring Up of Sludge

The survey of stirring up of sludge was intended to examine how much sludge would be stirred up as the overlay sand discharged from the conveyor barge hit the bottom sediment and what effect the silt contained in the overlay material would have. Water from the sediment at 1.5m and 10.0m was collected (Figure 8) and SS and turbidity were analyzed. Figures 9-11 show the changes in SS and turbidity.

At the same time, spot observation was carried on by means of a portable turbidity meter as well as successive observation, day and night, by means of a fixed type turbidity meter (the conveyor barge had a water examination port in the bottom).



A: String
B: Messenger Support
C: Transparent Cylinder
D: Sample Takeout Cock
E: Messenger

Figure 8. Kitahara type insulation water sampler

The survey results showed that the background before sand spreading was less than 5 ppm both near the bottom sediment and immediately below the water surface and after spreading was a maximum of 40 ppm and a minimum of 2 - 3 ppm or an average of 5 ppm or less. Thus, there was a limited amount of sludge stirring.

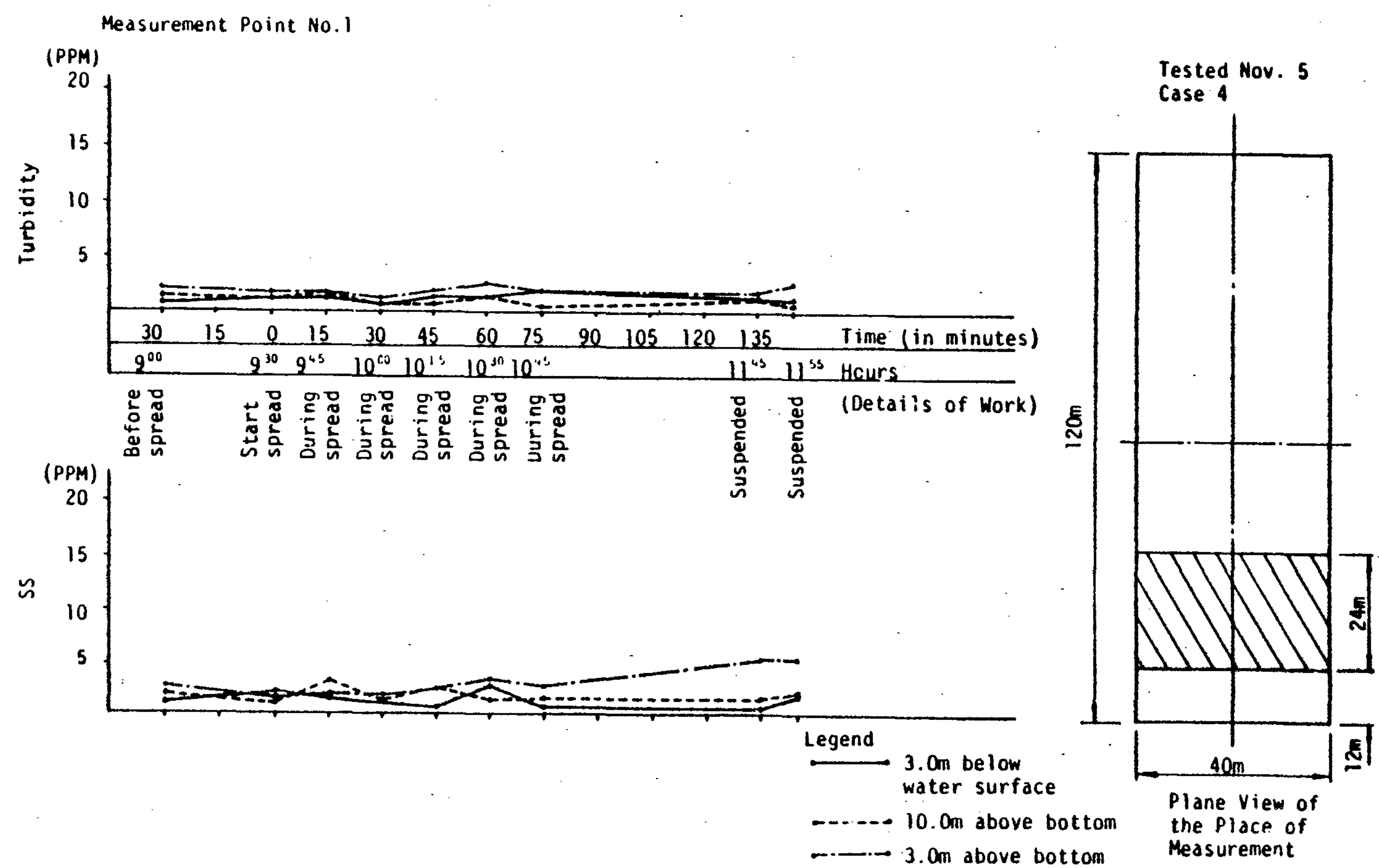


Figure 9. Changes in SS and turbidity, point 1
(Results of water sampling and analysis)

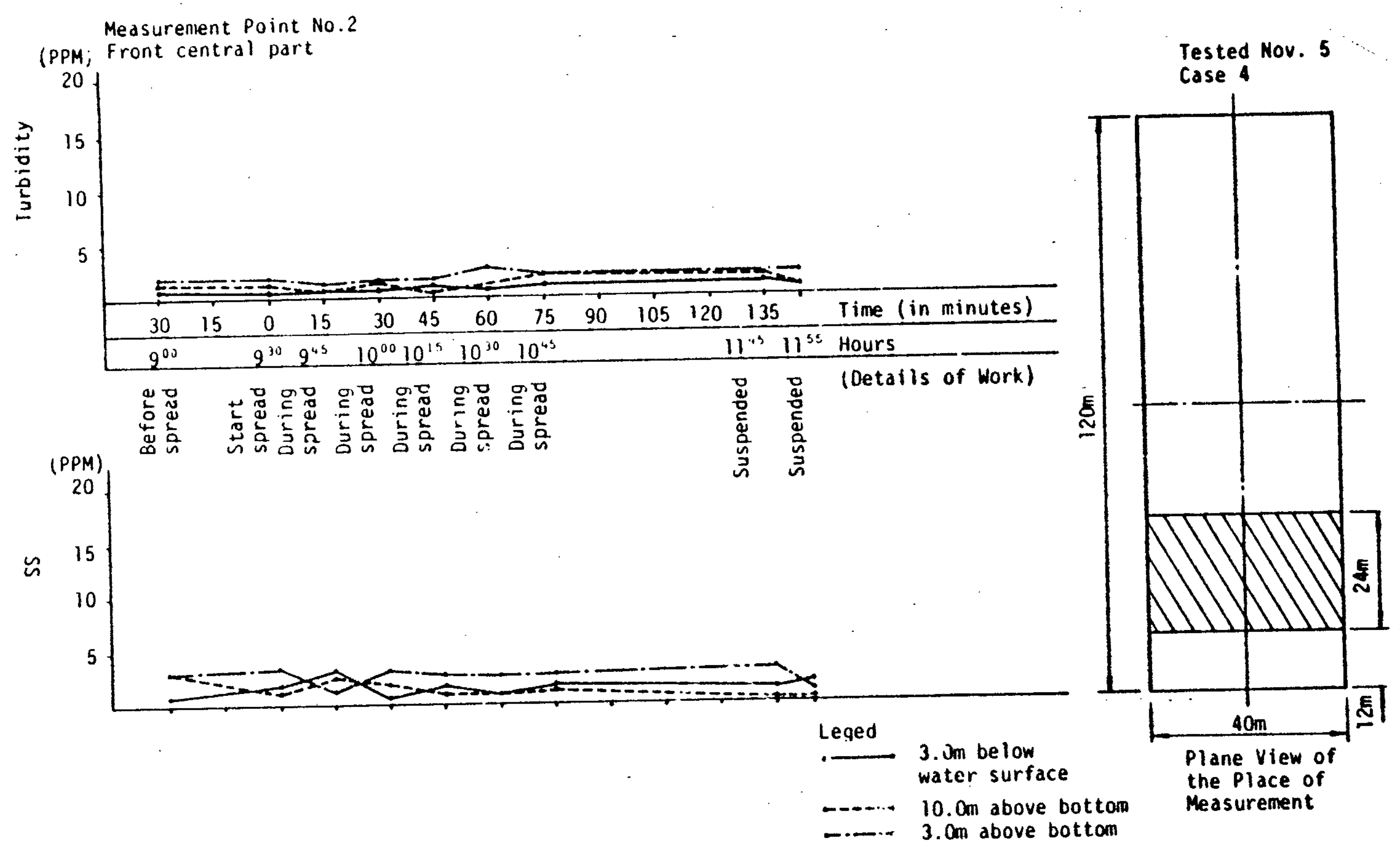


Figure 10. Changes in SS and turbidity, point 2
(Results of water sampling and analysis)

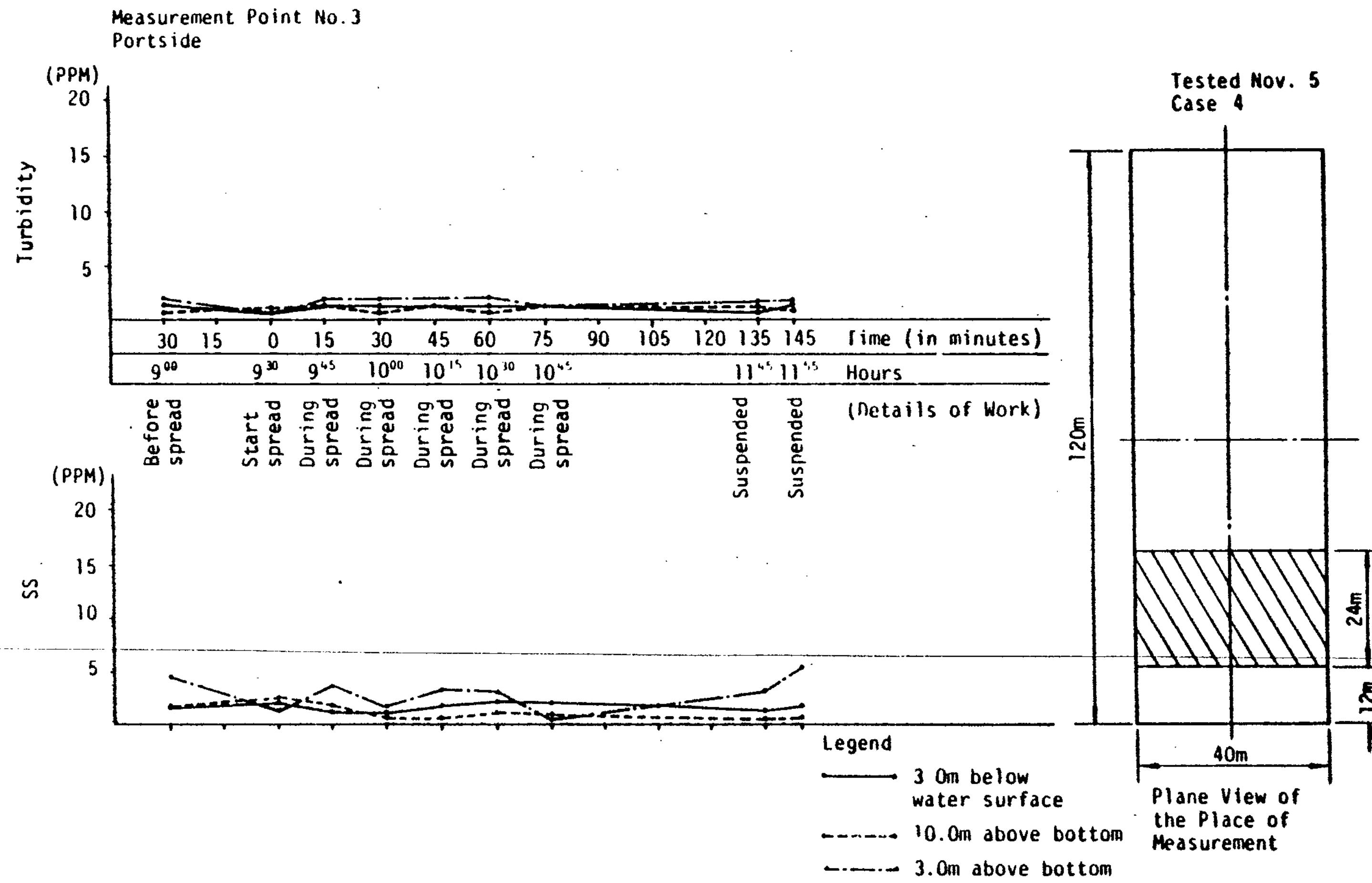


Figure 11. Changes in SS and turbidity, point 3
(Results of water sampling and analysis)

Survey of Settlement

The survey of settlement was intended to examine how the stirred sludge and silt in the overlay material would settle with the passing of time. But, the survey was a failure because a dish was used for collecting samples, as shown in Figure 12. As the diver approached to check the height of deposition and then departed, the sediment was stirred up. Thus, the measurement of the height of deposition on the dish involved an unstable factor. Therefore, it was necessary to devise another method of collector installation.

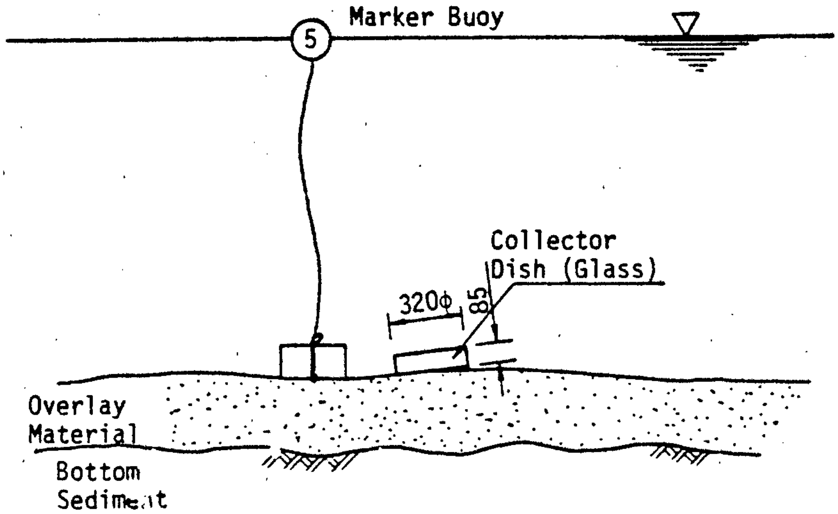


Figure 12. Settlement survey

Survey of Laps

Initially, it was expected that whenever sand was spread, the sand would form peaks as shown in Figure 13 and that such peaks would overlap with one another whenever the barge was moved back. Actually, however, the sand laid flat without peaks. (The conveyor barge was operated at 1/20 to 1/10 of its capacity.) Accordingly, it was not possible to measure the laps. This survey was, therefore, not successful, but it was satisfying that the overlay came out flat.

Survey of Unevenness

Unevenness was checked by both echo sounding and lead sounding. As the bottom sediment before overlaying was flat at an average of -21.3m, the overlay was flat as stated earlier.

Survey of Current

A diagram of the current meter used in this survey is given in Figure 14.

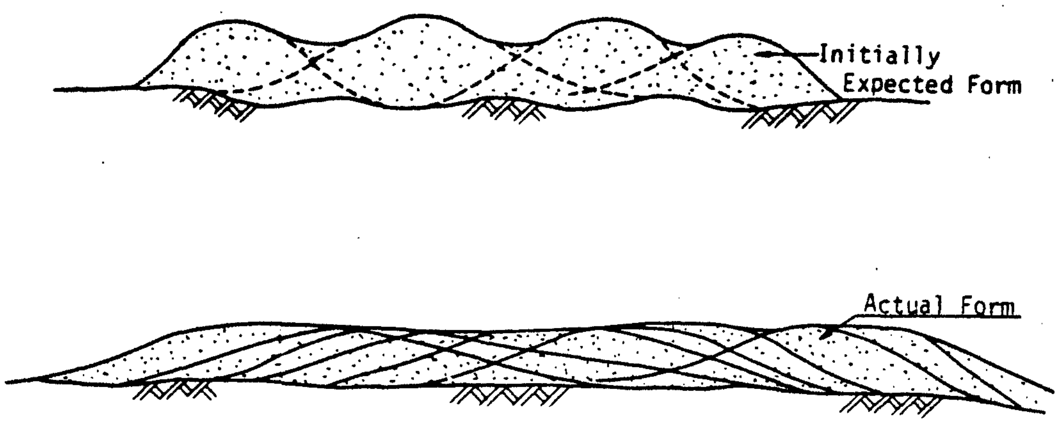


Figure 13. Lap surveys

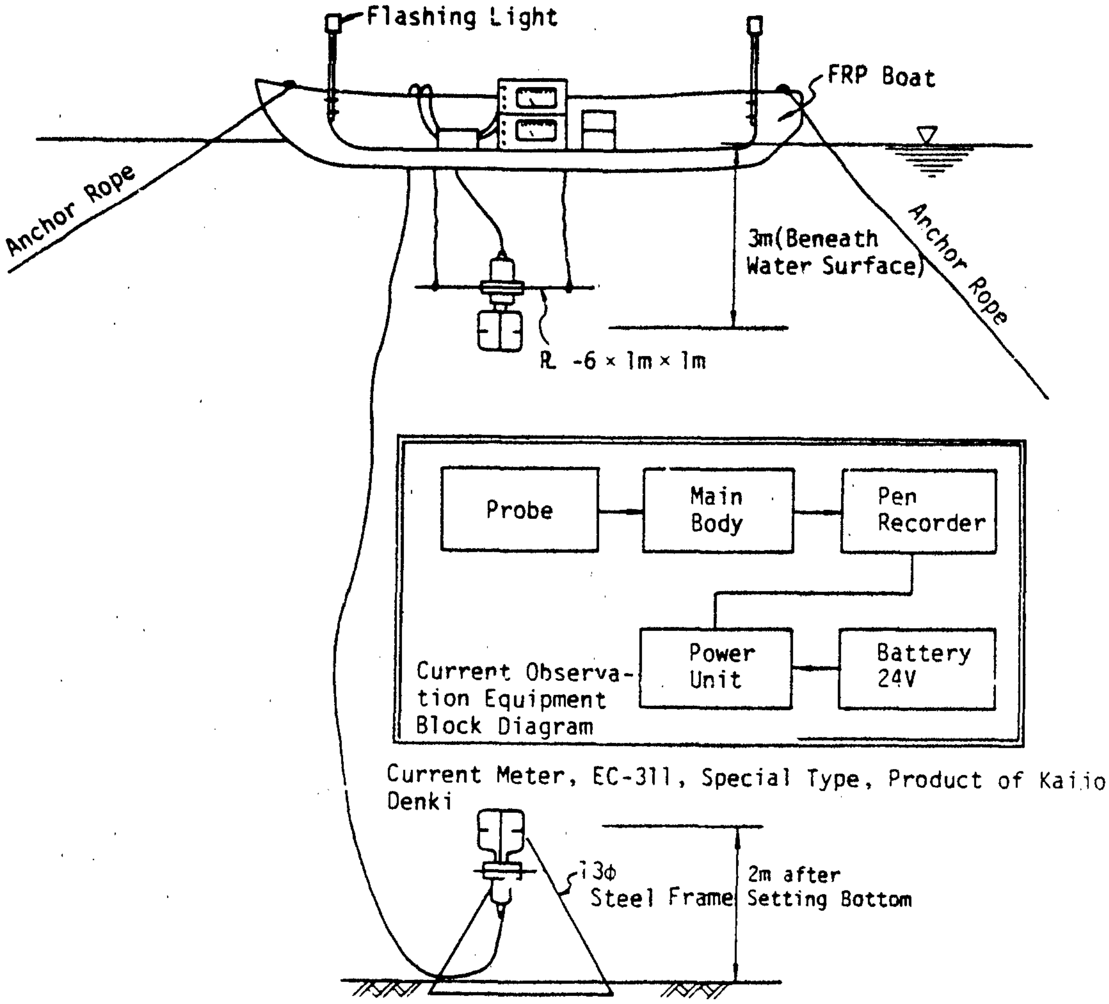
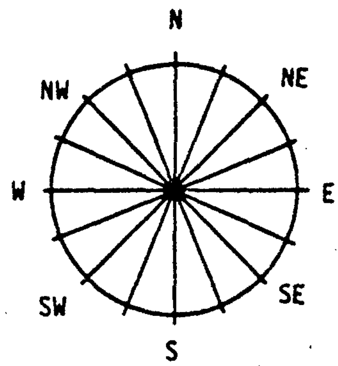
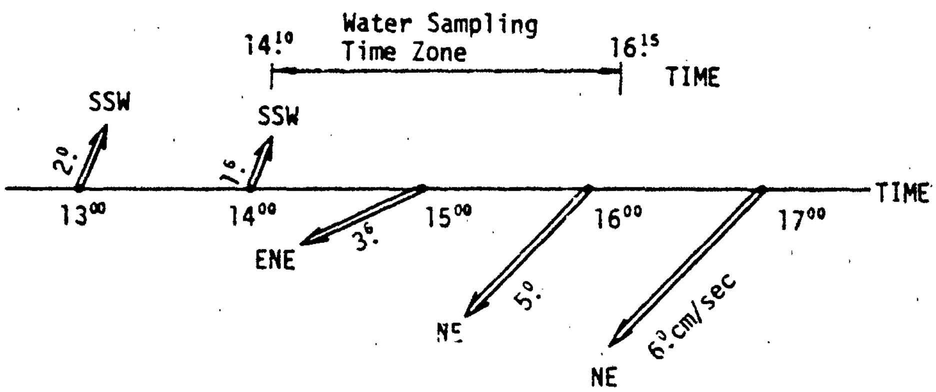


Figure 14. Measurement by ultrasonic pulse current meter

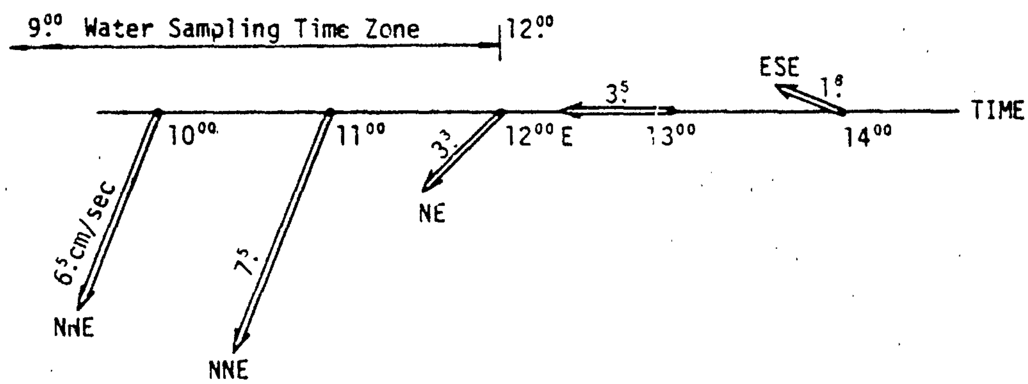
Typical results of measurement by an instrument installed as shown in Figure 14 are given below in current direction and speed diagrams against the time zones of the stirring up survey.

The time zone of survey conducted on November 1 was from 14:10 to 16:15 hours, and the flow directions and speeds from 13:00 to 17:00 hours are shown diagrammatically below.





November 5 Survey Time Zone (9:00 - 12:00) Flow Direction and Speed Diagram (10:00 - 14:00)



Taking of Video Pictures

Video pictures were taken mainly of the conditions of the overlay along the center line in the longitudinal direction (120m) of each case and also of the settlement plate (measuring instrument), stir up, settlement (condition of the dish), and laps.

Case 1: Pictures taken 3 days after the overlay; sand particles shown clearly and no unevenness found.

Case 2: Pictures taken immediately after overlaying; finished surface, measuring instrument, dish, and fish swimming around were shown in good images.

Case 3: Pictures taken immediately after overlaying; best and stable images obtained, showing particles of the overlaying material and shellfish and the conditions of the finished surface, dish, and unevenness.

Case 4: Pictures taken 2 days after overlaying; similar to Case 3, showing the condition of stirring up and the settlement plate; relatively good when compared with the pictures of Cases 1 and 2.

WORKING CRAFTS USED

Working vessels used in the work are shown below.

Vessels	Type	Number	Remarks
Conveyor barge	2,000m^3 loading	1	Ship's name CB2002
Anchor boat	240ps, 20 tons lifting capa.	1	No.6 Sanko-Maru
Traffic boat	50ps	1	For conveyor barge
Investigation boat	30ps	5	For various investigations
Working boat	30ps	4	
Survey boat	30ps	1	
Tugboat	2,000ps	1	
Patrol boat	50ps	2	

INTERDEPENDENCE OF TURBIDITY SPREADING AND CURRENT

What effect did the current have on changes in the turbidity in overlaying? According to the analyzed data, Case 3 had an SSW current flow average of about 2cm/sec during the spread time period, with the current reversing to ENE to NE at the end of the spread. In Case 4, the current was NNE at an average of about 7cm/sec in the spread time period and NNE to NE at an average of about 5cm/sec for some time after termination of the spread. Under these conditions, the turbidity in Case 3 was less than 5 ppm and decreased with time on the portside of the conveyor barge, but at the front central part, under the influence of the SSW current, it showed a trend of increase by only 2 - 3 ppm. But, in either case, the turbidity was low, below 5 ppm. In Case 4, the conveyor barge was positioned downstream, and at the measuring points located upstream, the turbidity showed no effect from the spread. Thus, it was confirmed from the range of measuring points around the barge that the discharge caused little spreading of the turbidity, the current had little effect on the turbidity, and the turbidity was not spreading much.

OVERALL EVALUATION OF SPREAD METHOD

An overall evaluation of each of the spread methods was made as shown in Table 3. For evaluation, points were given in the order of 5, 4, 3, and 2 from the best, and for a weighted evaluation, 50%, 10%, 10%, 10%, and 20% were given in the order of the numbers 1, 2, 3, 4, and 5 in the left column of the table. The evaluation was made of the following items:

Number 1. Sand layer thickness: An average thickness of 50cm or more was secured in each case, but the rating was made according to the extent of variation.

2. Unevenness: Extent of variation of unevenness as measured.

3. Stirring up: Extent of variation of SS at 1.5m from the bottom.

4. Settling: Height of deposition, taking the value of the survey 3 days after the overlaying.

5. Turbidity: Degree of SS.

Points of gain and the order of the spread methods are also shown in Table 3.

TABLE 3. POINTS MARKED AND ORDER

Number	Item \ Cases	1	2	3	4
1	Sand layer thickness	2.0	1.5	2.5	1.0
2	Unevenness	0.2	0.4	0.5	0.3
3	Stirring up	0.4	0.2	0.5	0.3
4	Settling	0.3	0.4	0.2	0.5
5	Turbidity	0.6	0.4	1.0	0.8
Overall evaluation		3.5	2.9	4.7	2.9
	Order	2	3	1	3

SUMMARY

Case 3 was determined to be the best method. In this method of sand spread, a volume equivalent to 25cm of overlay is placed twice successively (by full swing) from a height 10 - 12m above the bottom (middle stage discharging). The fact that this method was found to be the best is attributable to such factors that the sand thickness was stable due to successive discharges and the impact of the overlaying material on the bottom sediment was diminished by the middle stage discharging with less stirring up causing turbidity and less resettling. In all the methods, turbidity was nearly completely eliminated through the use of the tremie tube's telescopic function.

The cunveyor barge method is promising as a mobile and efficient sand overlaying method. This barge system is capable of overlaying sand in a short period and is applicable to a wide range of areas.

SAND OVERLAYING FOR BOTTOM SEDIMENT IMPROVEMENT BY SAND SPREADER

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ABSTRACT

In order to prevent further pollution of the ocean environment in the Inland Sea of Japan, the Ministry of Transport conducted a bottom sediment improvement test by sand overlaying in Hiroshima Bay. Prior to execution of this test, a test to overlay the bottom sediment with sand of a thin layer was conducted by using a barge unloader sand spreader. As a result, the following facts were discovered:

a. It is possible to evenly spread a sand cover over bottom sediment to a specified thickness with relative ease.

b. The disturbance to bottom sediment is minor because the sand is gently spread.

c. Water pollution caused by the resuspension of bottom sediment or overlying sand is minor.

It was confirmed, therefore, that the sand spreader process is feasible for practical use as a sand overlaying process for bottom sediment improvement.

INTRODUCTION

The Ministry of Transport decided to implement an ocean environment consolidation pilot project in order to prevent further pollution of the ocean environment in the Seto Inland Sea. A bottom sediment improvement test of overlaying the bottom sediment with sand in Hiroshima Bay was conducted as a part of this project. The test works commenced in 1979, and various surveys and investigations are still in progress.

Sand overlaying for bottom sediment improvement is one of the measures for separating seawater from bottom sediment and reducing the release load of nutrients from the bottom sediment (one of causes of entrophication in the enclosed sea).

A part of the results of investigations in this test work was presented at 6th US/Japan Experts Meeting on Management of Bottom Sediments containing Toxic Substances and effectiveness of sand overlaying has been corroborated.

The problem with execution of the sand overlaying process is how to spread quality overlaying material over the bottom sediment to an equal thickness without exception in the required area.

A barge unloader sand spreader of suction dredge type was used on a trial basis for spreading cover material. Good results were obtained; therefore, its outline is introduced below.

SAND OVERLAYING PROCESS

The problems involved with the release of organic substances and nutrients from the bottom sediment by sand overlaying are as follows:

a. The overlaying material should be equally spread to prevent positive exposure of the bottom sediment. Furthermore, after overlaying, the surface layer should not be disturbed by working anchors and so forth.

b. Quality overlaying material must be used to prevent pollution of the working area.

c. The surface layer of the bottom sediment is extremely soft, making it possible for sliding disruption of the surface layer of the bottom sediment to occur due to the spreading of overlaying material; enclosure of the bottom sediment is thereby disabled. Therefore, overlaying material should be spread as thinly as possible and methods that partially pile up overlaying material should be avoided.

d. The release of nutrients cannot be prevented if the overlaying thickness is insufficent; on the other hand, it is possible that the release load increases due to consolidation of bottom sediment if the overlaying thickness is excessive. Consequently, it is necessary to select a suitable thickness.

e. Reliability is required for the sand overlaying process. It is desirable, therefore, that management is made by means of a work execution management system that is capable of understanding the working conditions at all times.

f. When the sand covering process is actually adopted, a broad area is involved and facilities that provide a large working capacity (working area per unit time) are required. Consequently, it is necessary to examine working methods capable of satisfying these requirements.

SAND COVERING PROCESS WITH A SAND SPREADER

Various methods can be considered for spreading cover material:

a. Mechanical method (clamshell, belt converyor, etc.).

b. Hydraulic method.

c. Pneumatic method.

Of the three, the hydraulic method has been popularly adopted for improvement of soft ground. As a broad area sand overlaying process, the hydraulic method makes use of suction dredges. This method is available in two systems: suction dredge and sand spreader and barge unloader and sand spreader.

Suction Dredge and Sand Spreader

In this system, a sand pit is provided near the working area; overlaying material (sand) is stored in the pit; and the sand is sucked with a suction dredge and fed to the sand spreader located in the overlaying area by pipeline. The sand overlaying work is executed by operating the sand spreader in back and forth and right and left directions.

Barge Unloader and Sand Spreader

In this system, the sand transported with a barge is sucked with a barge unloader of suction type, fed to the sand spreader by the method described above, and spread.

A sand spreader of this barge unloader type was used for this test work. The features of this process were as follows.

a. The overlaying material (sea sand) is spread after being mixed with water thereby making it possible to spread over a broad area at a time. Therefore, sand spreading in a thin layer can be easily performed.

b. Overlaying on soft bottom sediment can also be accomplished because partial pile up of overlaying material will not occur.

c. Since the equipment is simple, management of execution of work is easy and working accuracy is high.

d. It is easy to expand the scale of the equipment and cope with large-scale work.

SAND OVERLAYING TEST

This test was conducted in the Kure area of Hiroshima Bay in July through October of 1980. Sand overlaying work was carried out in sections 200 m × 200 m and 60 m × 80 m at a depth of 21 m.

In addition to the sand overlaying test using sea sand, investigations to study the adaptability of oyster shells were also conducted since oyster shells are produced in large quantities in this region.

The locations of work are shown in Figure 1.

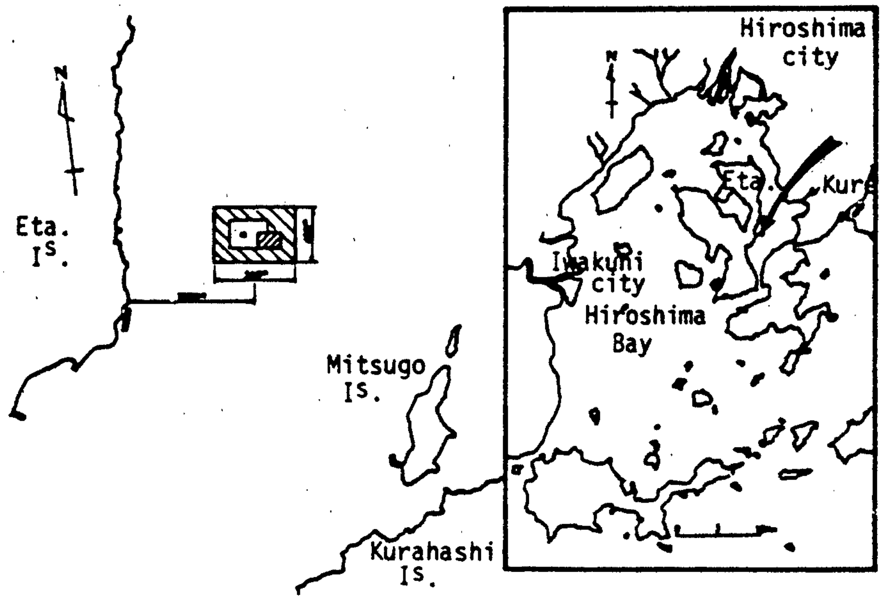


Figure 1. Location of test point

Overlaying Material Test

Physical, chemical, biological, and organic substance tests were conducted with two samples of sea sand and one sample of oyster shells to determine the various properties of sea bottom overlaying materials. The results are shown in Table 1.

Sea sand samples were of coarse particle size containing snells with silt content of 0.1 - 0.3%. No organic substances were detected, and, accordingly, they were judged to be suitable as overlaying material. The grain-size distribution is shown in Figure 2.

TABLE 1. PROPERTIES OF OVERLAYING MATERIALS

Items			Oyster shell July 24 '80	Sea sand 1 July 28 '80	Sea sand 2 Aug. 5 '80
Physical Test	Hue	--	Grayish white	Grayish yellow	Grayish yellow
	Odor	--	Oyster odor	No	No
	Specific gravity	--	2.567	2.617	2.622
	Bulk density		0.723	1.13	1.22
	Water content	%	33.6	4.26	5.74
Chemical Test	PH		8.8	9.4	9.4
	COD	Omg/g	3.7	Not detected*	Not detected
	T-P	mg/kg	460	44	100
	PO_4-P	mg/kg	310	Not detected	40
	T-N	mg/kg	497	107	35
	NH_4-N	mg/kg	23.3	4.6	7.5
	NO_2-N	mg/kg	Not detected	Not detected	Not detected
	NO_3-N	mg/kg	120	32.8	9.3
	TOC	%	Not detected	0.1	Not detected
	ORP EAgcl	mV	80	90	230
	ORP En.H.E.	mV	290	290	430
	Sulfides Free	Smg/g	Not detected	Not detected	Not detected
	Sulfides Banded	Smg/g	Not detected	Not detected	Not detected
	Sulfides All	Smg/g	Not detected	Not detected	Not detected
	Ignition loss	%	0.6	0.9	2.8
	C	%	11.5	0.6	1.6
	H	%	0.1 under	0.1 under	0.1 under
	N	%	0.4	0.3	0.1 under
Biological Test	General bacteria	/g	5×10^5	600	2000
	Sulfate reducing bacteria	/g	790	2	5
Organic Substances Test	Total mercury	mg/l	Not detected	Not detected	Not detected
	Alkyl mercury	mg/l	Not detected	Not detected	Not detected
	Cadmium	mg/l	Not detected	Not detected	Not detected
	Lead	mg/l	Not detected	Not detected	Not detected
	Total Chromium	mg/l	Not detected	Not detected	Not detected
	Hexavalent Chromium	mg/l	Not detected	Not detected	Not detected
	Arsenic	mg/l	Not detected	Not detected	Not detected
	BHC	mg/l	Not detected	Not detected	Not detected
	PCB	mg/l	Not detected	Not detected	Not detected

* "Not detected" means less than the limit of determination.

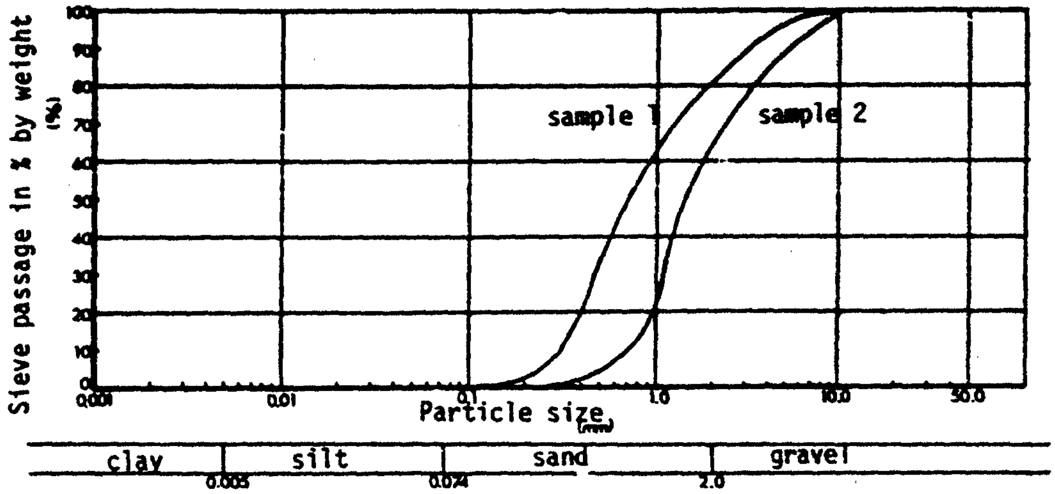


Figure 2. Grain-size distribution of sea sands

Investigation of process

To conduct the test, enclosures for the overlaying area were constructed first using oyster shells.

Next, overlaying using sea sand was executed with a sand spreader. To ensure that spreading was maintaining the specified thickness, small-scale pretest areas I and II were established, and pretests were conducted prior to full-scale operation.

Spreading of Oyster Shells

A grab hopper dredge was used for spreading the oyster shells; the oyster shells loaded in a hopper were grasped with a grab bucket and released at the fixed position. The water depth at release was varied as a test and the spreaded form was investigated; based on the result of this test, the optimum release depth was determined as 15 to 20 m.

The conditions after the oyster shells were spread were surveyed by divers and also by echo sounding. The results of the investigation are shown in Figure 3 and Table 2. It was confirmed that oyster shells were spread to the planned thickness.

With respect to enclosures, the thickness was 40 to 70 cm in the peripheral dike with a width of 6.0 to 8.0 m, and the layer thickness at the center was almost equal at 50 to 60 cm.

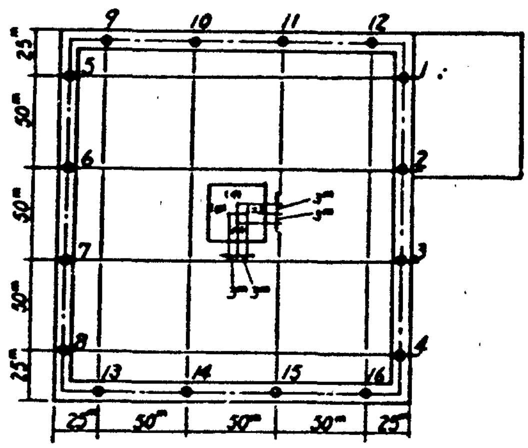


Figure 3. Oyster shell overlays

TABLE 2: OVERLAY ENCLOSURE OF OYSTER SHELL

Location No.	Thickness (m)	Width (m)	Location No.	Thickness (m)	Width (m)
1	0.55	6.0	11	0.70	6.0
2	0.60	7.0	12	0.40	7.0
3	0.45	7.0	13	0.60	6.5
4	0.55	8.0	14	0.55	6.0
5	0.65	7.0	15	0.45	7.0
6	0.60	7.0	16	0.55	7.5
7	0.70	7.0	(a)	0.55	
8	0.55	7.5	(b)	0.55	
9	0.55	7.0	(c)	0.55	
10	0.70	7.5	(d)	0.60	

Spreading of Sea Sand

a. Spreading method

Spreading of sea sand was carried out with a suction type barge unloader. A grab hopper dredge conveyed sea sand to a barge as shown in Figure 4, and the sea sand was dropped into the barge hold with a grab. The barge hold was filled with water until the volume of sea sand in the hold reached the specified level (200 m^3 this time). The mixture of water and sea sand was then sucked with a sand pump and spread over the sea bottom through a spreading pipe shown in Figure 5.

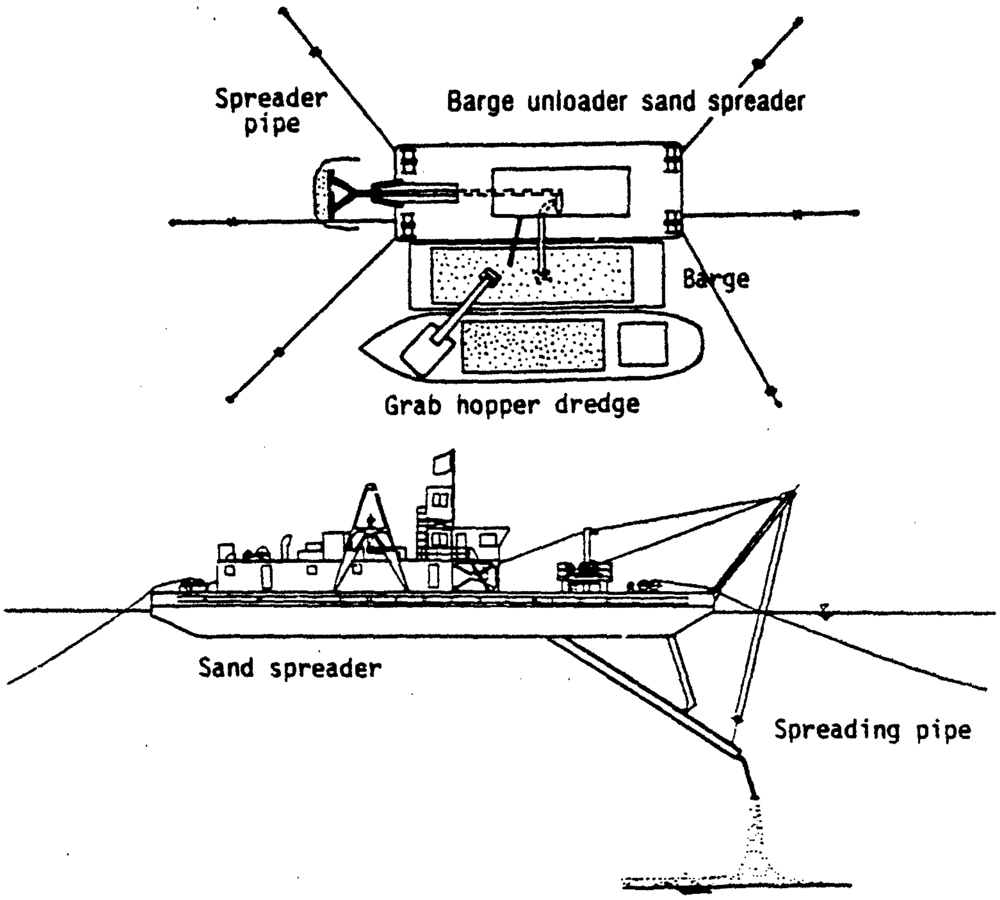


Figure 4. Outline of Sand Spreading Process

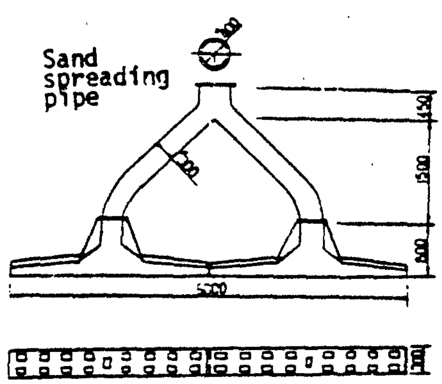


Figure 5. Profile of a Sand Spreader

Determination of the quantity of spread sand was made through measurement of suction negative pressure of the sand pump. The distance of movement of the unloader was measured with an advance meter mounted to the maneuvering winch wire; deviation in the back and forth direction as well as the right and left direction was managed by a system that made corrections based on sextant surveying.

b. Management of spreading rate

The sand pumping rate of the unloader can be roughly estimated through measurement of the suction negative pressure of the sand pump.

The flow rate, suction negative pressure, and actual suction height were measured in the test work section while the pump was running with water. The flow rate, discharge sand quantity, and suction negative pressure when sand content varied during sand-water mixture running were calculated, and Table 3 was compiled. The discharge sand quantity during the spreading operation was managed from the index of suction negative pressure by using Table 3.

TABLE 3. VARIATION IN SUCTION NEGATIVE PRESSURE AND DISCHARGE SAND QUANTITY BY SAND CONCENTRATION

True Sand Concentration %	Suction negative pressure, mmHg			Flow rate (m^3/sec)	Discharge sand quantity (m^3/h)
	min	Standard*	max		
2	154	228	301	0.30	51
4	169	243	316	0.29	99
6	169	243	316	0.27	140
8	176	250	324	0.26	179
10	176.8	257	338	0.25	214
12	191	272	353	0.24	248
14	199	279	360	0.23	279
20	206	294	382	0.21	360

* The standard value of suction negative pressure calculated for the suction actual height during sand-water mixture running is the same as the suction actual height (distance to pump center line from water level in barge) during the water delivery running test, and the minimum and maximum values are applicable to cases where the suction actual height varies by ±90 cm from the standard level.

c. Spreading method classified by test area

The spreading method classified by test area is shown in Table 4.

TABLE 4. SPREADING METHOD CLASSIFIED BY TEST AREA

Item		Pretest area I 1st row	Pretest area I 2nd-3rd row	Pretest area I 4th-6th row	Pretest area II	Test area
Spread time	Per advancement	4 min.	3 min.	3 min.	3 min.	3 min.
	Per row	136 min.	102 min.	69 min.	69 min.	69 min.
Advance distance at a time		2 m	2 m	3 m	3 m	3 m
Spreading pipe location		-10 m	-10 m	-10 m	-5 m	-10 m
Parallel moving distance		6 m	6 m	6 m	6 m	6.5 m

In pretest area I and II, investigations of overlaying conditions and of influence over the bottom sediment and water quality were carried out to determine the execution method to use in the actual work. The results are shown in Table 5.

TABLE 5. COMPARISON OF PRETEST AREA INVESTIGATION RESULT

Item	Description		Pretest area I	Pretest area II	Difference (II-I)
Resuspension	Turbidity 1.5 above bottom (deg)		2.14	2.31	0.17
	SS (mg/l)		9.43	7.29	-2.14
Influence	Upper layer	Turbidity (deg)	1.35	2.39	1.04
		SS (mg/l)	2.63	3.30	0.67
	Intermediate layer	Turbidity (deg)	0.39	1.05	0.66
		SS (mg/l)	2.63	2.97	0.34
	Lower layer	Turbidity (deg)	0.35	1.48	1.13
		SS (mg/l)	3.43	3.70	0.27
Irregularity	Mean value (cm)		4.59	5.67	1.08
	Standard deviation (cm)		1.70	1.81	0.11
Thickness	Mean value (cm)		37.43*	55.52	
	Deviation (cm)		6.58	10.44	3.86

* The values of the 4th-6th rows obtained by 3-min. spreading, 3-m advancement, and 6-m parallel movement, which are the same as that of pretest area II, were adopted as the values in pretest area I for the irregularity investigation and overlaying thickness investigation.

Better results were obtained in pretest area I when compared to area II regarding turbidity, suspended solids, irregularity, and overlaying thickness. Because the spreading pipe located 5 m below the water surface caused the center of overlaid sand to deviate from the center of the spreading pipe by 2 m, it was decided to carry out spreading with the spreading pipe located in a position 10 m below the water surface. From the results obtained, it was judged possible to overlay sand to the specified thickness; therefore, spreading work in the full-scale test area was executed such that spreading was for 3 min, advancement was 3 m, and the barge parallelly moved by 6.5 m after completion of spreading in a row, as shown in Table 4. The work was managed by further dividing the test area into subsections as shown in Figure 6.

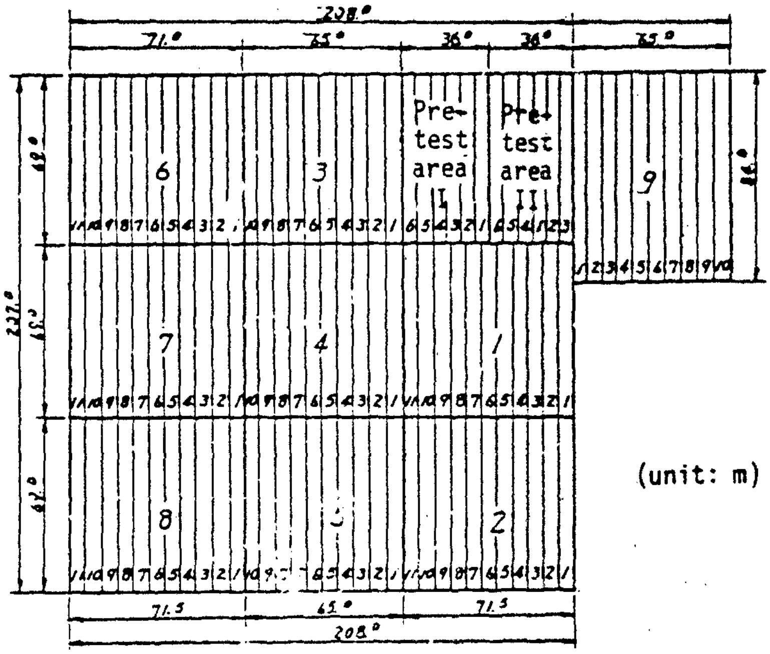


Figure 6. Sand spreading rows in the test area

Investigation of overlying sand thickness and sinking

After completion of the overlaying in test areas, the conditions of the overlying sand in the vertical direction were investigated by using overlying sand thickness gauges, core samplers, sand samplers, and depth measuring bars (Table 6).

TABLE 6. OVERLYING SAND THICKNESS INVESTIGATION

Item	Pretest area I	Pretest area II	Test area	Remark
Sand thickness gauge	3 units	3 units	10 units	3 after oyster shell spread. 16 after sand spread
Core sampling	8 units (2 of them for particle size analysis)	4 units (2 of them for particle size analysis)	34 units (1 of them for particle size analysis)	16 measuring bars used together in the test area
Sand sampling	7 units	7 units	24 units	24 measuring bars used together in the test area
Depth measuring bar	30 places	30 places	455 places	

Overlying Sand Depth Gauge

a. Method of investigation

Overlying soil depth/settlement gauges were erected in the positions shown in Figure 7; the height of the top of each overlayer thickness gauge (Figure 8) was measured before and after spreading. In this way, the overlying sand depth and settlement were measured.

b. Results of investigation

The results of the investigation are shown in Table 7.

Accurate details are known because only a few days passed after spreading, but it can be estimated that the settlement of sea sand is larger than that of oyster shell.

Depth Measuring Bar

a. Method of investigation

By thrusting depth measuring bars of 15 mm (diameter) × 1 m (length) into overlying sand, divers investigated overlying sand depth by response.

Depth measuring bar investigations were carried out at the same time as the core sampling and sand sampling measurements were made.

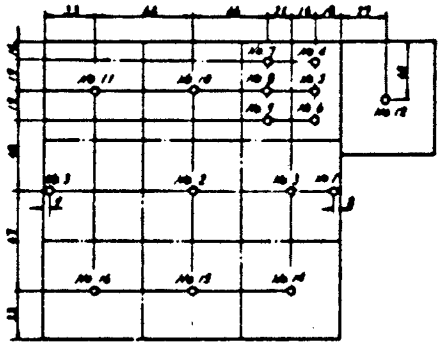


Figure 7. Location of overlayer thickness gauges

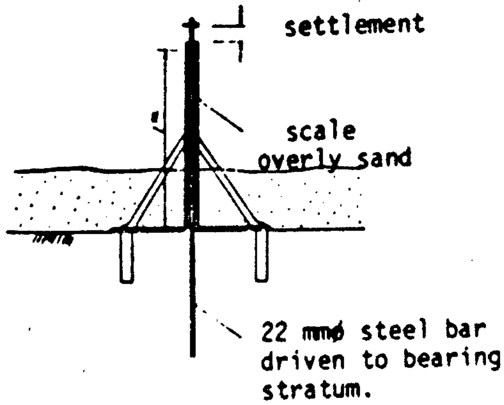


Figure 8. Overlayer thickness/settlement gauge

TABLE 7. RESULTS OF MEASUREMENT BY OVERLAYER THICKNESS GAUGE

Gauge No.	Date of measurement (cm)	Layer thickness (cm)	Settlement (cm)	Remarks
1	July 24	25	25	
2	July 26	50	25	After oyster shell spreading
3	July 25	20	20	
1	August 20	40	35	45° incline
2		80	22	20° incline
3		60	5	
4	August 1	25	12	
5		50	13	
6		75	18	
7		30	10	30° incline
8		60	21	
9		46	26	
10	August 20	35	--	Measure bar slipped off
11		45	27	30° incline
12		55	40	45° incline
13		--	--	Fell down
14		35	18	
15		45	25	
16		--	--	Fell down

b. Results of investigation

The results of investigation are as shown in Table 8 and Figure 9; variation coefficients ranged from 0.14 to 0.38.

TABLE 8. OVERLAYER THICKNESS MEASUREMENT RESULTS BY DEPTH MEASURING BAR

Item / Area	Mean value (cm)	Standard deviation (cm)	Variation coeff.
Pretest area I (a)	66.60	15.34	0.23
Pretest area I (b)	35.80	5.72	0.16
Pretest area II	57.91	7.84	0.14
Test area 1	50.98	19.43	0.38
Test area 2	41.34	6.41	0.16
Test area 3	52.15	17.41	0.33
Test area 4	37.68	8.43	0.22
Test area 5	38.38	10.78	0.28
Test area 6	37.04	10.31	0.28
Test area 7	39.87	6.25	0.16
Test area 8	42.04	6.16	0.15
Test area 9	41.10	10.22	0.25

Core Sampling and Sand Sampling

a. Method of investigation

(1) Core sampling

After overlaying work, tubes made of acrylic resin were driven into the overlying sand by divers, columnar samples were collected, and overlying sand depth and sand penetration depth into the original sea bottom were investigated (Figure 10).

(2) Sand sampling

After overlaying work, samplers (Figure 11) were pushed into the overlying sand by divers, columnar samples were collected, and the overlying sand depth and sand penetration depth into the original sea bottom were measured.

b. Results of investigation

Results of the investigation are shown in Table 9. The correlation between measured values obtained with depth measuring bars and measurements obtained with samplers is shown in Figure 12.

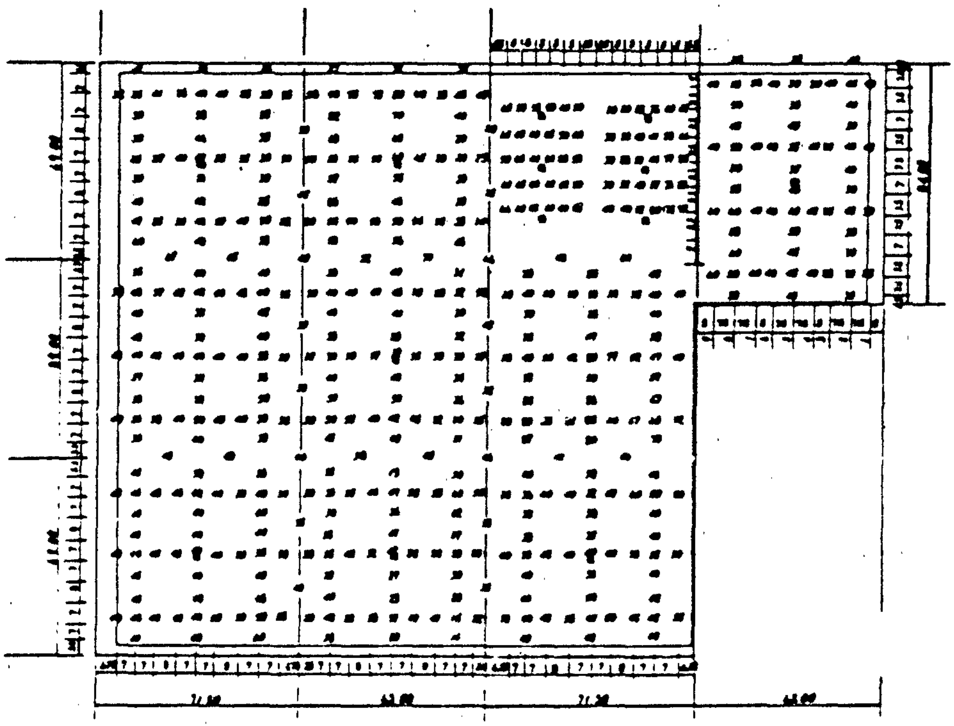


Figure 9. Measurement records of overlayer thickness with depth measuring bars. unit: cm

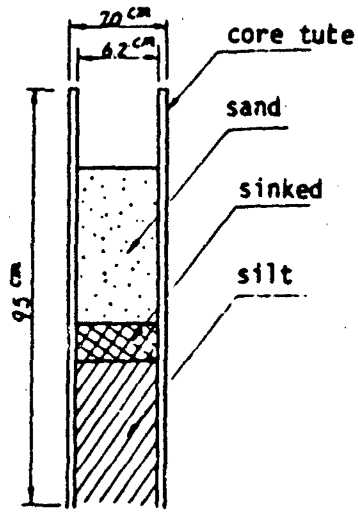


Figure 10. Core tube

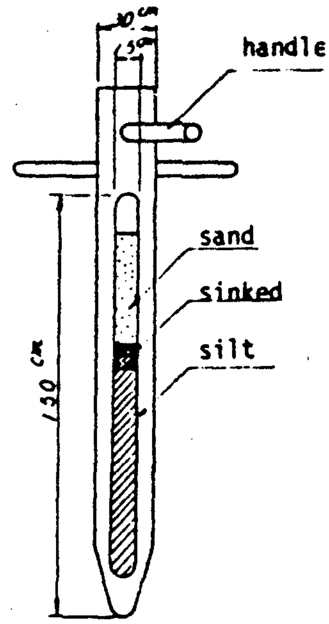


Figure 11. Sand sampler

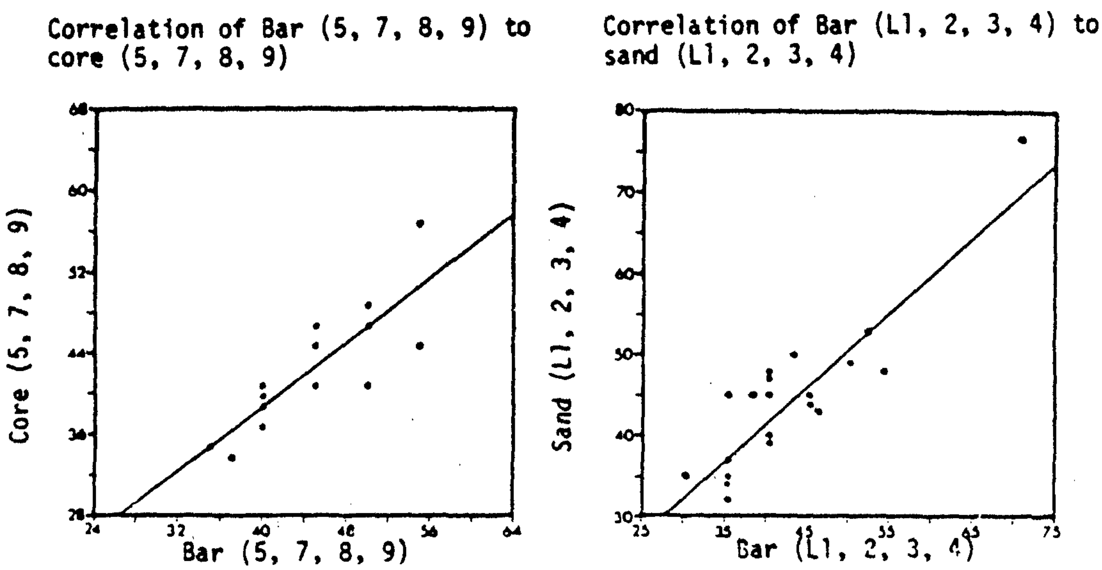


Figure 12. Correlation of core sampling and sand sampling measurement to bar measurement

TABLE 9. COMPARISON OF RESULTS OF CORE SAMPLING AND SAND SAMPLING

Item		Core Sampling			Sand Sampling		
		Sand thickness (cm)	Sinked depth (cm)	Sand thickness + sinked (cm)	Sand thickness (cm)	Sinked depth (cm)	Sand thickness + sinked (cm)
Pretest area I	Mean value	32.5	4.62	37.1	44.4	5.86	50.3
	Standard deviation	7.79	1.22	7.87	6.00	6.01	9.35
	Variation coefficient	0.240	0.264	0.212	0.135	1.03	0.186
Pretest area II	Mean value	29.5	3.75	33.3	40.4	12.3	52.7
	Standard deviation	8.05	1.30	7.82	8.36	5.12	12.6
	Variation coefficient	0.273	0.347	0.235	0.207	0.416	0.239
Test area	Mean value	37.3	4.55	41.9	38.7	5.92	44.4
	Standard deviation	7.44	0.711	7.51	7.33	1.94	7.85
	Variation coefficient	0.199	0.156	0.179	0.189	0.328	0.177

Particle-Size Analysis

Particle-size analysis was made with core samples obtained at the boundaries in order to investigate penetration of overlaying material into the bottom sediment.

a. Method of analysis

As the method of analysis, 10-cm samples were produced as shown in Figure 13 out of two core tube samples each in pretest area I and II and one core tube sample in test area 5; particle-size analysis was based on JIS A 1204.

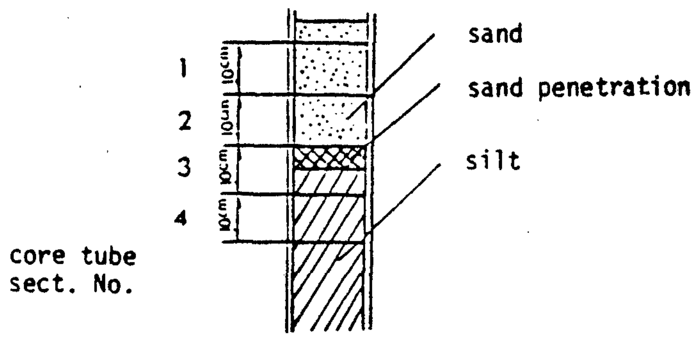


Figure 13. Sectioning of core tube sample

b. Results of analysis

The results of analysis are shown in Table 10. Penetration of overlying sand into the bottom sediment was relatively small.

Overlay Form

The overlay form is shown by a histogram indicated in Figure 14 from the results stated above. An almost level surface to a mean depth of 42 cm resulted. The mean penetration depth was 6 cm.

Investigation of resuspension

Resuspension of the bottom sediment and overlying sand during sand overlaying work was measured with a portable turbidity meter. In addition, water samples were collected and laboratory analysis of turbidity was conducted. The results (shown in Figure 15) showed that resuspension of the bottom sediment is up to 1.5 m above sea bottom.

TABLE 10. PARTICLE-SIZE DESTRIBUTION OF CORE TUBE SAMPLES

Area	Location No.	Core tube sec. No.	Clay and silt content (74 μ or less) %	Sand and gravel pebble content (over 74 μ)%
Pretest area I	1	1	0.5	99.5
		2	0.1	99.9
		3	52.8	47.2
		4	94.1	5.9
	4	1	0.2	99.8
		2	0.2	99.8
		3	39.9	60.1
		4	91.9	8.1
Pretest area II	3	1	0.2	99.8
		2	1.6	98.4
		3	93.4	6.6
		4	93.5	6.5
	4	1	0.2	99.8
		2	0.4	99.6
		3	83.1	16.9
		4	95.1	5.0
Test area 5	4	1	0.1	99.9
		2	0.1	99.9
		3	77.5	22.5
		4	96.6	3.4

Investigation of Resettlement

Two types of glass laboratory dishes, 30 cm diameter × 8.5 cm high and 30 cm diameter × 15 cm high, were placed on the overlying sand by divers immediately after sand overlaying work, and resettlement was investigated by divers for three days after sand overlaying work.

The results of the investigation are shown in Table 11. Accumulation of sand is observed in all dishes, and this sand is considered to be spread sea sand of slow settlement or resuspended spread sea sand after arrival at the bottom.

Investigation of Finished Surface

To determine the irregularity of the finished surface of the sand overlay, a pole was placed on top of two adjacent peaks of sand as shown in Figure 16 and the depth of the valley between the peaks was measured. The depths of these valleys were 6 to 7 cm at maximum, and conspicuous irregularity was not observed.

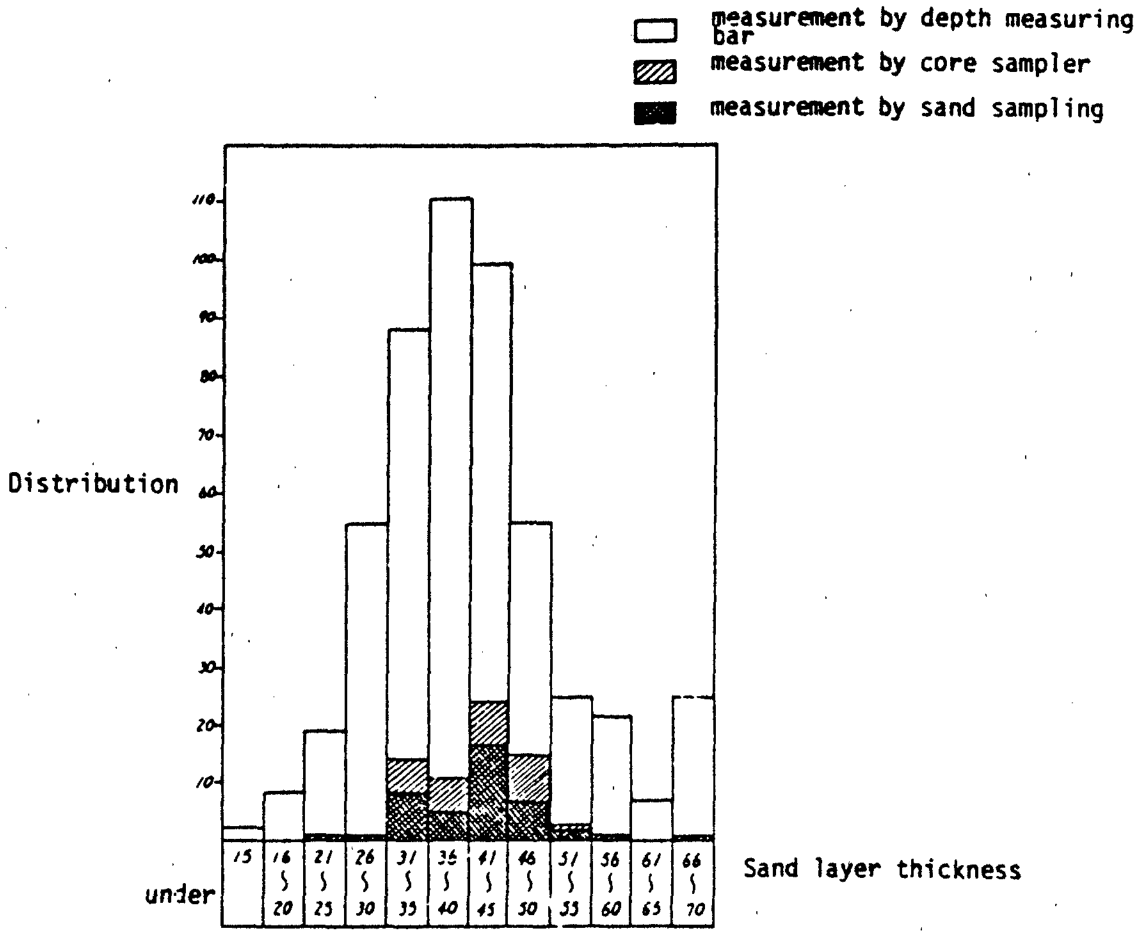


Figure 14. Overlayer thickness histogram

Investigation of Turbidity

In order to investigate the range and diffusion of turbidity generated during sand overlaying work, water samples were collected at three layers at 15-min intervals beginning 30 min before commencement of sand overlaying. Sampling positions are shown in Figure 17. The turbidity of these samples was measured.

The results are shown in Figure 18; very little turbidity caused by sand overlaying work was observed.

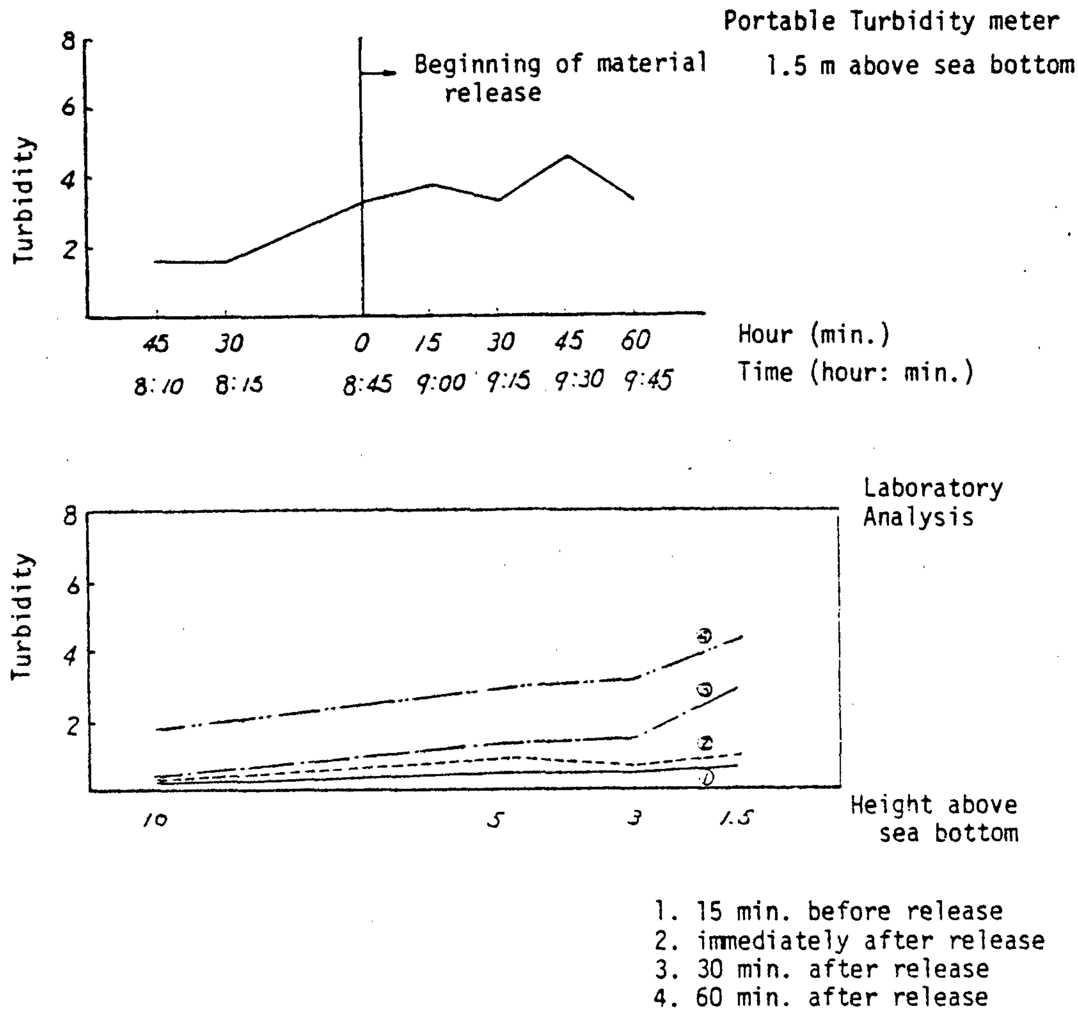


Figure 15. Typical results of the resuspension investigation

Confirmation Investigation

In order to collectively understand the sand overlaying conditions, the conditions of the bottom were investigated by using a sonar before and after sand overlaying work.

The results of the investigation are shown in Figure 19. The conditions of the bottom are almost identical.

TABLE 11. RESULTS OF RESETTLEMENT INVESTIGATION

No.	1 day later	2 days later	3 days later	Remarks
1	1 mm Sand, silt (1/3)	1 mm Sand, silt (1/3)	1 mm Sand, silt (1/3)	several tiny shrimp,* 1 tiny crab (dead)
2	1 mm Sand	1 mm Sand	1 mm Sand	several tiny shrimp, 2 tiny crab (dead)
3	1 mm Sand	1 mm Sand	1 mm almost silt	1 tiny crab
4	1 mm Sand	1 mm Sand	2 mm Sand, silt (1/3)	
5	1 mm Sand	1 mm Sand	3 mm Sand, silt (minor)	
6	1 mm** Sand, silt (minor)	1.5 mm Sand, silt (minor)	3 mm Sand, silt (minor)	3 tiny shrimp 4 tiny crab
7	1 mm Sand, silt (minor)	1.5 mm Sand, silt (minor)	1.5 mm Sand, silt (minor)	15 tiny shrimp 9 tiny crab

* Check of creatures was made when dishes were brought up 3 days later.
** Silt (minor) means minor unmeasurable volume.

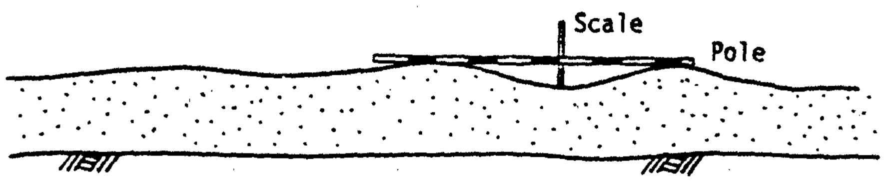
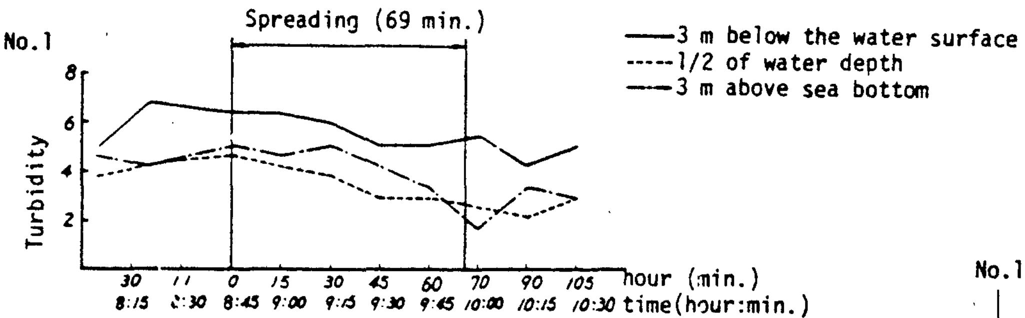
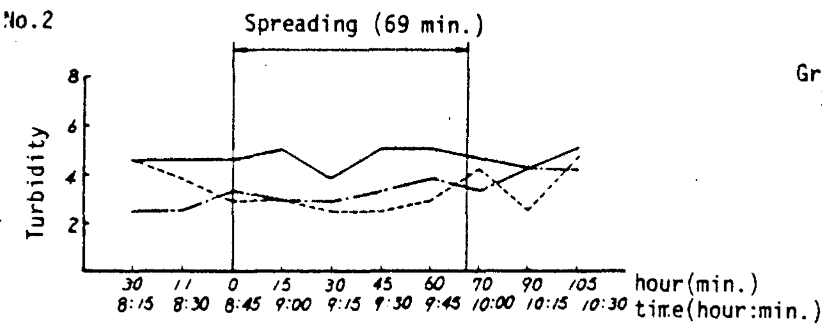


Figure 16. Surface irregularity measuring method





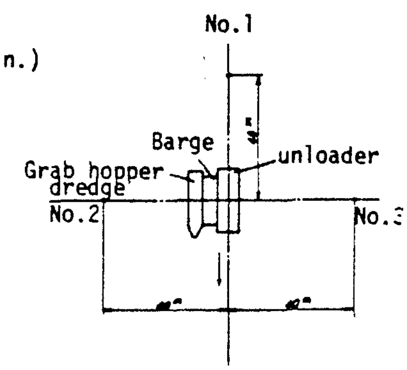


Figure 17. Turbidity investigation points

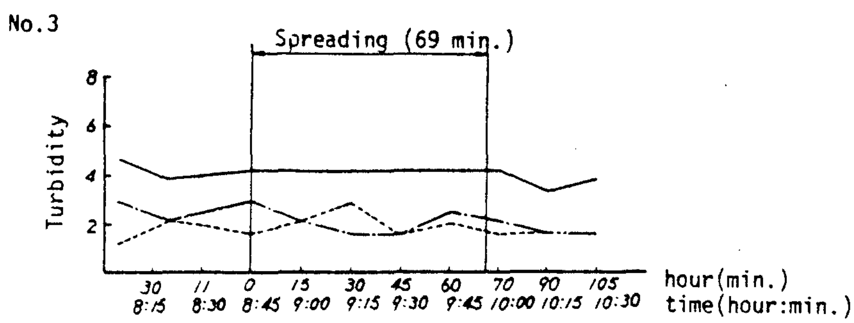


Figure 18. Results of measurement of turbidity influence investigation

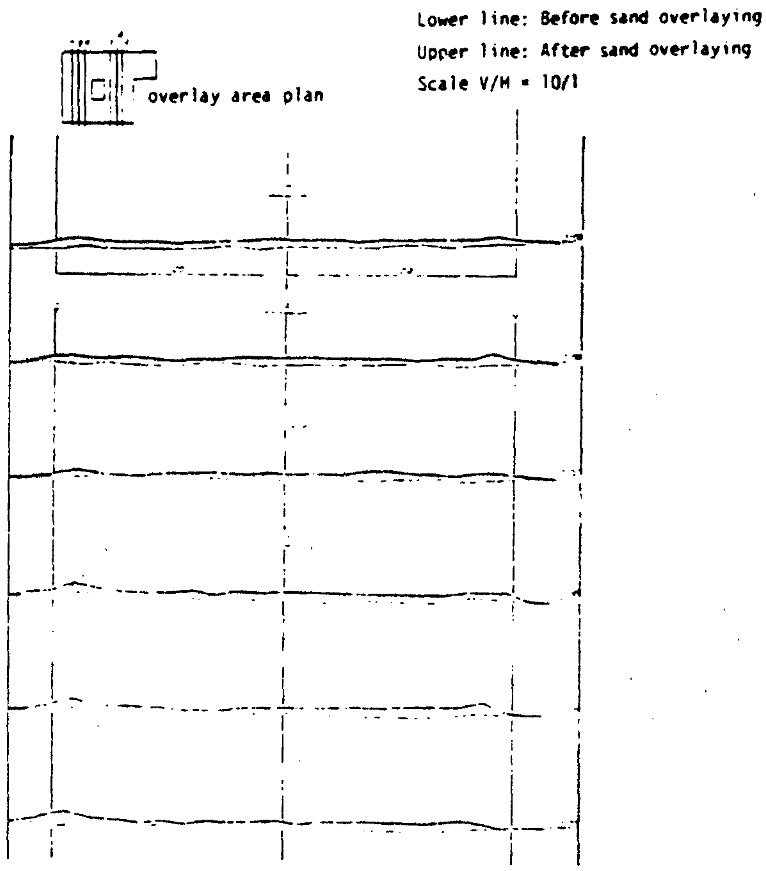


Figure 19. Sectional view of overlying sand form

CONCLUSIONS

The following conclusions can be drawn from this study:

a. The results of these investigations showed that the sea sand overlaying process using a barge unloader sand spreader is fully capable of finishing the entire area of spreading to the specified thickness with little irregularity.

b. In the range investigated, conspicuous differences were not observed in the influence of depth of spreading.

c. The sand overlaying work did cause turbulence in the bottom sediment; but contamination of surrounding water did not occur.

d. This was the first attempt at a sand overlaying process for bottom sediment improvement by spreader, and success levels were higher than expected.

e. A new type of sand spreader will have to be developed for future large-scale sand overlaying work; it will not be possible to simply increase the size and scale. The new type of sand spreader will have to incorporate large-size spreading pipes, equipment for feeding spreading sand at a fixed rate, and ship-operating equipment that does not require anchors.

f. A follow-up investigation is in progress to prevent the release of nutrients from the bottom sediment after sand overlaying; the findings will be reported at a later date.

AD P002397

STUDIES ON CAPPING OF CONTAMINATED DREDGED MATERIAL IN NEW ENGLAND DIVISION

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ABSTRACT

Contaminated dredged sediments were covered with less contaminated sediments in a controlled and monitored series of operations in Long Island Sound at a depth of 20 m. Observations have yielded useful information on formation of mounds, stability under stress of wave and current energy, and technology of marking, measurement, and data acquisition. Efficiency of the caps of two dissimilar sediments is evaluated in terms of physical behavior and chemical leaching.

The obligation to manage the disposal of dredged material in a manner which is responsive to regulatory mandates and to public concerns led our agency to initiate the development of subaqueous construction methods popularly called "capping." This will summarize the planning, operational features, and observations to date of one such operation conducted since 1979 off New Haven, Connecticut.

As historical background, the New England Division of the Corps of Engineers began various studies of dumping grounds in 1967 through a series of contractual agreements with marine sciences institutions in our region. These studies were the forerunners of a more formal program for monitoring environmental effects which is known by the acronym DAMOS. This program, employing a prime contractor, continues the association with academia through various subprograms. A most significant aspect of these early efforts was the development of techniques and subsequent evolution of much of the instrumentation without which the undertaking being described would not have been practicable.

The problem to be addressed by "capping" arose as a result of the need to restore certain channels in Connecticut Harbors to safe depths particularly at Stamford Harbor, located in Long Island Sound. Sediments which had accumulated over 20 years were enriched with various heavy metals and hydrocarbons to a degree which created concern over conventional subaqueous disposal. Historically, Long Island Sound, a semienclosed estuary, had been used for disposal, but was in the spotlight because of the clean water initiatives.

All activities were suspect. Therefore, even though no firm scientific basis had been advanced as cause for concern, it would not have been possible to dump sediments within this water body if the public perception was that they were contaminated.

In the absence of alternative means of disposal, and in light of mounting economic pressure to maintain the channel, our agency advanced a plan designed to isolate the contaminated sediments beneath a strata of materials accepted as being "clean." While past observations of disposal area mounds had yielded much practical information with regard to dumping operations, there were no instances where mounds were formed entirely of what would be characterized as "maintenance," or sediments of recent origin. Therefore, we were interested in sediment behavior with regard to mounding, lateral spread, erodability, consolidation, and any other physical factors which might be observable. A plan was formulated whereby two mounds of contaminated material would be formed at marker buoys placed within the 1-mile-square disposal area. Marker buoys were to be spaced approximately 1000 m equidistant from a relic mound formed in 1974. The mounds were oriented normal to the tidal flow in order to minimize any effects of one on another. A feature of the plan was to utilize and compare the effectiveness of cover material of two distinct sediment types: fine-grained cohesive silts and clays in one case, and fine sands in the other. The plan and its results are generally discussed in this paper. Appendix A contains a more detailed discussion of the capping study.

The plan called for periodic observations of the development of the mound and its cover by bathymetric surveys supported by visual and photographic evidence. To this end, wires were placed along the bottom radiating from the center with appropriate markings, and stakes were imbedded as a further aid to measuring lateral spread and depth of the mounds. In retrospect, these provisions were unnecessary since, ultimately, the boundaries of each mound were readily identifiable by sharp contrast in color and texture, and the natural delineation provided by an extensive population of the stalk hydroid corymorpha found over the entire area. Extensive baseline measurements of both physical and chemical parameters were logged prior to the start of dumping operations.

As the average water depth of the disposal area was 20 m, it was possible to utilize taut-wire moored buoys as markers which provided a constant reference to the tow boat operator. Even under adverse conditions, disposal generally took place within 25 m of the designated point. The records indicate that, if anything, the mounds formed more steeply than initially predicted, and that future dumping operations should address this aspect.

Two mounds of the Stamford contaminated material were constructed: south, 37,800 cu m; and north, 26,000 cu m. Evaluation during this phase indicated excellent correlation of mound volumes with scow measure. It was estimated that greater than 80 percent of the material being dredged by clamshell bucket was transferred from the dump scow to the bottom as a cohesive unit, forming a mount. The balance formed a turbidite-type deposit radially from the disposal point. Obviously, the type of dredge utilized has a most significant effect on the final angle of repose. This was most apparent when capping material was dredged from the New Haven Harbor channel. The south pile was capped by 76,000 cu m of bucket-dredged cohesive sediment, and the north pile was capped by 84,000 cu m of sandy materials dredged by the Corps of Engineers hopper dredge ESSAYONS. While each cap attained the thickness and extent of coverage desired, the contrast in surface texture was pronounced and, as it turned out, significant.

Upon completion, the sand cover on the north had a maximum thickness of 3.5 m. This cape was a smooth blanket and difficult to penetrate, judged by diver's reports. The south mound had a cap of up to 4 m thickness, characterized by roughness features attributable to the large clumps of cohesive sediment.

Following the dumping operations, periodic observations and measurements began. The first, approximately 1 month after completion, detected slight consolidation in each mound, which was consistent with expectations. However, 4 months later, another survey indicated that approximately 10,000 cu m had been displaced from the top of the south pile. While the integrity of the cap remained whole, the phenomenon gave rise to extensive analysis of the probable cause.

Through deduction, subsequent observation, and based upon theoretical calculations, the logical explanation for the loss of material was the wave energy developed by passage of a hurricane in the third month after deposition. The conclusion reached was that the high roughness factor of this mound resulting from clumps of cohesive sediment interacted with storm waves to create a shear stress and cause movement. The two other mounds, though in slightly shallower water, possessed smoother surfaces and were unaffected.

Observations have continued on a regular basis since the storm event, with no further changes being detected. Chemical and biological observations continue as well in order to measure what, if any, special characteristics can be attributed to the presence of the mounds. Based on observations on other mounds, we expect that the roughness factor of the south mound will be overcome in time, primarily by biological activity, and as a result of fracturing and normal erosion.

From our studies we have thus far concluded that certain essentials should govern the choices available to the manager. If possible, cohesion of the underlying material should be maintained by choice of dredging equipment. The exposed surface area of the resulting mound should be as small as possible, but may need to be extended when working in shallow water to reduce exposure. Covering materials, if cohesive, should be reworked by dredging, or smoothed after dumping if roughness poses a problem in the energy field present.

The degree of coverage necessary to inhibit any diffusion to the water column has not been determined, and there is question whether field measurements will be sensitive enough to verify any theoretical model. Therefore, the approach should be a conservative one, based on whatever stability calculations are possible. A key element in any similar operation is the availability of accurate control and sounding equipment with the capability to replicate exactly each line of measurement and make continuous comparisons. This equipment is the manager's eyes, and is indispensable.

SCIENCE APPLICATIONS, INC.

AD P002398

"CAPPING" PROCEDURES
AS AN ALTERNATIVE TECHNIQUE TO
ISOLATE CONTAMINATED DREDGE MATERIAL
IN THE MARINE ENVIRONMENT

DAMOS CONTRIBUTION #11

Written Statement submitted to:

U.S. House of Representatives
Committee on Merchant Marine and Fisheries
May 21, 1980

Submitted by:

Robert W. Morton, Ph.D.
Science Applications, Inc.
Ocean Science & Technology Division
Newport, RI 02840

INTRODUCTION

Many of the major harbors on the northeast coast of the United States require extensive dredging of material that is contaminated with industrial waste products, principally heavy metals and PCBs. Because of the large quantities to be dredged, the lack of suitable upland or shore line disposal sites, and the prohibitive costs of transport beyond the continental shelf, placement of these sediments on the shelf is often the only viable method of disposal. During the past several years, attempts have been made to isolate small amounts of this material by covering it with cleaner material through specific management techniques such as dredging from the head to the mouth of an estuary, dredging docks and other "hot" spots during the initial phases of the operation, and combining clean material from nearby dredging operations at a common disposal point. The success of these procedures has led to the development of "capping" operations in which larger volumes of contaminated materials are dumped at a specific point and then covered with cleaner material as part of a carefully managed and monitored program of dredge spoil disposal.

One such capping operation has been conducted by the New England Division of the U.S. Army Corps of Engineers, and several other capping procedures have been proposed for ongoing and future disposal operations. The purpose of this testimony is to describe the results of the New England operation and to discuss the feasibility, costs and possible ecological effects to be expected in future capping operations.

STAMFORD-NEW HAVEN CAPPING OPERATION

The extreme shoaling conditions existing in Stamford and New Haven harbors required that dredging of these areas be conducted during 1979 to insure passage of commercial and particularly oil related traffic to terminals in those cities. Because bulk sediment analyses indicated that sediment originating from Stamford Harbor would be rich in heavy metals, management procedures were initiated to "cap" the Stamford material with silt and sand from New Haven Harbor. The objectives of these capping procedures were to isolate the enriched material from the benthic fauna and the overlying water column and to evaluate the relative merits of sand and silt as capping materials in terms of coverage, stability, effectiveness in isolating contaminants and recolonization potential.

Monitoring of the disposal operation was conducted as part of the Disposal Area Monitoring System (DAMOS) and consisted of precision bathymetric mapping of spoil distribution, visual observations of the spoil surface and margins, chemical comparisons of spoil and natural sediment and sampling of benthic populations for recolonization and bioaccumulation studies.

Baseline studies of all these parameters were made prior to disposal. Replicate precision bathymetric surveys, diver observations and chemical sampling were used during the disposal operation to monitor the volume and distribution of Stamford spoil at the disposal site, to manage the capping operation insuring coverage of the enriched spoils and to measure the thickness and distribution of capping material. Following disposal, additional replicate surveys were made and are continuing to monitor the stability of the spoil mounds created and to assess the long term effectiveness of the capping procedure.

The precision bathymetric survey monitoring procedures combined with the diver observation have resulted in data which represent a significant improvement over previous disposal monitoring efforts for several reasons including: 1) use of precision navigation control to survey at 25 meter lane spacing, 2) the nearly flat bottom available to provide a baseline datum, 3) the application of computer software to complete data sets to provide better calibration between surveys, 4) the careful management of the disposal operation to create topographic features for precision measurements of volume and 5) the ability to combine visual observations with physical measurements to more completely evaluate the environmental factors affecting the dredge material.

Whether or not these conditions can be duplicated in other areas will be seen in the future, however, this study provides a unique opportunity to accurately measure spoil volumes and evaluate the importance of such environmental parameters.

As described earlier there were two major objectives to be achieved through disposal of spoils at the Central Long Island Site. (Figure 1) These were: 1) containment and isolation of Stamford spoils by capping with New Haven material; and 2) an evaluation of the effectiveness of the procedure in general, with particular emphasis on the effectiveness of sand versus silt as a capping material. In order to compare the sand and silt caps, two disposal points were designated 1000 m north and south of the spoil mound created by the New Haven project in 1974 (Figure 1). The south site was designated for capping with silt from the inner harbor and the north site with sand from the outer breakwater area of New Haven Harbor. The North-South orientation was selected since tidal flow through the site is in an east-west direction, thus potential effects resulting from the older mound would be minimized.

Precision disposal of Stamford spoils was essential to minimize their areal distribution prior to capping. This was accomplished through installation of two, taut-wire moored buoys at the designated disposal points using a Trisponder system for navigation control. Towboat operators were then instructed to dispose of material close aboard the south side of each buoy. Even under adverse conditions, disposal generally took place within 25 meters of the designated point.

Initial disposal of Stamford material took place between March 25 and April 22, 1979 at the southern disposal point. After April 23, silt from New Haven was dumped at the south site to provide capping material, and disposal of Stamford spoils was restricted to the north site. Disposal of silt continued until June 15 when dredging was halted to prevent impact to oyster larvae by siltation caused by the dredging operation. Likewise, dredging of Stamford Harbor and associated disposal at the north site was halted on June 15. Between June 15 and June 21, the hopper dredge ESSAYONS removed sandy sediment from the mouth of the New Haven harbor and used this material to cap the north site.

Disposal of dredge spoil from Stamford Harbor at the southern site reached a total of 37,800 m^3 (based on scow load records) on April 22, 1979. A survey of the site was conducted on

CENTRAL LONG ISLAND SOUND DISPOSAL SITE

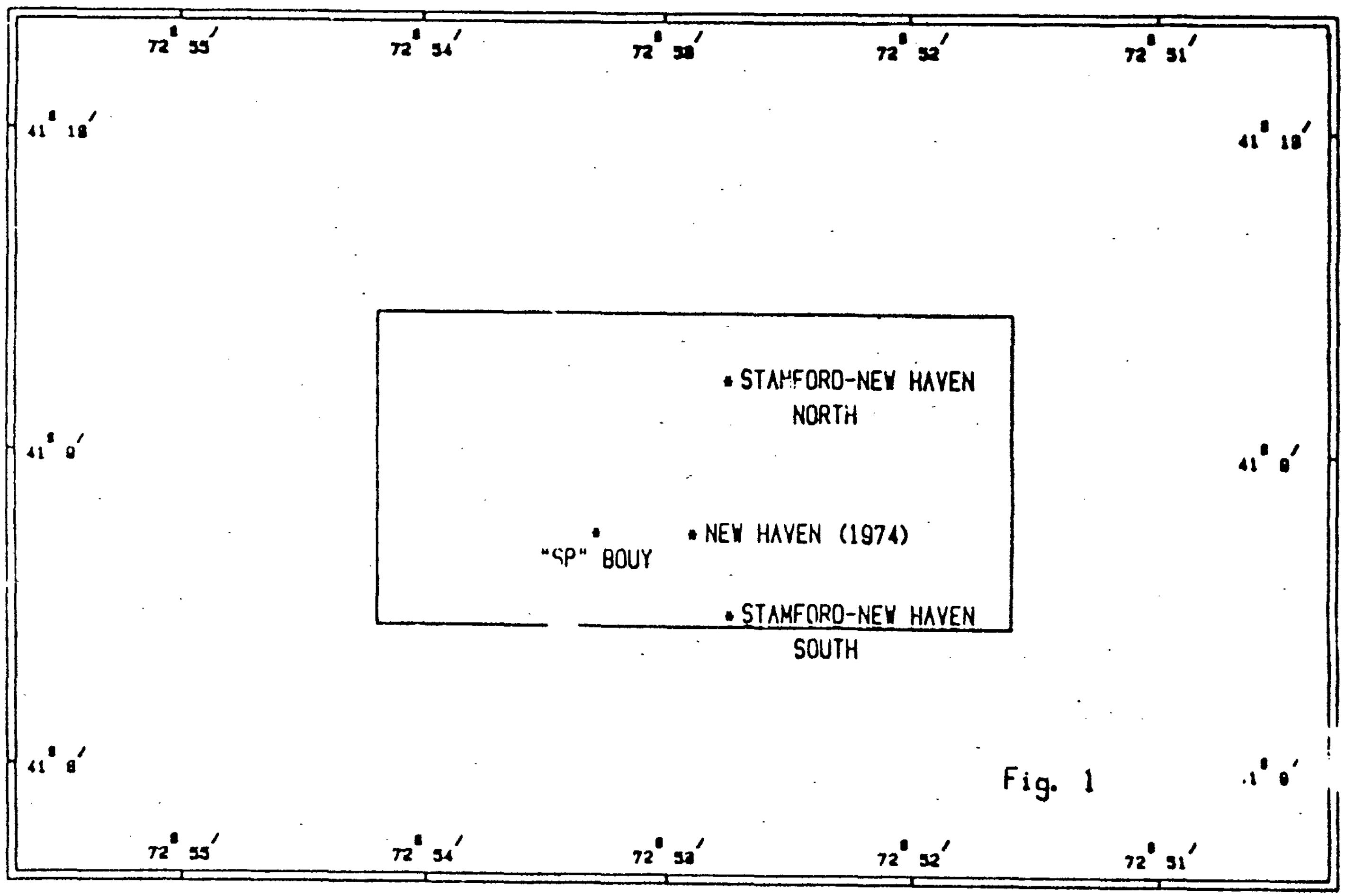


Fig. 1

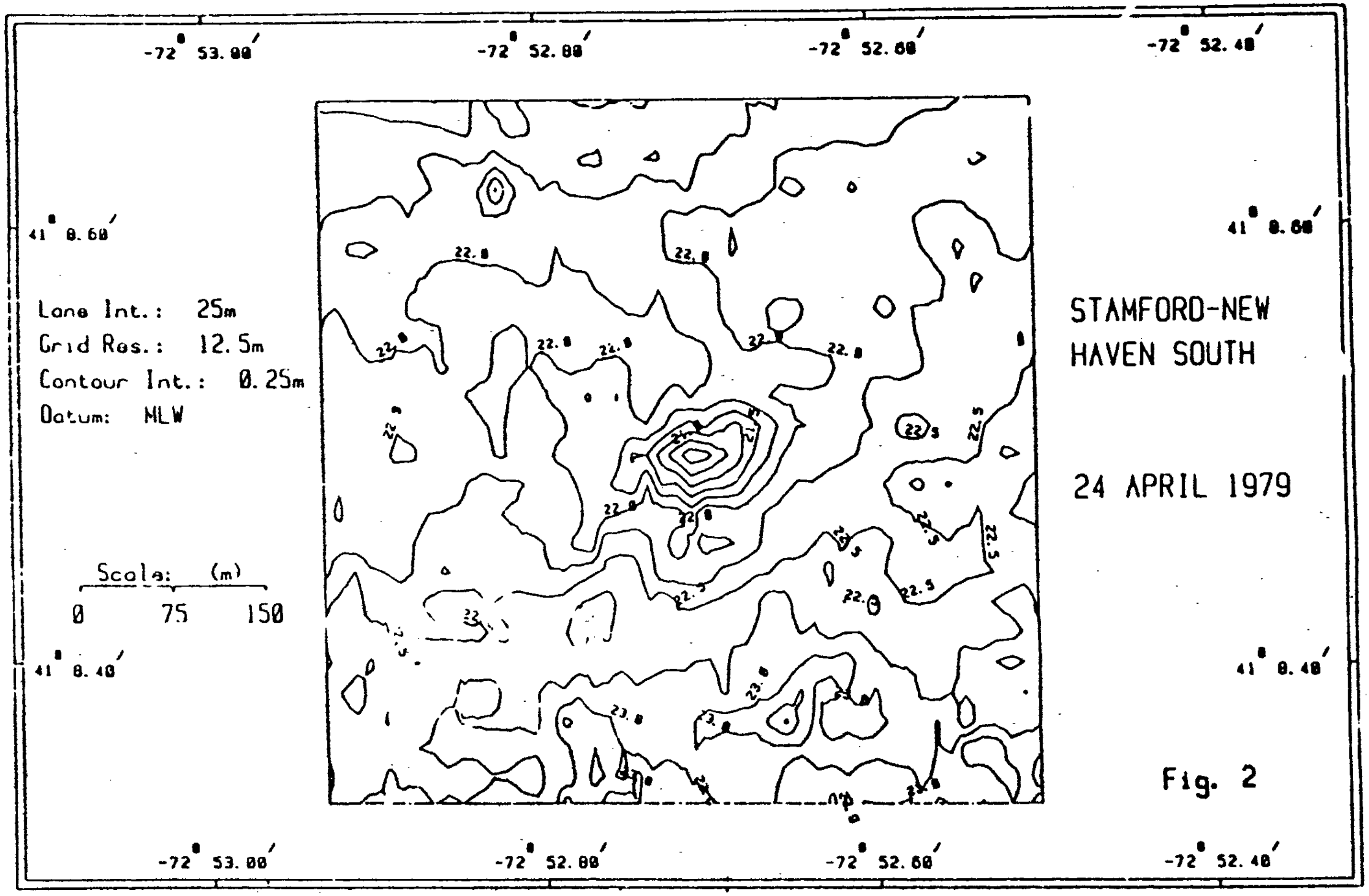
April 24, to determine the distribution of spoil material prior to capping (Figure 2). This survey indicated that the disposal procedure was successful in developing a small mound approximately 100m in diameter and 1.25m thick.

Close examination of the vertical profiles for lanes 13-16 (Figure 3) indicates that the topography of this mound was quite variable, and thicknesses of two meters relative to the initial bottom were present. The rough topography exhibited in the vertical profiles was substantiated by diving observations and attributed to the cohesive nature of the spoils. Toward the margins of the spoil mound, specific barge loads could be identified as separate topographic features.

Calculations of total Stamford spoil detected relative to the baseline survey accounted for approximately 90% of the estimated volume deposited. The contour difference chart (Figure 4) indicated that there was additional material present beyond the immediate spoil mound, and it was possible that significant amounts of spoil might not be detected by acoustic measurements.

This problem was addressed through a combination of visual diver observations and precision (50m spacing) remote sampling of the fringes of the mound with a Smith-McIntyre grab. During the period of disposal an extensive population of the stalk hydroid, Corymorpha, was growing over the entire bottom. However, when dredge spoil was present to any significant degree, these hydroids were covered or destroyed. Consequently, divers could identify the boundary of the spoils by the presence of absence of these animals. Furthermore, the dark, organic spoils provided a sharp contrast to the natural, brown oxidized muds of the disposal site thus the thickness of spoils on the margins of the mound could be directly measured in the grab sampler.

The most striking result of these measurements was the rapid decrease in spoil thickness at the margins of the spoil mound. In the east and west directions the change from thickness greater than 50 cm to less than 5 cm occurred between 100 and 150 meters from the disposal point; while in the north-south direction, the change was between 50 and 100 m. In either case, it was apparent



-72° 53.00'
-72° 52.80'
-72° 52.60'
-72° 52.40'
41° 8.60'
41° 8.40'
Lane Int.: 25m
Grid Res.: 12.5m
Contour Int.: 0.25m
Datum: MLW
Scale: (m)
0 75 150
STAMFORD-NEW
HAVEN SOUTH
24 APRIL 1979

Fig. 2

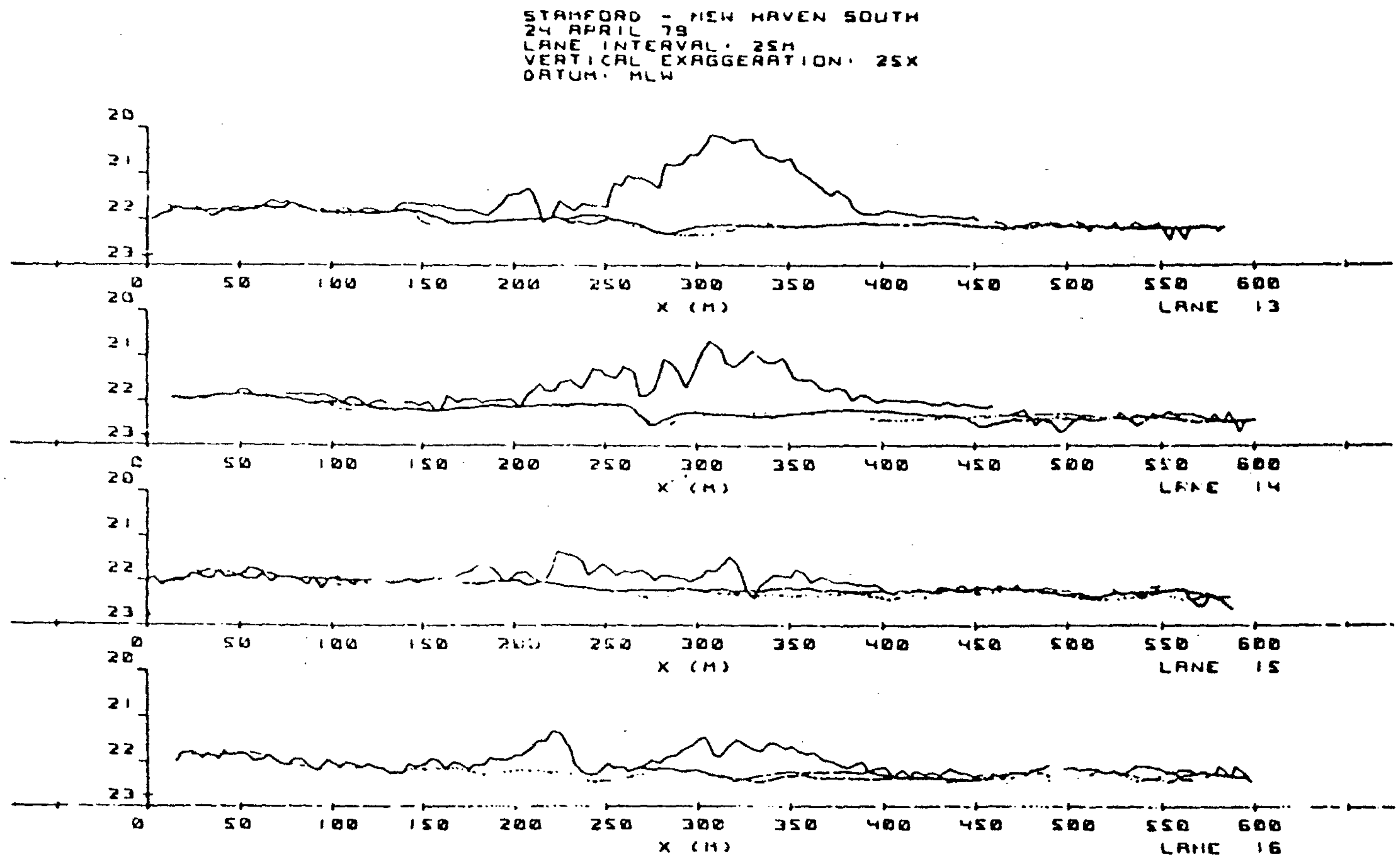

STAMFORD - NEW HAVEN SOUTH
24 APRIL 79
LANE INTERVAL: 25M
VERTICAL EXAGGERATION: 25X
DATUM: MLW
20
21
22
23
0
50
100
150
200
250
300
350
400
450
500
550
600
X (M)
LANE 13
LANE 14
LANE 15
LANE 16

Fig. 3

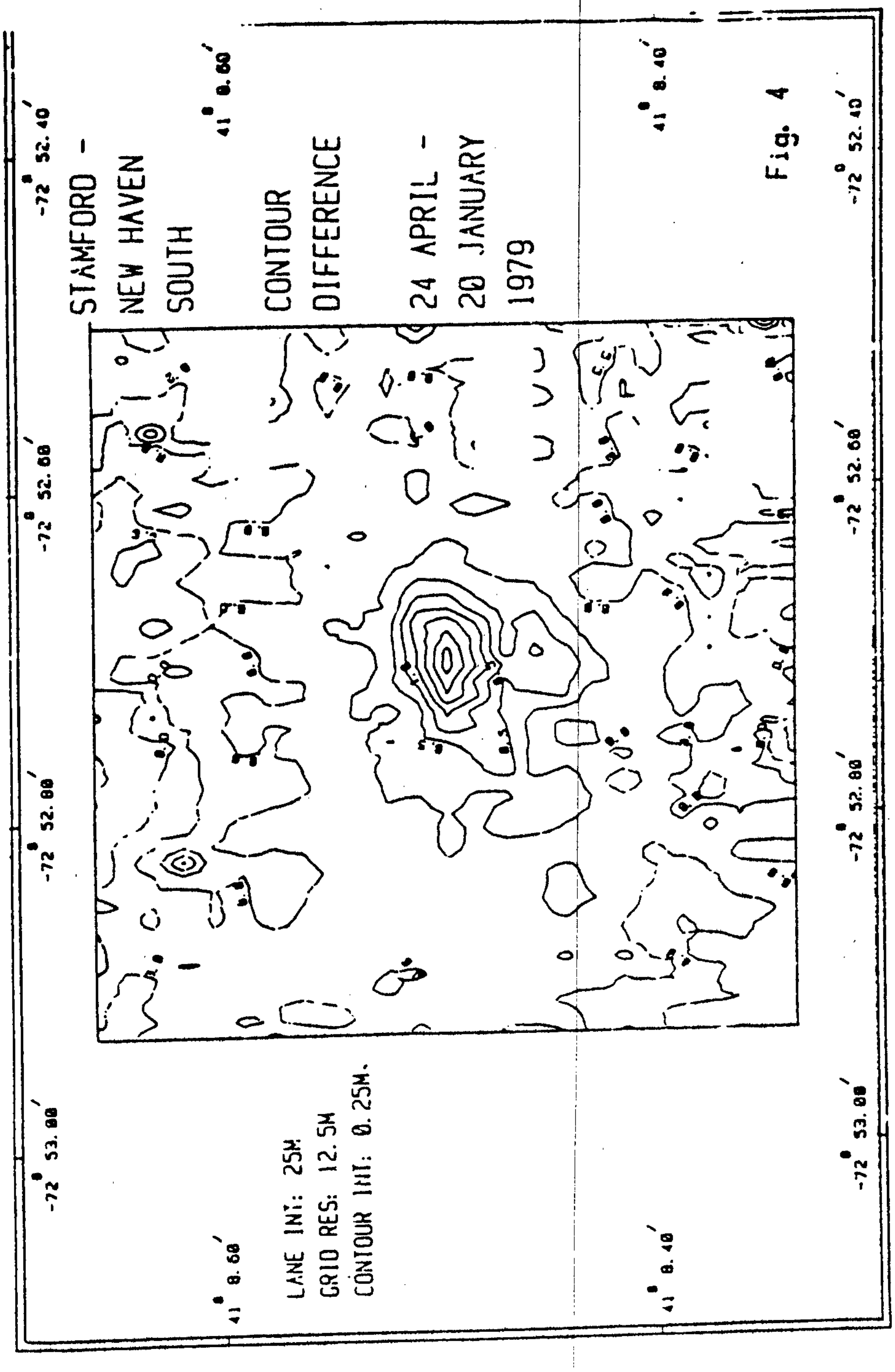

STAMFORD -
NEW HAVEN
SOUTH
CONTOUR
DIFFERENCE
24 APRIL -
20 JANUARY
1979
LANE INT: 25M
GRID RES: 12.5M
CONTOUR INT: 0.25M.
-72° 52.40′
-72° 52.60′
-72° 52.80′
-72° 53.00′
41° 8.60′
41° 8.40′

Fig. 4

that the cohesive nature of the spoil material was creating a definite mound with discernable boundaries that could be detected acoustically to a spatial accuracy certainly better than 50 meters.

From these data, it is apparent that for cohesive spoils dredged with a clamshell bucket and transported by scow, most of the sediment (> 80%) is transferred to the bottom as a cohesive unit and forms a mound, while the remaining material forms a turbidite type deposit radially from the disposal point since the coarseness of the particles in the fringe areas have been observed to be inversely proportional to distance from the disposal point. Furthermore, these data indicated that the initial disposal of Stamford material was tightly controlled by the taut-wire buoy and subsequent capping with New Haven material should be successful. Disposal of additonal Stamford spoil at the north site was also accomplished successfully and a monitoring survey conducted on 21 May (Figure 5) indicated the development of a small mound similar to that observed at the south site. Twenty-six thousand cubic meters of Stamford material were deposited at this location prior to capping.

As described earlier, silt from New Haven Harbor was dumped on the Stamford material at the south site and sand from the breakwater area was used to cap the northern site. All capping procedures were completed by June 22, 1979. One June 20, a survey was made of the southern site (Figure 6) to determine the success of the silt capping operation. The contour chart and the vertical profiles (Figure 7) both indicated a distinct mound had developed at the disposal site with a minimum depth of 16 meters and a thickness of up to 4 meters over the Stamford spoils. Because the silt material from New Haven was cohesive, the resulting spoil mound did not have extensive spreading. Although the vertical profiles indicate all Stamford material was capped, future operations with silt should be designed to spread the capping sediment and reduce the thickness to some extent. The volume of New Haven spoil dumped at the south site was estimated at 76,000 m^3 from scow load measurements, of which 72,000 m^3, or 95% was accounted for by volume calculations.

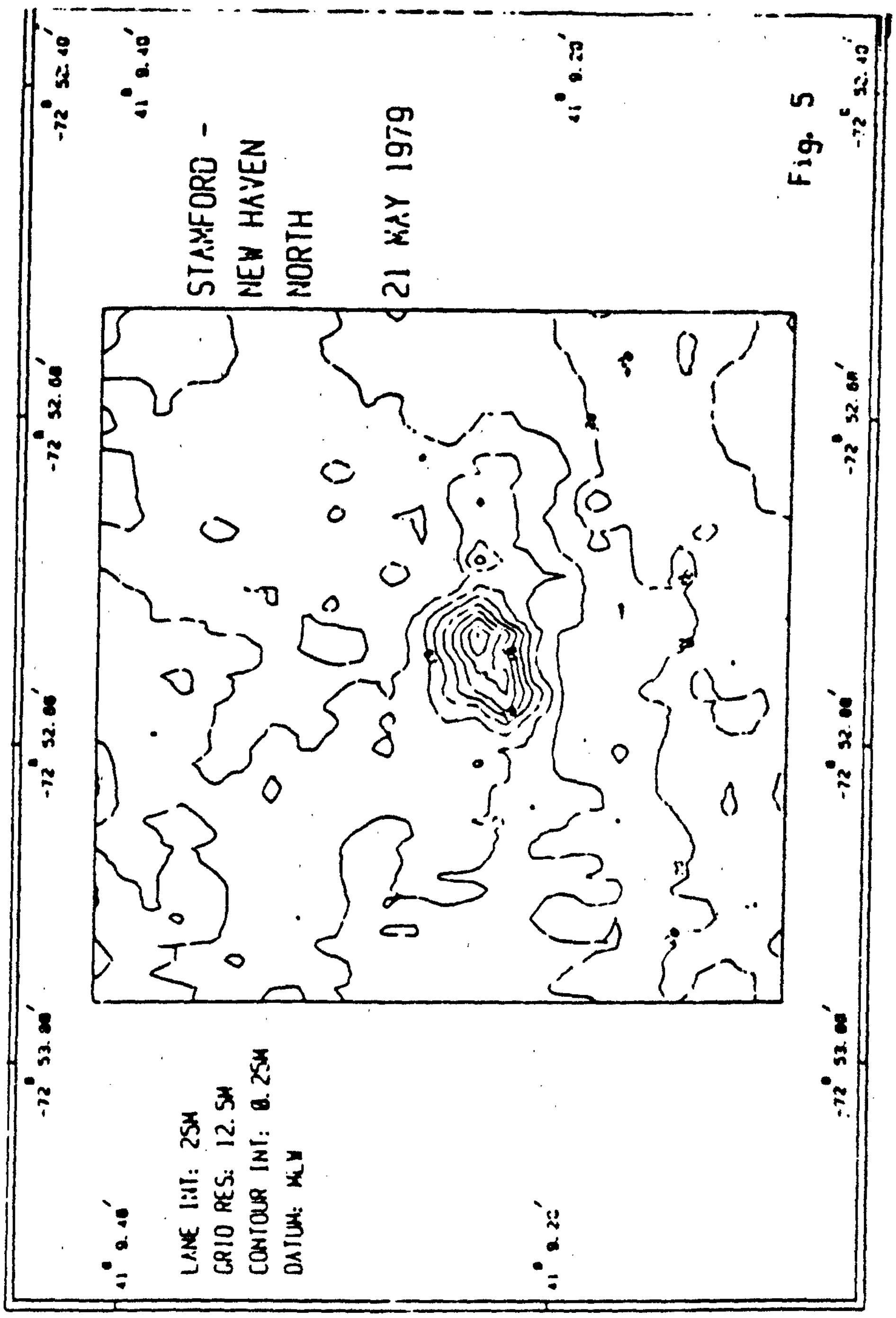

STAMFORD -
NEW HAVEN
NORTH
21 MAY 1979
LANE INT: 25M
GRID RES: 12.5M
CONTOUR INT: 0.25M
DATUM: MLW

Fig. 5

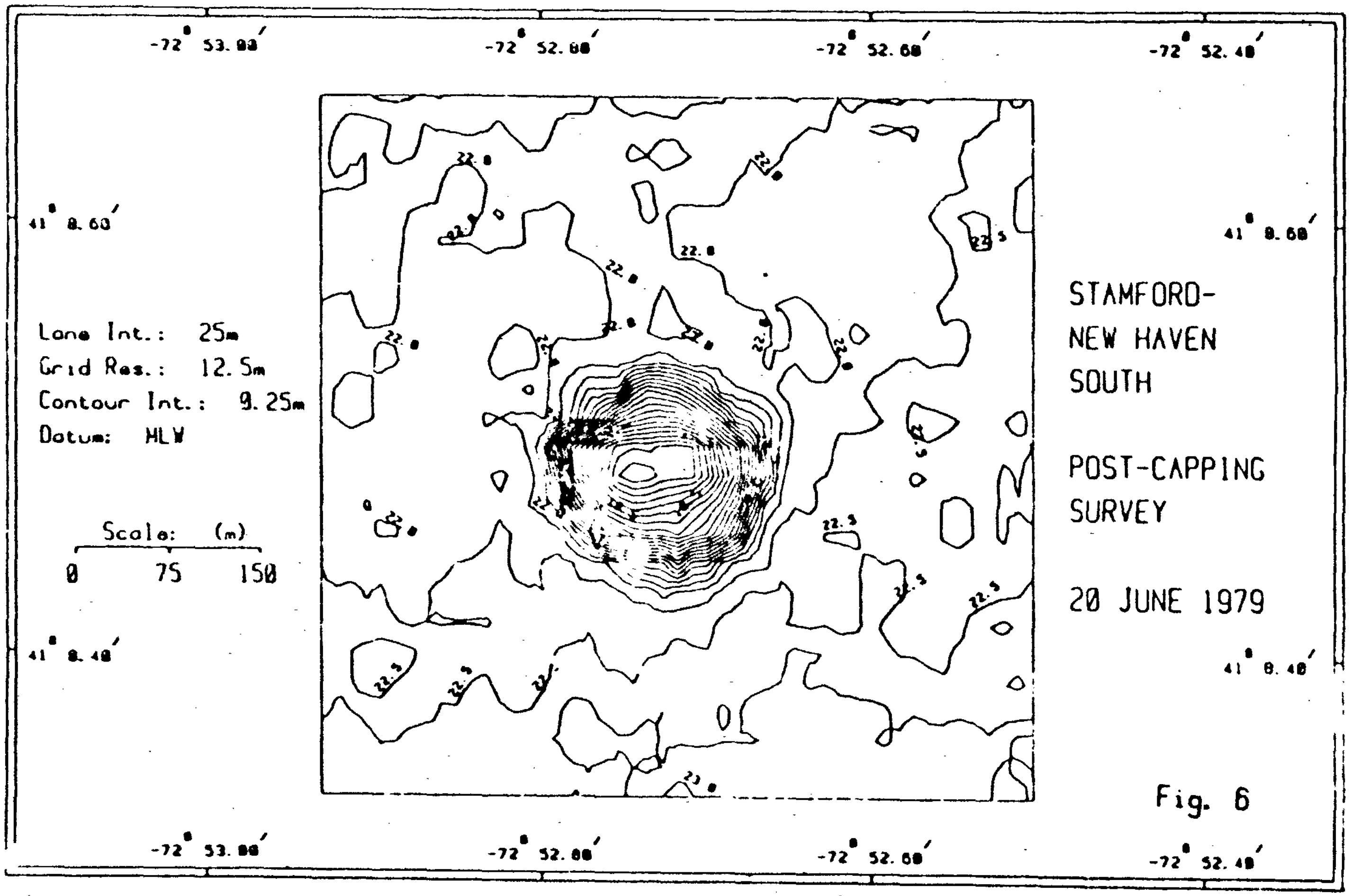

-72° 53.00'
-72° 52.80'
-72° 52.60'
-72° 52.40'
41° 8.60'
41° 8.40'
Lane Int.: 25m
Grid Res.: 12.5m
Contour Int.: 0.25m
Datum: MLW
Scale: (m)
0 75 150
STAMFORD-
NEW HAVEN
SOUTH
POST-CAPPING
SURVEY
20 JUNE 1979

Fig. 6

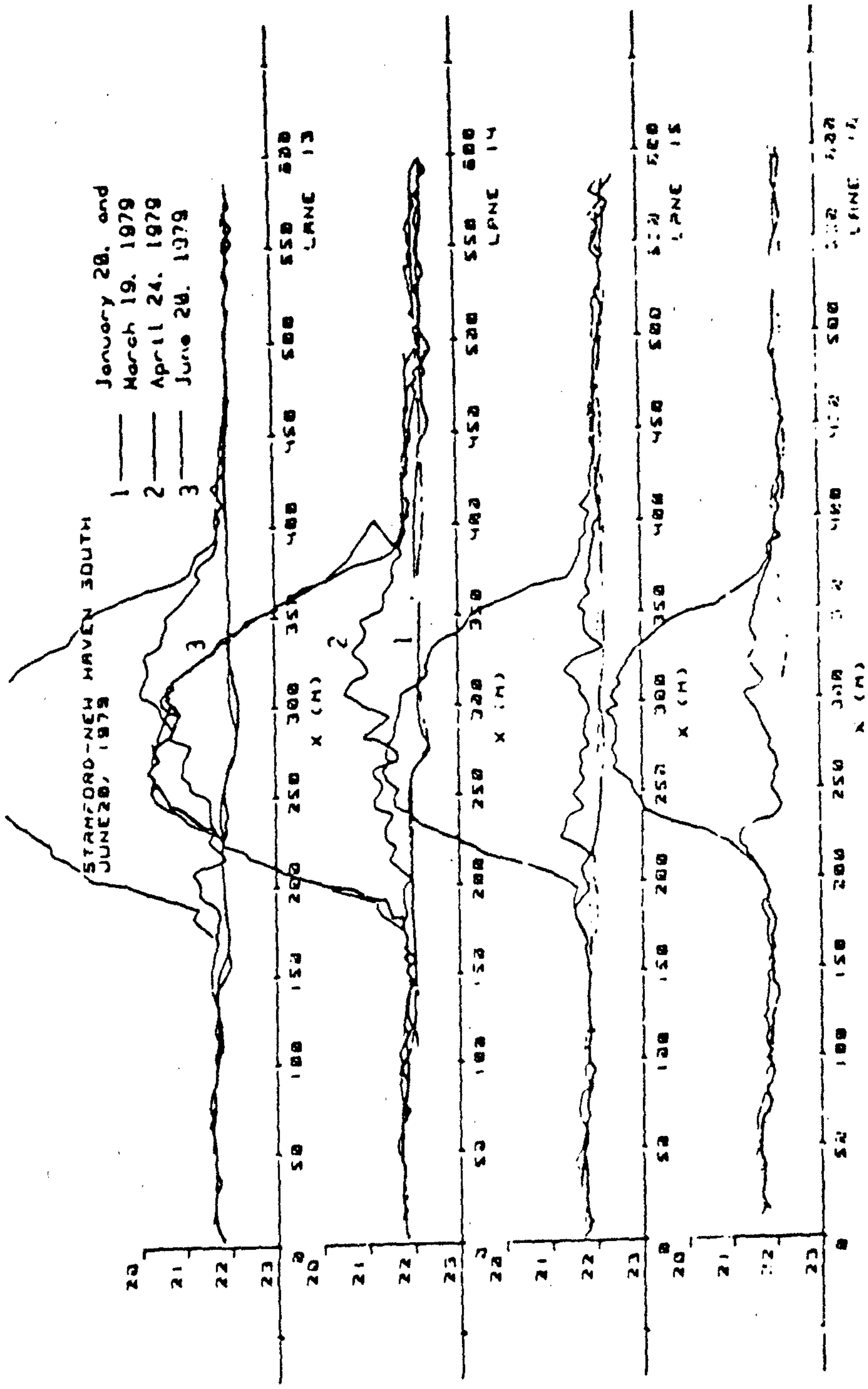

STAMFORD-NEW HAVEN SOUTH
JUNE28, 1979
1 —— January 28, and
2 —— March 19, 1979
3 —— April 24, 1979
June 28, 1979
X (M)
LANE 13
LANE 14
LANE 15

Fig. 7

Capping of Stamford spoils at the northern disposal site was accomplished in six days using the hopper dredge ESSAYONS to create a sand layer. Management of this operation was aided by a bathymetric survey on June 19, to determine any areas that were not covered by sand, and the dredge was directed to dump additional material east of the disposal buoy to insure complete coverage. A final survey was conducted on June 22, after completion of the capping operation (Figure 8). This survey and the associated vertical profiles (Figure 9) indicate that all Stamford spoils were capped by the sand material. However, since the sand was less cohesive, it tended to flow during deposition thus creating a broader, flatter mound than that developed by silt at the southern site.

At the time of the June 22 survey the capping layer had a maximum thickness of 3.5m over the Stamford spoil mound. This cap was a smooth blanket of sand that divers were unable to penetrate more than 10-15 cm by digging with their hands. A calculation of the volume of spoil and sand deposited since the May 21 survey indicated an increase of 33,000 m^3. This volume compared favorably with dredge volumes specified by the ESSAYONS, however, large correction factors based on density and water content of the sand, made comparisons tenuous and calculations of volume and percentage lost to the water column meaningless.

The results of these surveys indicated that the capping procedures employed during the Stamford/New Haven disposal operation were extremely successful. The precision disposal of Stamford spoils resulted in a small compact mound that was readily covered with New Haven material. Apparently, there is little difference in the ability of sand or silt to accomplish the desired capping. In the case of sand, the capping layer is not as thick, but the smooth, dense nature of the deposit acts as a tough, impervious blanket over the capped sediment. Silt deposits on the other hand, derive their capping ability from the cohesive nature of the sediment, developing a thicker deposit with rougher micro-topography.

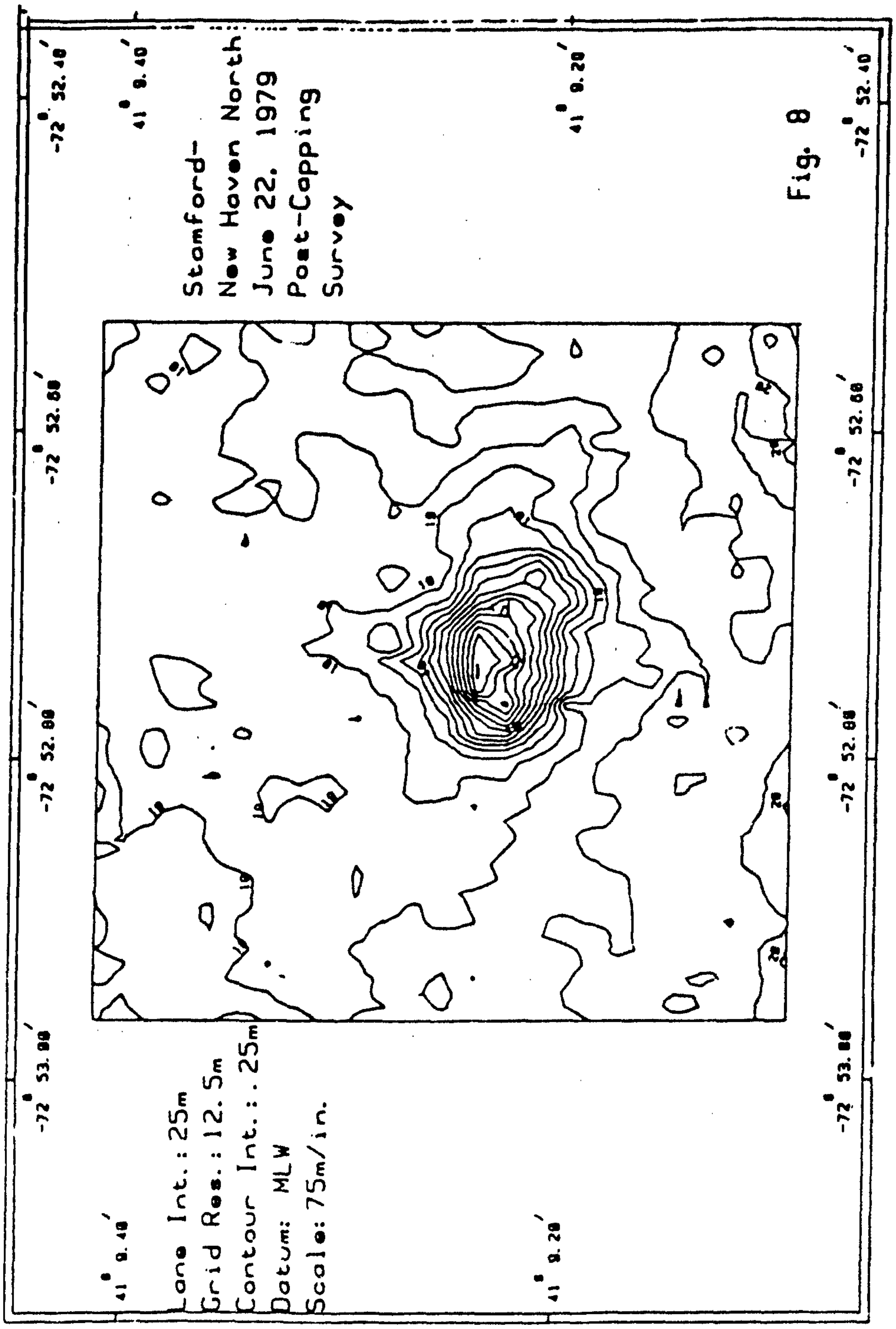

Stamford-
New Haven North
June 22, 1979
Post-Capping
Survey
Lane Int.: 25m
Grid Res.: 12.5m
Contour Int.: .25m
Datum: MLW
Scale: 75m/in.
-72° 52.40'
-72° 52.60'
-72° 52.80'
-72° 53.00'
41° 9.40'
41° 9.20'

Fig. 8

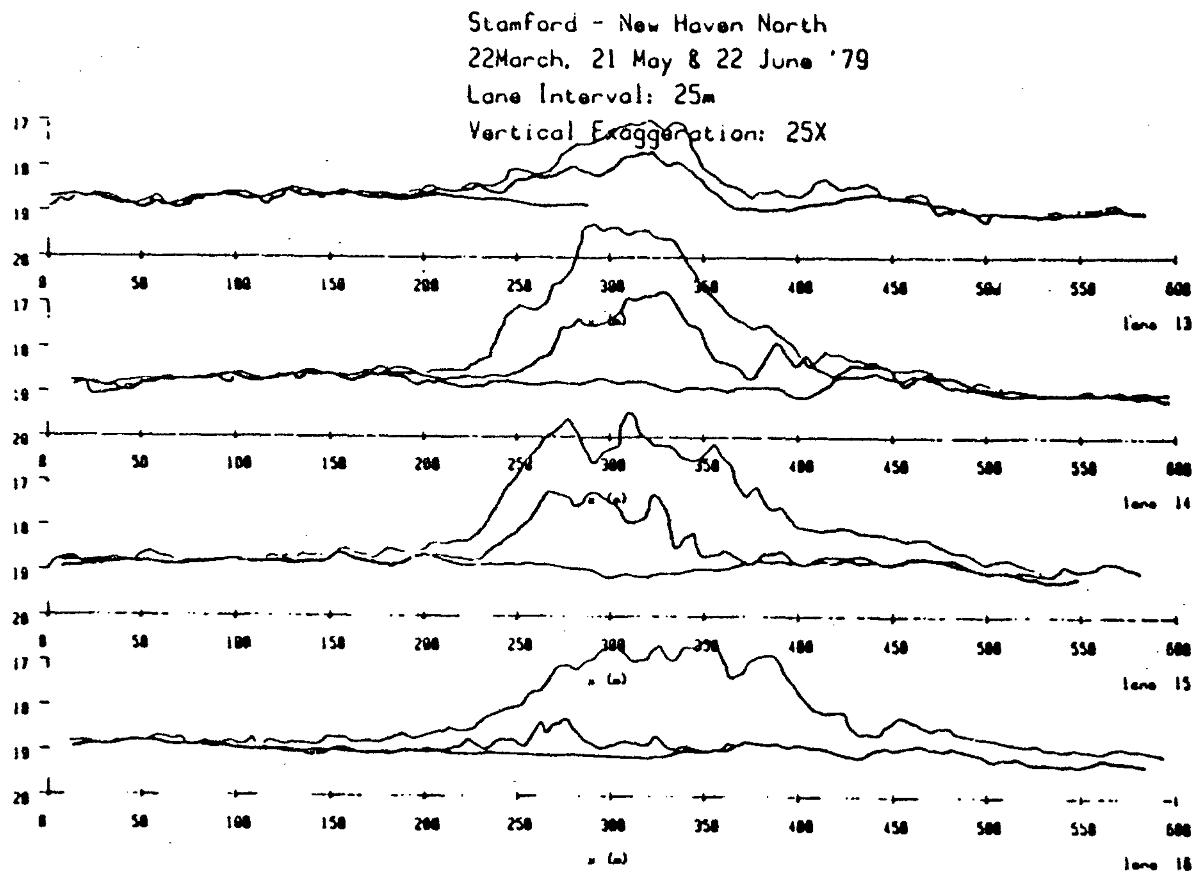

Stamford - New Haven North
22March, 21 May & 22 June '79
Lane Interval: 25m
Vertical Exaggeration: 25X
17
18
19
20
0
50
100
150
200
250
300
350
400
450
500
550
600
x (m)
lane 13
lane 14
lane 15
lane 16

Fig. 9

Several recommendations for future capping operations can be made based on the data obtained from this study.

- The spoils to be covered must be cohesive to reduce their spatial distribution. This would normally be the case since the forces that attract pollutants to the spoils also cause cohesion. However, dredging procedures should be conducted in a manner to preserve this cohesiveness.
- Point dumping of the material to be covered should be done as accurately as possible, preferably with a taut wire moored buoy as a disposal marker.
- Disposal of the capping material should be accomplished as soon as possible also using the buoy as a marker.
- After disposal of approximately 2/3 of the capping material at the disposal point, the remainder should be dumped in a circle with a radius equal to that of the initial spoil mound to insure capping of the flanks.
- Monitoring of the capping operation with bathymetric techniques should be done during disposal to allow for modifications in disposal operations required to insure coverage.

Prior to the disposal operation, chemical and biological samples were obtained from the proposed disposal site to provide baseline data for future monitoring. Bulk analyses of sediments from each harbor and the disposal site were made and used to develop statistical criteria for identifying sediment from each location. Using these criteria, it was then possible to confirm that the capping material was in fact New Haven spoil and that Stamford material was not displaced toward the surface of the mound during the capping operation.

Baseline benthic population parameters and infaunal body burden measurements were also made prior to disposal, however, post disposal data have not yet been analyzed.

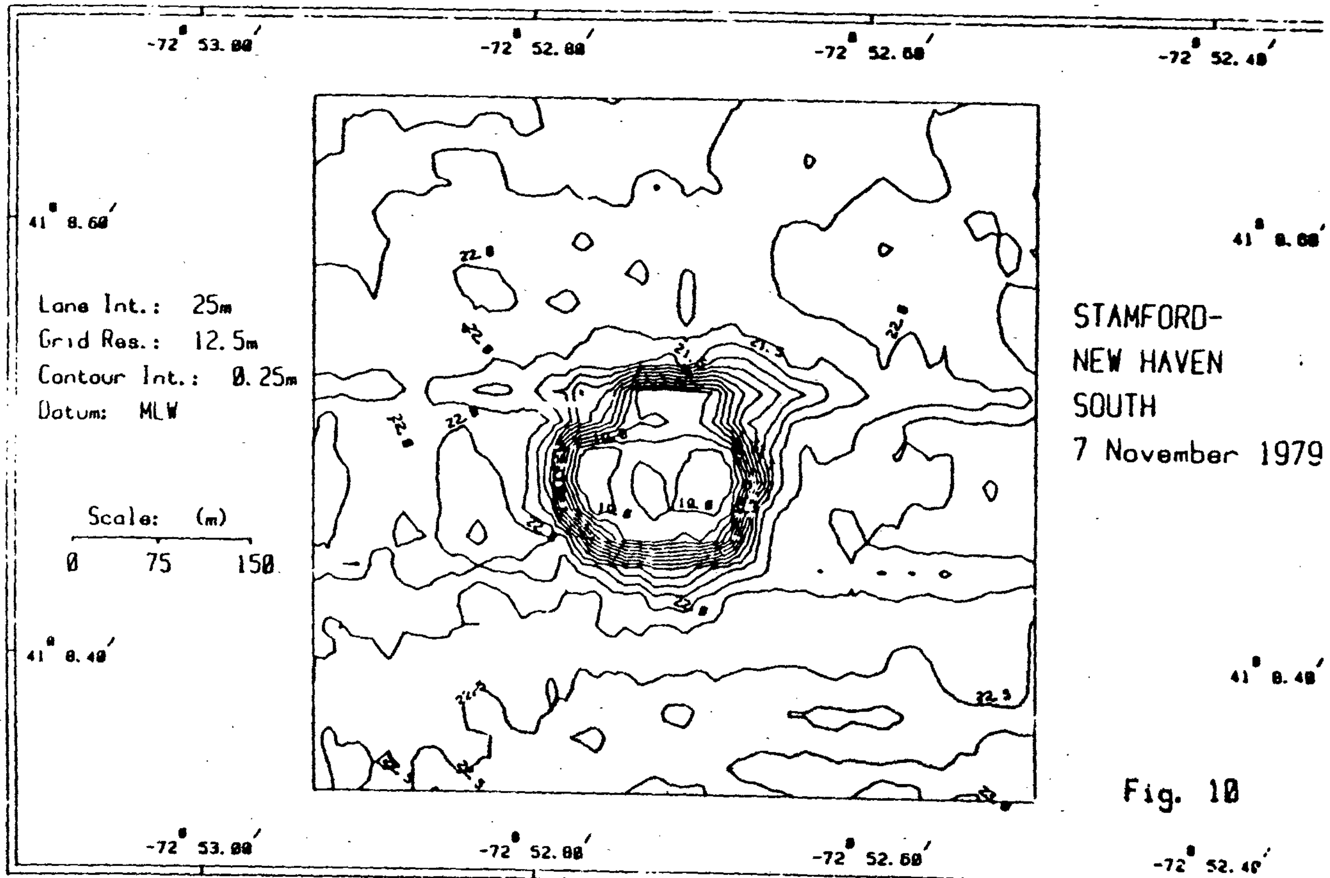
Although the operational techniques for capping Stamford material with silt and sand from New Haven Harbor were successful, the effectiveness of the procedure depends on the stability of the resulting cap and its ability to isolate the enriched spoils from the biota and the water column. Consequently, following deposition of the spoils the thrust of the monitoring effort changed to evaluation of the stability of the resulting mounds with time. Again, this was a multidisciplined effort involving physical, chemical and biological measurements.

On 7 August 1979, a bathymetric survey of the North disposal site was conducted that indicated there were no major changes in the topography of the spoil mound. Although the specific topographic features between surveys were consistant, the mound had settled or compressed slightly increasing the mean depth by approximately 20 cm. Calculation of volume differences between the June and August surveys indicated that the volume loss due to this compression was 1700 m^3.

A survey of the southern site was also run on August 7, 1979 which likewise indicated no major differences in the spoil mound. All transects across the mound had a slight increase of 20-40 cm that was similar to the settling or consolidation observed on the north mound. Calculation of the spoil volume difference indicated the total volume change for the entire survey was a decrease of 900 m^3 or approximately half the change on the north site. There was some indication of slumping on the north margin of the spoil mound where a broad decrease in depth of 20-40 cm occurred.

In summary, the results of the August surveys indicated no significant changes in the spoil mounds or the capping material could be detected. Slight settling or consolidation of both spoil mounds did occur, however, these results were expected since the spoil mound from the 1974 dredging operation has been stable for several years indicating the containment potential of the disposal site.

A second post-disposal survey was conducted on the southern site on November 7, 1979 (Figure 10). The results of that survey showed a major change in the topography of the spoil mound resulting from the loss of approximately 10,000 m^3 of spoil from the top of the mound. Vertical profiles across the center of the mound (Figure 11) revealed a flat surface at 19 meters which was also readily apparent on the contour chart.



-72° 53.00'
-72° 52.80'
-72° 52.60'
-72° 52.40'
41° 8.60'
41° 8.40'
Lane Int.: 25m
Grid Res.: 12.5m
Contour Int.: 0.25m
Datum: MLW
Scale: (m)
0 75 150
STAMFORD-
NEW HAVEN
SOUTH
7 November 1979

Fig. 10

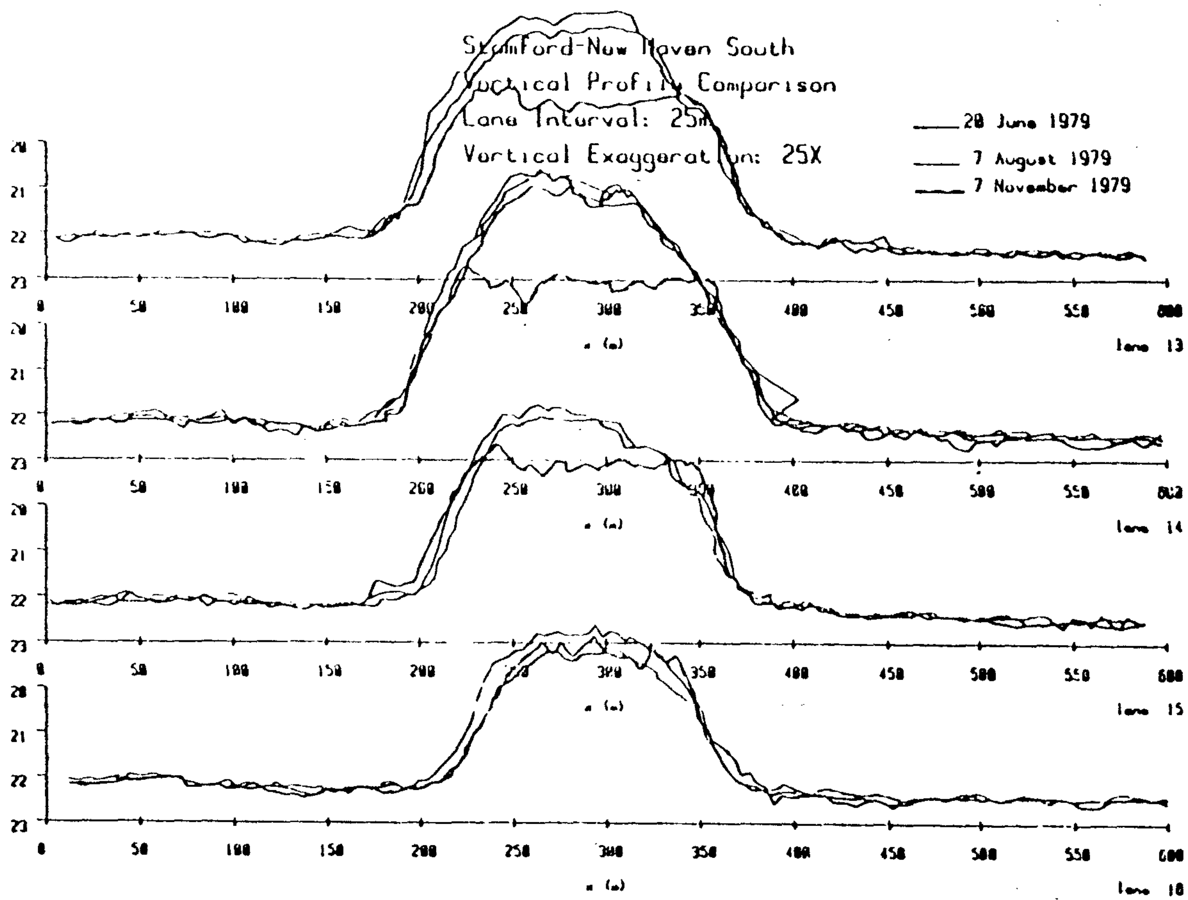

Stamford-New Haven South
Vertical Profile Comparison
Lane Interval: 25m
Vertical Exaggeration: 25X
20 June 1979
7 August 1979
7 November 1979
x (m)
lane 13
lane 14
lane 15
lane 16

Fig. 11

Although this loss of material did not expose any Stamford spoil, further investigations were initiated to determine the causes of spoil movement and to evaluate conditions at the other sites.

The flat topography of the spoil surface at a constant depth suggested that wave action was most likely responsible for the movement of material and the passage of Hurricane David through the area on September 6 provided an energy source to create the wave motion required. Consequently, additional work was conducted to survey the other disposal sites and to determine the potential stress exerted on the spoil mounds as a result of the hurricane. Surveys were made of the north disposal site and the 1974 New Haven spoil mound on November 15, 1979. Both of these surveys were conducted using the same precision techniques, and both surveys indicated that no significant changes had occurred in either mound during the period in which the southern site was affected.

It is important to note that both the Stamford/New Haven North and the 1974 New Haven deposit have minimum depths that are less than the southern site, and thus should be more susceptible to wave motion. Since these three mounds are all within a mile of each other, on a comparatively flat bottom, it is highly unlikely that one site would experience markedly different environmental stress exerted by currents or wave action than would be expected at the other sites. Therefore, an explanation for the loss of material from the southern mound must account for the lack of movement at shallower depths through differences between the physical and lithological properties of the spoil mounds.

The Stamford/New Haven North and the 1974 New Haven spoil mounds can be distinguished from the southern site on the basis of a surface of fine sand material which is probably thicker on the newer spoil mound. This lithology is in sharp contrast to the cohesive silt surface of the southern mound which is characterized by clumps of cohesive clay interspersed within a fine silty matrix.

Movement of spoil material at the south mound could have been caused by stress induced by tidal currents, wave motion or a combination of both forces. There are several reasons to suggest

In summary, the effectiveness of capping enriched spoils with cleaner material looks promising, but requires additional monitoring to evaluate long term stability and recolonization effects. The fact that both the sand and silt caps were effective in containing the contaminated spoils during the passage of a 10 year frequency storm such as Hurricane David is a strong indication of the potential of this procedure.

An explanation for the selective movement of silt material on the south site has been proposed based on the interaction of storm waves resulting from Hurricane David and the roughness parameters of the cohesive New Haven spoils. The implications of these conclusions are important to future disposal and/or capping operations. Consolidated, cohesive spoils are common in the New England area, and clamshell dredges which preserve the cohesive nature of the spoils must be used to reduce suspended load and spreading of spoils at both the dredging and disposal sites. Consequently, while these properties aid in reducing the area of coverage, most spoil mounds will have surface roughness comparable to the New Haven south site after disposal. These features have been observed at the New London site, but the cohesive clumps have broken down over a period of time primarily due to biological activity, but also as a result of fracturing and erosion (Stewart, 1979 personal communication).

From the results of this study, it is apparent that the stress created by the roughness factor associated with these clumps under storm wave conditions is more important than the depth of the spoil surface, the strength of currents or the cohesive nature of the sediment in determining the stability of spoils. The occurrence of a major storm such as Hurricane David, before the surface of the spoil mound has been smoothed by natural forces thus creates a potential for large scale erosion and transport of material.

Future capping operations with silt, might therefore, consider methods to produce a smooth spoil surface at the conslusion of the dumping procedure. Additional work is needed to determine if these smoothing procedures are in fact necessary and to more accurately evaluate and predict the recurrence of the effects observed at the New Haven south site. The problem of spoil stability is being addressed to some extent under the DAMOS program through a combination of bottom turbulence and spoil erosion studies, however, the phenomena observed at the Central Long Island Sound Site emphasize the importance of monitoring disposal areas and of understanding the interaction of the energy regime with spoil material.

OTHER CAPPING PROCEDURES

In addition to the capping operations recently completed in Central Long Island Sound, several proposals for capping of contaminated spoils are presently being corsidered or are currently underway. The dredging of Norwalk Harbor, Connecticut includes two specific capping procedures in the operation plan. Approximately, 1500 m^3 of sediment contaminated by a chemical spill of napthaleen and nitrobenzine will be placed in a pit dredged from the adjacent channel area and covered with cleaner material from other sections of the channel. This procedure, which will be closely monitored by EPA Region 1 representatives, should isolate the contaminated spoils without requiring transport of the material thereby reducing the exposure time of the material to the atmosphere and the chances of an accidental dump or spill.

Approximately 20,000 m^3 of Norwalk material which is considered Class III material under Connecticut's spoil classification program will be transported to the Central Long Island Sound disposal site, deposited at a new taut-wire buoy position and capped in a manner similar to that described earlier with additional clean dredge material from Norwalk Harbor.

Current disposal of PCB enriched material from the New York - New Jersey area which is taking place at the taut-wire buoy placed in the Mud Dump is slated for capping with cleaner material in the near future. Management and monitoring of this operation is under control of the New York District of the Corps of Engineers. Although this operation has many aspects in common with the capping procedure that took place in Long Island Sound, there are several differences that should be considered in developing this management and monitoring program:

- The volume of material to be covered is significantly larger, therefore, correspondingly larger volumes of suitable capping material must be identified and dredged.
- The disposal site is deeper, which combined with the larger volumes of material will expand the areal extent of the spoils to be capped. Therefore, some mechanism must be provided to monitor and control the capping operation to insure coverage.
- The disposal site is exposed to more severe wave action than the Long Island Sound Site and therefore, the spoil mound should be only as high as necessary to provide an adequate cap and should be as smooth as possible to reduce the stress exerted by wave action.

All of these considerations can be readily accomodated through implementation of a reasonable management plan centered around precision navigation control of the capping operation. Furthermore, a monitoring effort oriented toward evaluating the stability and containment characteristics of the deposit, and biological parameters beyond the margins of the mound should insure that overall environmental impacts are minimal.

Another approach to capping and containment of contaminated spoils has been proposed by Dr. Henry Bokuniewicz and others from the State University of New York at Stony Brook. This procedure would utilize existing submarine burrow pits resulting from sand mining in outer New York harbor as containment sites for contaminated sediments followed by isolation of the spoils through capping with sand of similar lithology to the surrounding area.

Several favorable aspects to the use of these burrow pits as defined by Dr. Bokuniewicz include:

- Many of these pits have demonstrated an ability to trap fine sediment, and therefore, should exhibit characteristics of containment sites.

- Filling of the pits and capping of the spoils would remove potential zones of anoxic conditions and would reduce the effect these deep holes might have on wave energy refraction.
- Filling of pits would most likely permit additional mining to be accomplished without drastically altering the ambient conditions in Lower New York Harbor.
- The location of the pits near the area to be dredged makes them economically attractive.

However, before such a procedure can be made operational several environmental parameters must be assessed; most important of these is the stability of the contaminated sediment deposit in the burrow pit prior to and after disposal of the capping material. This concern is warranted due to the shallow ambient bottom (approximately 4.5m) in the area and the average depth of the pit which is generally less than 15 meters. Therefore, any deposits in these pits would have surface depths on the order of 10 meters and be susceptible to extensive wave action. Data on existing sediment lithology indicate, however, that silty deposits do exist in these pits at depths of 9 meters, thus suggesting containment is possible. Obviously, contaminated spoils should be capped as soon as possible to reduce the potential for dispersion.

Once deposited, the sand cap should not be subject to erosion, since comparisions of bathymetric surveys over a period of years have shown only minor changes in the overall topography of the area. There will, however, always be an inherently unstable condition when dense sand is placed over less dense mud, and it is possible that deformation and sinking of the sand cap might occur. The conditions causing this deformation and the rate at which it might occur have not yet been fully evaluated.

COSTS ASSOCIATED WITH CAPPING

The additional expenses required to conduct a capping operation are directly related to the availability of suitable capping material. The operating costs associated with installation of taut-wire buoys or use of precision navigation systems to control the dumping operations are quite small in terms of the overall project costs. Therefore, if suitable capping material is available in an area that must be dredged as part of the project being considered or associated with other projects, then proper management of the dredging and disposal operation can produce a capped deposit at very little expense.

However, if additional dredging must be done to provide capping material the costs will increase substantially. On the Stamford/New Haven operation, approximately 30,000 m^3 of contaminated material were capped with sand, using the hopper dredge ESSAYONS for approximately $140,000. Since it was necessary to dredge this sand to open the outer channel of New Haven harbor these cost did not constitute an addition to the program. However, they do indicate the expenses involved for additional dredging. It should be remembered that it may be necessary for the volume of the cap to be substantially greater than that of the contaminated material, and therefore, costs for dredging this cap could be more than the initial operation.

SUMMARY

Under certain conditions, the use of uncontaminated dredge material to cap contaminated sediment appears to be an operationally feasible, cost-effective and environmentally sound method for disposal in the marine environment. Although additional management and operational controls are required to conduct these procedures, they are neither expensive nor complicated and are certainly within the capabilities of todays dredging and disposal technology.

The operational feasibility of the technique has been demonstrated at the Central Long Island Sound site, and its application to deeper waters on the shelf is currently being accomplished through the procedures at the Mud Dump Site in New York Bight. Although initial indications concerning the environmental considerations of capping are favorable, continued monitoring must be conducted to insure long term effects such as sand/silt instabilities, bioturbation, storm effects, etc. do not reduce the effectiveness of the cap in isolating contaminants from the environment.

AD P002399

STUDIES ON CAPPING OF CONTAMINATED DREDGED MATERIAL BY THE NEW YORK DISTRICT, CORPS OF ENGINEERS

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ABSTRACT

The sediments in New York Harbor are contaminated with a wide variety of chemical constituents. Results of testing conducted in accordance with the EPA Ocean Dumping Criteria by several permit applicants in 1979 indicated a bioaccumulation potential for PCB in the marine worm being tested. Approximately 650,000 cubic meters of material dredged from the projects were precision dumped at a taut-moored buoy located in about 27 meters of water in the Atlantic Ocean. The deposit was then capped with approximately 1.4 million cubic meters of uncontaminated dredged material in an attempt to isolate the contaminated sediments from the marine ecosystem. Studies were initiated to determine the stability of the capped mound and the biological effectiveness of the cap. An additional study was initiated to determine a unique chemical signature for the disposal sediments such that the burial location of the contaminated sediments could be identified and subsequently monitored if necessary. The studies are all presently ongoing with final results due in early 1982.

INTRODUCTION

Approximately 8 million cubic meters of sediment must be removed from New York Harbor each year in order to maintain safe navigation within the Port. Historically, most of the dredged harbor sediments have been deposited at an offshore site in the Atlantic Ocean known as the "Mud Dump." Currently, this disposal option is the only one available for the disposal of large volumes of dredged material from the Harbor.

Because of the large volume of waste discharged into New York Harbor, the sediments are repositories for a wide variety of contaminants. Sediments proposed for ocean dumping must satisfy the requirements of the EPA Ocean Dumping Criteria. When sediments are suspected of possible contamination, they must be subjected to rigorous chemical and biological testing. Suszkowski and Mansky (1) have described the testing protocol and have summarized the results of bioassay and bioaccumulation testing conducted for the New York District.

In 1979, routine bioaccumulation testing was implemented by the New York District. Applicants for Dept. of the Army permits to ocean dump dredged material were required to submit the results of bioassay and bioaccumulation testing. Six applicants in 1979 submitted test results that showed no significant toxicity, but did show a bioaccumulation potential for PCB. The potential for PCB bioaccumulation was evident in only one of the three test organisms, Nereis sp. (a marine worm). PCB concentrations in the control animals for each of the tests were undetectable at a detection limit of 0.025 ppm. PCB concentrations in the test animals ranged between 0.17 and 0.34 ppm for the six dredging projects.

The test results prompted considerable scientific debate over the significance of the levels of bioaccumulation shown. The debate caused serious delays in the permiting process. One of the permit applications involved the dredging of the Passenger Ship Terminal in New York City. The delays were threatening the admittance of the Queen Elizabeth II into her berth in the Harbor. This situation attracted considerable press and radio coverage along with intense political interest.

CAPPING LOGISTICS

Since an ocean dumping alternative was the only available disposal option for the dredged material in question, the Federal agencies involved in the scientific review of the bioaccumulation data during the regulatory review process came to a concensus that an attempt should be made to isolate the material from the marine ecosystem. This was to be accomplished by capping the contaminated deposit with appropriate uncontaminated sediments. The capping exercise was based upon two premises: (1) that the capped mound would be physically stable, and (2) that the cap would be biologically effective in sealing off the contaminated material from the overlying marine ecosystem.

The New York District of the Corps of Engineers accepted the responsibility for planning the logistics of the capping operation and developing monitoring studies. The first step in the logistical planning was to establish an appropriate disposal location. Currently, all ocean dumped dredged material from New York Harbor is deposited at the "Mud Dump" located in the Atlantic Ocean about 11 kilometers east of New Jersey. Figure 1 shows the dimensions of the Mud Dump, which is a rectangular-shaped area having borders of approximately 1.9 and 3.7 kilometers in length. Since

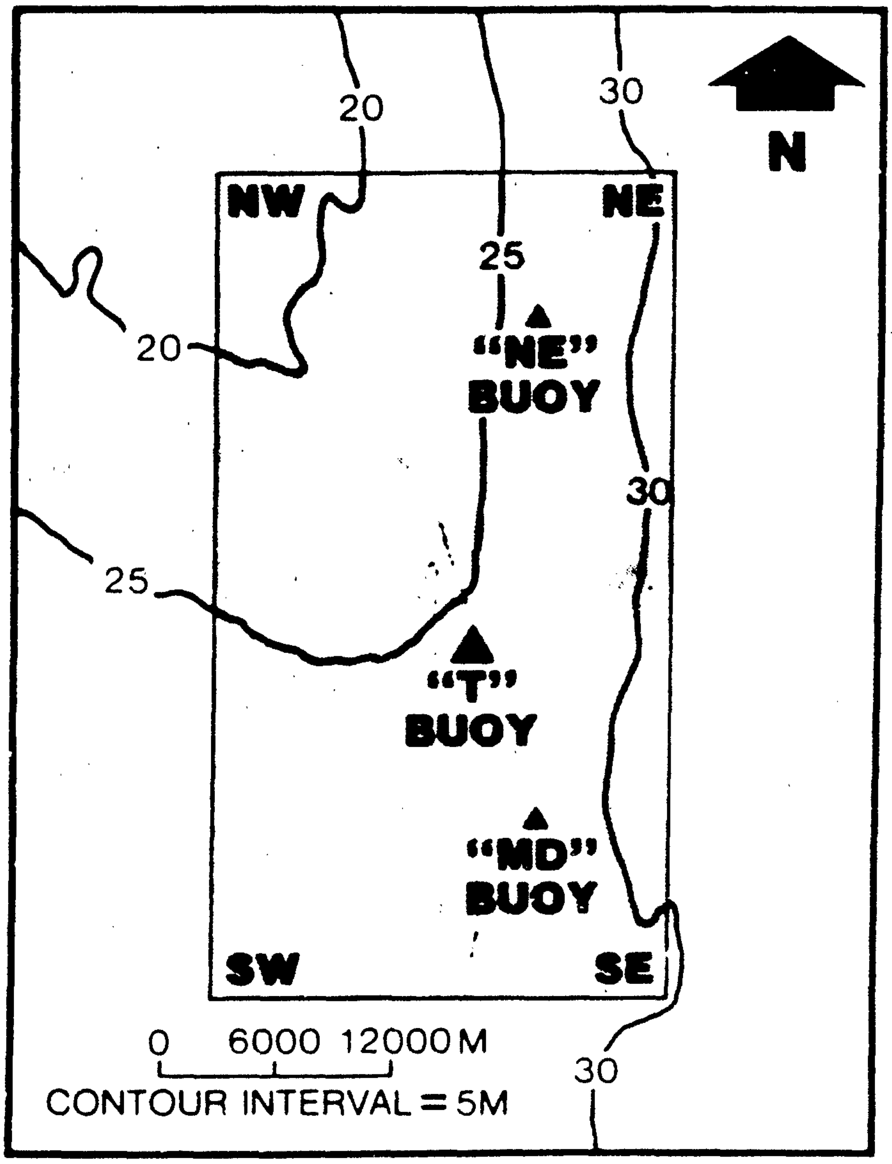

Figure 1. Boundaries of the Mud Dump and buoy locations

TABLE 1. QUANTITIES OF DREDGED MATERIAL REQUIRING CAPPING

Project		Quantity (Cubic Meters)
(1)	Seatrain	70,000
(2)	Port Auth. of N.Y. & N.J. Port Newark and Port Elizabeth	89,000
(3)	Port Auth. of N.Y. & N.J. Passenger Ship Terminal	229,000
(4)	U.S. Gypsum Co.	154,000
(5)	Jackson Engineering Co.	106,000
(6)	Monsanto Corp.	6,000
(7)	Westchester County DPW	3,000
	TOTAL	657,000

TABLE 2. QUANTITIES OF DREDGED MATERIAL USED AS CAP

Project	Quantity (Cubic Meters)
Bronx River	127,000
Westchester Creek	97,000
Ambrose Channel	1,173,000
TOTAL	1,397,000

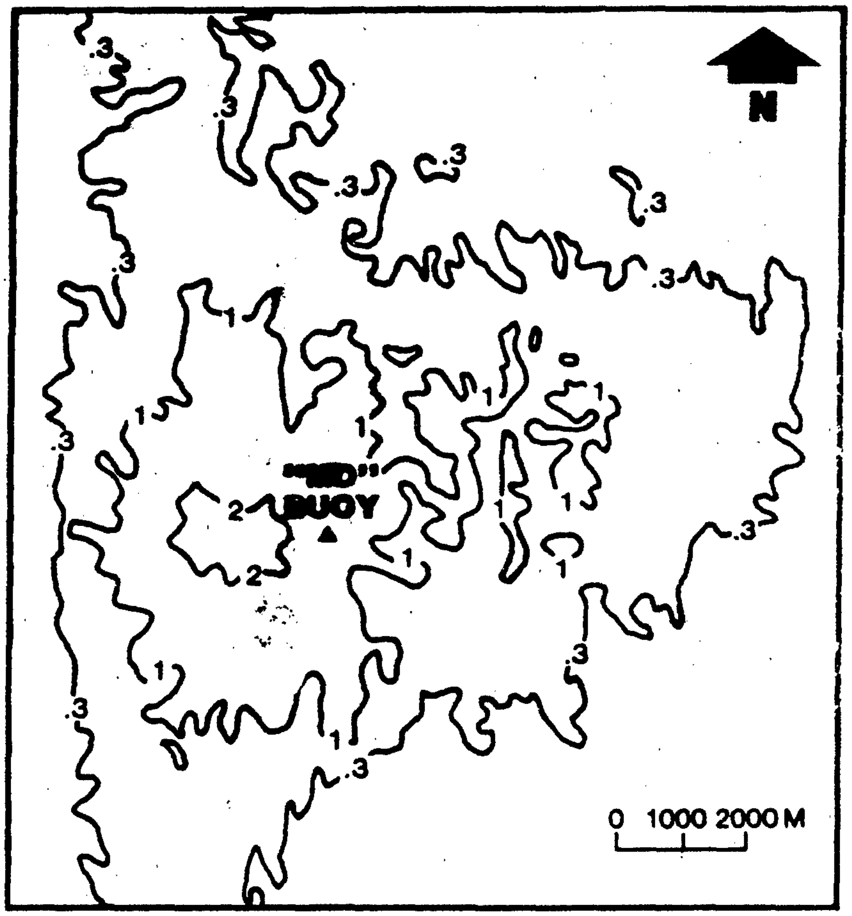

Figure 2. Accumulation of contaminated dredged material prior to capping as derived from bathymetric surveys of March and July 1980 (contour interval in meters)

1914, the majority of sediments dumped in the ocean were deposited in the northwest quadrant of the dumpsite. A location within the dumpsite was selected for the capping operation that avoided routine dumping activities and established a "new" disposal area which could be carefully monitored. It was decided that the capping operation be conducted within the southeast quadrant of the Mud Dump.

To facilitate precision dumping, a taut-moored buoy, designated as the "MD" Buoy, was placed as shown in Figure 1 within the southeast dumpsite quadrant where water depths approximated 27 meters. A taut-moored buoy constructed by the Naico Corporation was utilized in the capping exercise to maintain a precise disposal location. The taut-moored buoy system consisted of a surface buoy attached to chain and elastic tethers to allow the buoy to rise and fall with waves and tides. According to the manufacturer, the buoy watch circle radius was within 5% of the installation water depth. Therefore, for the capping operation, it was anticipated that the buoy could precisely mark the disposal point within a lateral distance of 1.5 meters. The buoy was emplaced after a detailed bathymetric survey of the disposal area.

Dept. of the Army permits were issued between March and June of 1980 to the six applicants whose test results indicated a bioaccumulation potential for PCB. A seventh permit was included in the capping operation. The permit, issued to the Westchester County Dept. of Public Works, was included because a bioaccumulation potential for cadmium was indicated by tests performed on the grass shrimp, Palaemonetes sp. The seven permittees having material to be capped are shown in Table 1 along with the volume of material dredged for each.

The permits were issued with conditions specifying that disposal take place at the "MD" Buoy and that Corps of Engineers inspectors be aboard the disposal vessels during each disposal event. The permittees were required to reimburse the Corps of Engineers for the expenses of the inspectors. All of the dredging and disposal was accomplished between March and July, 1980. Dredging was accomplished with the use of clamshell or bucket dredges. The material was placed into scows and subsequently hauled to the disposal site.

A bathymetric survey of the dumpsite was conducted after the seven permittees completed their work. A comparison of the March and July surveys is shown in Figure 2. The deposit is skewed toward deeper water to the east. By knowing the dimensions of the deposited sediment, a sequence of capping could then be established.

It was decided that uncontaminated sediments from three Federal dredging projects would be utilized as capping material. The quantities of dredged material from these projects are given in Table 2. The Bronx River and Westchester Creek projects are relatively small in comparison to the Ambrose Channel Project and both were composed of fine-grained sediments as compared to sand dredged from Ambrose Channel.

Since the cap would have to isolate the contaminated sediments from direct contact by marine organisms, it would therefore have to be of sufficient thickness to prevent burrowing animals from reaching the underlying material. Benthic organisms do have the capacity to burrow and rework sediments (2) and have been found to be vertically mobile to depths of 60 cm. However, Pratt and O'Conner (3) have found in Long Island Sound that most benthic species occur at depths less than 0.1 meter. It was therefore thought that a cap of at least 0.6 meters would be sufficient to isolate the contaminated deposit from the marine ecosystem.

Dredged material from the Bronx River and Westchester Creek Projects was placed at "MD" Buoy. The projects were dredged with a clamshell dredge and the material was dumped with scows. Ambrose Channel was dredged using the Corps of Engineers hopper dredge "GOETHALS". The "GOETHALS" has a dredged material capacity of approximately 4500 cubic meters.

Prior to the Ambrose Channel dredging, a series of disposal points was established to ensure the placement of at least a 0.6-meter sand cap on the entire deposit. Using the equations contained in reference (4), concerning the areal spread of discharged dredged material from a moving vessel, 127 disposal points were established. It was determined that two disposals were desirable at each point to produce a final sand cap of at least 0.6 meters. During the capping operation, the "GOETHALS" carried out 303 individual disposals.

To precisely navigate the "GOETHALS" to the disposal points, a Motorola "Mini-Ranger" navigational aid was used. The accuracy of this instrument at the Mud Dump during the capping was estimated to be within 3 meters. During each dump, the "GOETHALS" would navigate to the pre-determined disposal point, stop all engines, and empty all of the hoppers.

CAPPING STUDIES

A series of investigations was initiated to determine the effectiveness of the capping operation. The logistics of carrying out the operation was the most critical phase of the capping exercise. The logistical effectiveness could best be determined by conducting periodic bathymetric surveys and then comparing the changes to actually see what transpired during the operation. The bathymetric survey work is being conducted in-house by the New York District.

The major concern of those who were part of the capping decision was the short- and long-term stability of the capped mound. To address this concern, the New York District engaged the assistance of the Atlantic Oceanographic and Meteorological Laboratories of the National Oceanic and Atmospheric Administration (NOAA). A study effort was initiated in November of 1980 to determine the extent to which the cap will be stable with respect to the hydraulic regime in the vicinity of the dumpsite.

NOAA's (5) approach to answering the stability question is as follows:

a. The cap materials, the bottom roughness of the cap surface, and the flow regime over the cap are being examined.

b. The response characteristics of the sediment cap to the flow regime during an eight-month period are being examined.

c. Historical current meter data are being evaluated to determine the long-term flow climate.

The field program to address (a) and (b) above has been completed. Bottom sediments were collected; flow measurements and suspended sediment concentrations were measured with in situ probes for an eight-month period; side-scan sonar was accomplished; and a SEAFLUME was utilized to measure bottom shear stress. Graduated rods were also placed around the capping site and monitored through diver observations to measure erosion and/or deposition.

The SEAFLUME measurements of bottom shear stress were originally only scheduled to be made over the cap, which is predominately sand. Though sand is desirable as a cap in the New York Bight since it is similar to naturally occurring continental shelf deposits, fine-grained material has advantages as capping material since it is the most abundant type of sediment being dredged from New York Harbor and its lower permeability may be desirable in preventing leaching of contaminants. To evaluate the erodability of freshly deposited fine-grained sediments, fine-grained dredged material was deposited at the "T" Buoy. SEAFLUME measurements were then made directly over the mound.

As previously mentioned, it was thought that removing the contaminated sediments from direct contact by marine organisms was the most important factor in mitigating the bioaccumulation potential. Any leaching of contaminants through the cap was thought to be of minor significance if it would occur at all. To determine the significance of any potential leaching, mussels (Mytilus edulis) were deployed over the capping site and at several reference locations within the New York Bight and the Harbor. The reference stations were deployed in August of 1980 while the platform over the capping site was installed in November 1980. Weekly mussel samples were collected for the first month after initial deployment. Bi-monthly samples were then routinely collected at each site thereafter and until July of 1981. Mussel tissue was analyzed for Cd, Hg, Pb, PCB, DDT, and petroleum hydrocarbons in triplicate to allow for statistical interpretations between sites. The New Jersey Marine Sciences Consortium is presently conducting this work.

One final study was initiated to aid in determing the effectiveness of the capping operation. It involves the determination of a unique chemical and/or physical "signature" for different dredging projects such that the "signature" could be used to vertically and horizontaly identify distinct projects within a capped mound. The first objective was to establish identifying "signatures" to differentiate contaminated material from capping material. The second objective was to develop "signatures" for all dredging projects utilized in the operation. The results of this study will be used to identify distinct horizontal and/or vertical horizons and to then interpret the processes (i.e. dumping, post-depositional compaction) most responsible for the observed profiles. Sediment samples from each dump scow and hopper dredge load have been collected and are being systematically analyzed by the New York University Medical Center. Core samplings of the capping site have been collected and are also being analyzed.

RESULTS

Except for a comparison of the bathymetric surveys, the work associated with all of the other studies is still in progress. It is anticipated that a capping synthesis report will be available in March of 1982.

Figure 3 shows a comparison between bathymetric surveys conducted in July and November of 1980. The contours reflect the amount of capping material deposited between that time period. In comparing Figure 3 with Figure 2, it is evident that most of the contaminated sediments have been covered with a meter or more of capping material.

CONCLUSIONS

Since all of the studies have yet to be completed, it is premature to pass final judgment on the effectiveness of the capping exercise. It is clear, however, that technology is currently available that can facilitate precision dumping during a capping operation. In addition, the necessary tools are available to measure the effectiveness of such an operation.

The prospect of capping contaminated sediments offers a unique disposal opportunity for sediments requiring special handling. It is anticipated that only a small percentage of sediments within New York Harbor will require special handling in the future. Besides capping in ocean waters, the New York District is also studying the feasibility of placement of dredged material into subaqueous borrow pits within the Harbor. These pits were created through past sand and gravel mining operations. The District plans to study the feasibility of placing contaminated sediments into the pits and subsequently capping them. The District's present studies involve the use of uncontaminated sediments.

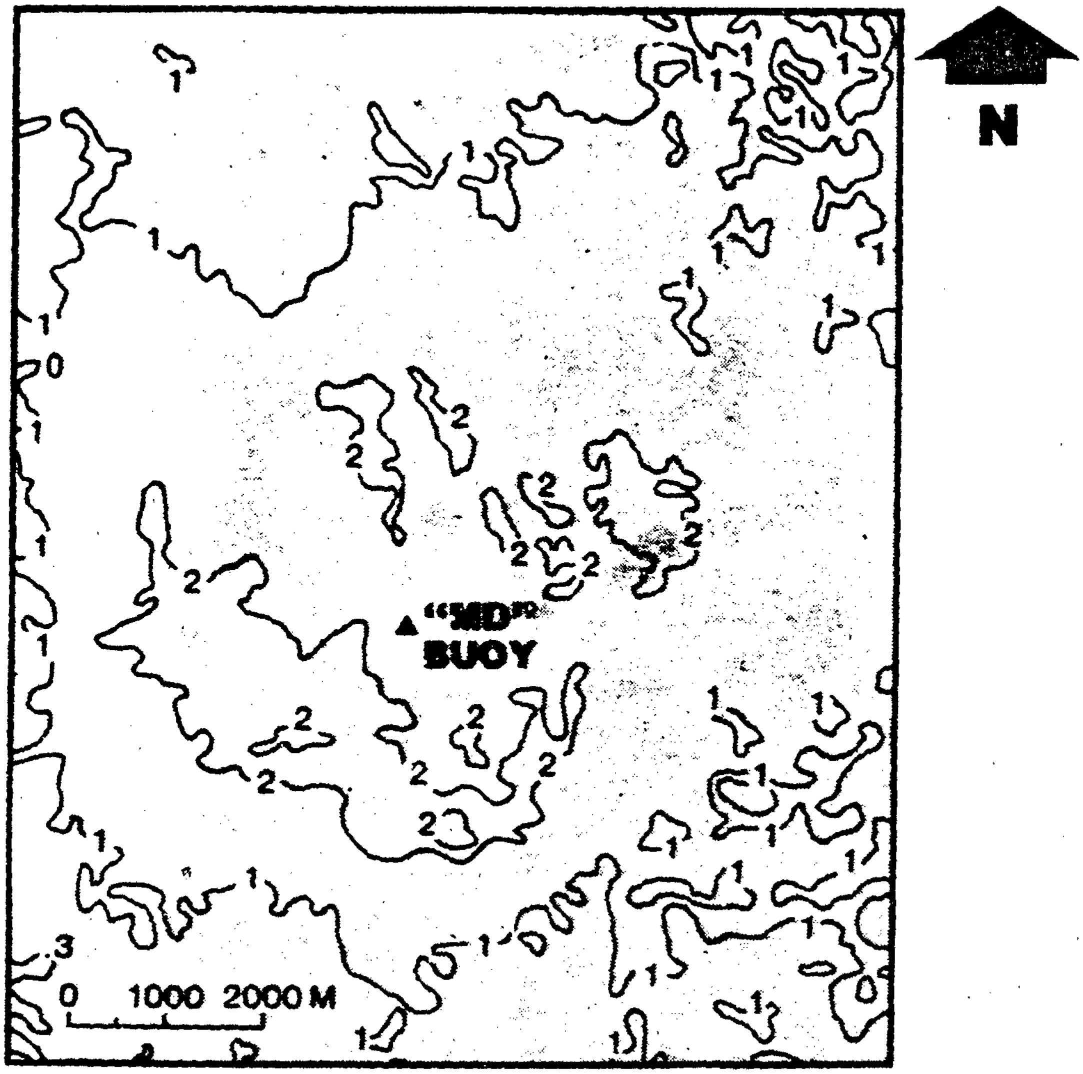

Figure 3. Accumulation of capping material as derived from bathymetric surveys of July and December 1980 (contour interval in meters)

If capping proves to be an acceptable disposal technique, it will greatly enhance the overall management scheme for disposal of dredged material from New York Harbor. A range of disposal options to handle differing qualities of dredged material is essential for efficient port operations.

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EXPERIENCES WITH THE STABILIZATION OF SEDIMENTS

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ABSTRACT

This paper deals with stabilizing methods for dredged material such as (1) progressive trenching, (2) solidification of surface layers, and (3) sand compaction piling. To study the progressive trenching method, which was developed in the United States, a small-scale test was carried out for dredged material from Lake Kasumigaura. The test results are reported herein. The solidification of the surface layer by a powdery material instead of a slurry is discussed with examples. A new method of sand compaction piling tested to prevent turbidity from sea work is also reported.

INTRODUCTION

When planning sediment management, decisions are generally made according to the procedure in Table 1.

Sediments are treated to improve their properties according to the purpose of the final procedure. The characteristics of sediments are thus improved:

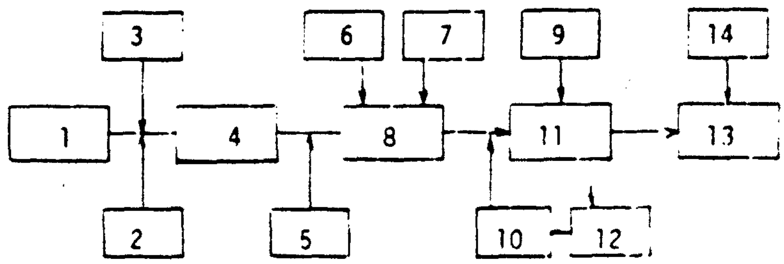
(1) to attain the required soil strength
(2) to reduce the sediment volume
(3) to prevent the leaching of toxic substances

The treatment of sediment is divided into the following three principles from the view of soil mechanics:

(1) reduction of contact pressure
(2) dewatering
(3) solidificaion

The relationships between the treatment and sediment characteristics are indicated in Table 2.

TABLE 1. PROCEDURE OF DECISIONS FOR SEDIMENT MANAGEMENT



1. purpose of planned project

2. Natural conditions
[geological
topographical
meterological
oceonographic
hydrological]

3. social and economical conditions: compensation
[environmental impacts]

4. judgment on propriety of management

5. local conditions
[properties of sediment
site and work conditions]

6. legal regulations

7. harmony with the natural scene

8. decision

9. safty control

10. amended design

11. execution

12. unknown factors

13. maintenance
[supervision]

14. periodic inspection

TABLE 2. RELATIONSHIPS BETWEEN TREATMENT AND SEDIMENT CHARACTERISTICS

Principle	Reduction of Contact Pressure	Dewatering	Solidification
Attainment of soil strength	△	○	○
Volume reduction		○	△
Prevention of leaching			○

NOTE: ○ Very effective
△ Effective

Among these, the reduction of contact pressure is often applied in the preliminary stages (before the main treatment) in order to spread out the burdens. In this paper, three methods for stabilizing sediment are discussed: progressive trenching, solidification of surface layers, and sand compaction piling.

PROGRESSIVE TRENCHING

Regarding the progressive trenching method, C. C. Calhoun, Jr., presented two papers at the previous meetings that aroused much interest in the Japanese people concerned with sediment management. In order to determine the effects of this method applied to our sediments, tests were assigned to our association by the Kasumigaura Construction Office (a branch of the Ministry of Construction) from Jan. to Dec. in 1980.

The test ponds, which consist of 6 compartments as Fig. 1 shows, were made in one corner of some reclaimed land which was being filled by dredged material from Lake Kasumigaura. The filled depth was 1.3 m.

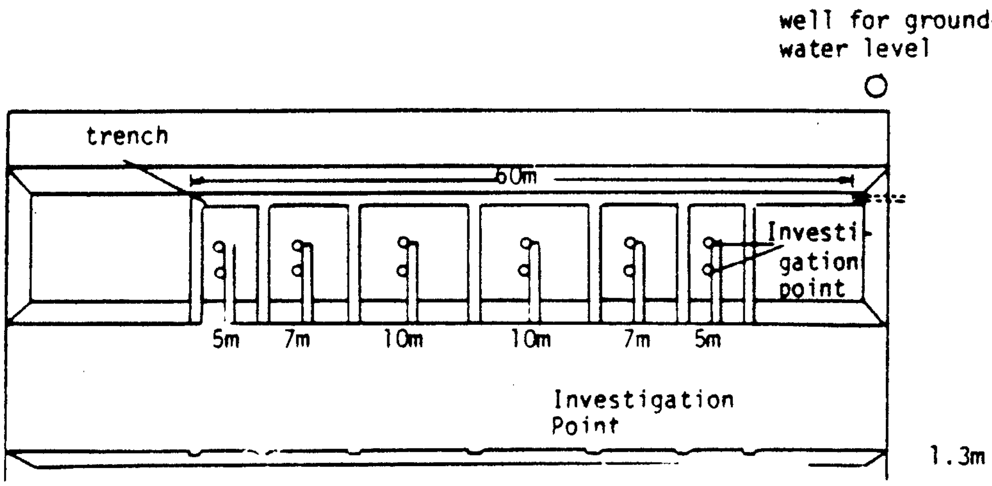


Figure 1. Test ponds for progressive trenching

The basic properties of the lake sediment are shown in Table 3. The relationships between the volumetic change ratio and the compressive strength are indicated in Fig. 2 and Fig. 3.

TABLE 3. PROPERTIES OF LAKE SEDIMENT

Basic properties		Mean value
Water content ω		288.1 %
Sp.weight of soil particle Gs		2.62
Unit weight γ_t		1.18g/cm^3
Particle Sizes	Sand (74 ∿ 2000μ)	12.7 %
	Silt (5 ∿ 74μ)	38.0 %
	Clay (< 5μ)	49.3 %
Consistency	Liquid limit ω_L	100.8 %
	Plastic limit ω_p	37.6 %
	Shrinkage limit ω_s	29.4 %
Volume Change	Compression index Cc	0.60
	Coefficient of shrinkage Cs	3.94

The trench work was conducted as follows:

(1) 7 trench ditches of 1.0 m width were excavated along the longitudinal direction and one along the side wall.

(2) Progressive trenching was conducted 6 times from April to September, that is, at a mean rate of one time per month.

(3) The trench ditches were excavated by hand from the first until the fifth trenching and by backhoe for the sixth trenching due to the size of the test pond.

(4) The trench depths were about 10 cm until the fourth trenching, about 30 cm for the fifth, and about 60 cm for the sixth.

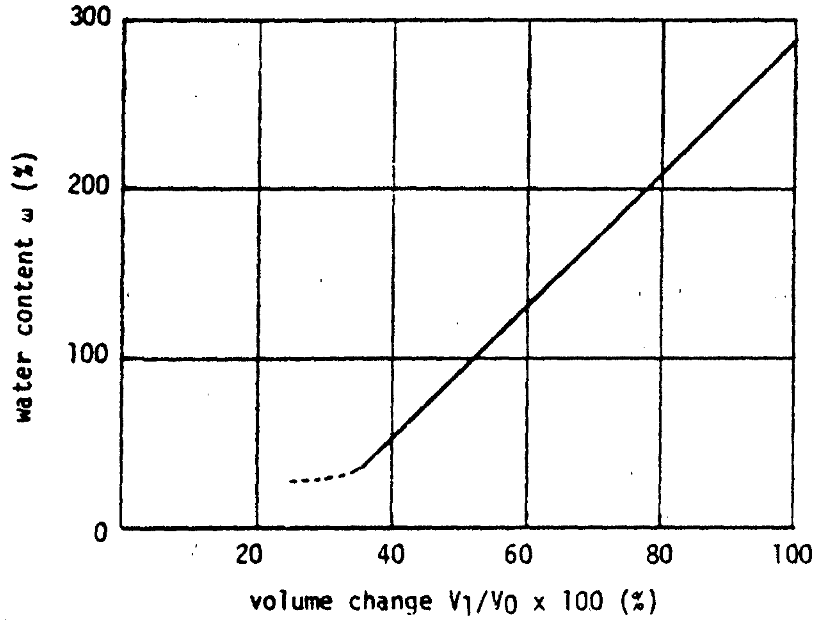


Figure 2. Relationships between water content and volume change

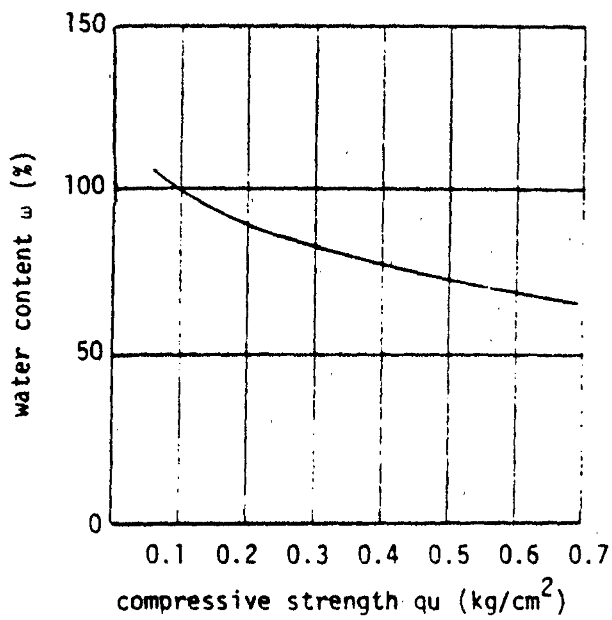


Figure 3. Relationships between water content and compressive strength

(5) The pitches of the trenches were 5, 7, and 10 m.

(6) The spill water from sediment water and runoff was drained from the trenches.

(7) The water content of the sediment, its shrinkage, crust depth, groundwater level, and soil strength from a cone penetrator were measured before and after trenching.

Test Results and Considerations

The water content of the sediment in the case of the 10-m trench pitch decreases with time and reaches the liquid limit after about 200 days, as Fig. 4 shows. The effects of trench pitch on decreasing rates of water content could not be determined.

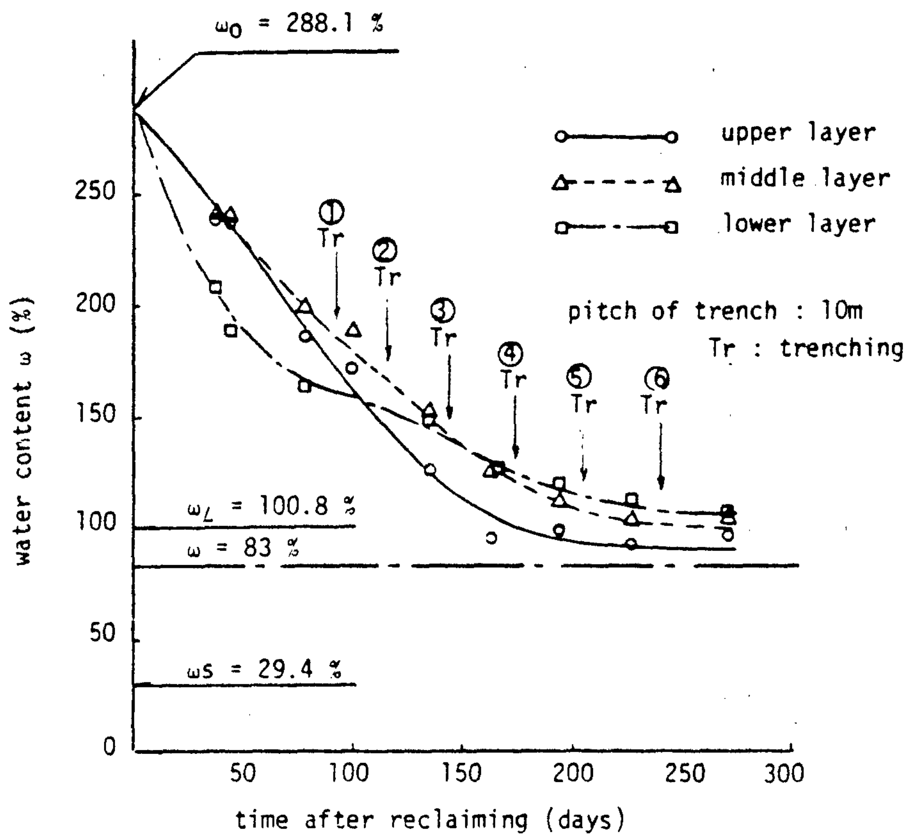


Figure 4. Water content versus days after reclaiming

The comparison between measured settlements in our test and the calculated ones from the DMRP prediction formula is indicated in Fig. 5.

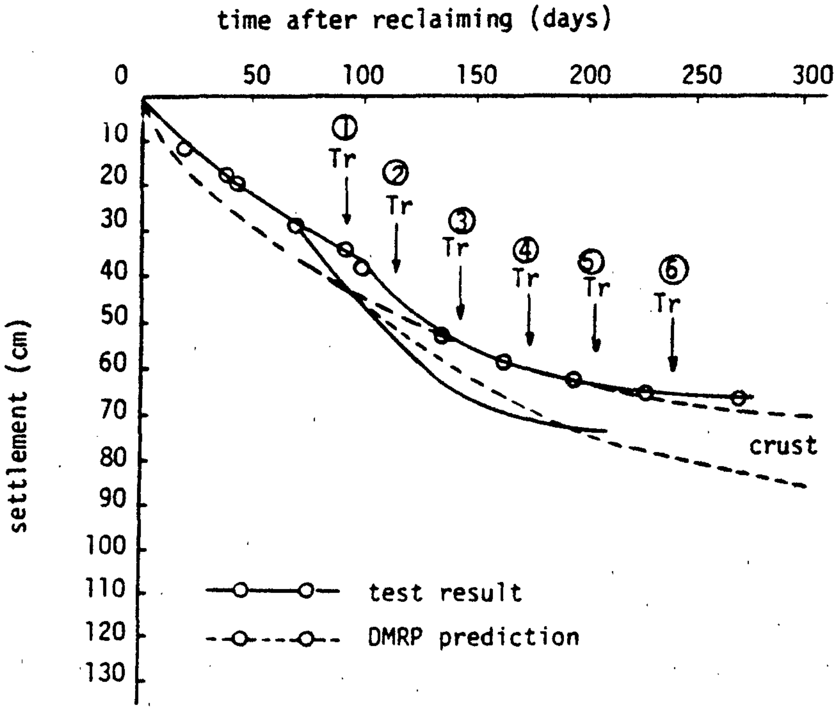


Figure 5. Settlement versus days after reclaiming

As the figure shows, the measurements are in good agreement. This means that the DMRP calculation formulas for progressive trenching were verified in our country.

We found that sun-drying dredged material requires about one year at Lake Kasumigaura. The test results demonstrated that the drying time would be shortened to 7 months if the trenching method is applied in this area. Photos 1-5 show the various stages of trenching.

SOLIDIFICATION OF SURFACE LAYER

The methods of hardening soft ground by solidificants such as cement or lime can be divided into two categories: solidification of the surface layer and solidification of the deep layer, both of which are often used in our country. The former is used to attain trafficability of soft ground, while the latter is used to provide stability for structures to be built on reclaimed land or naturally soft ground. For dredged materials, solidification of the surface layer is often applied.

The solidifying method is generally conducted by using a slurry made of cement or lime because it is easier to do the work in a slurried state than a powdery one. Besides workability, the economics and the results of the work done should also be taken into account.

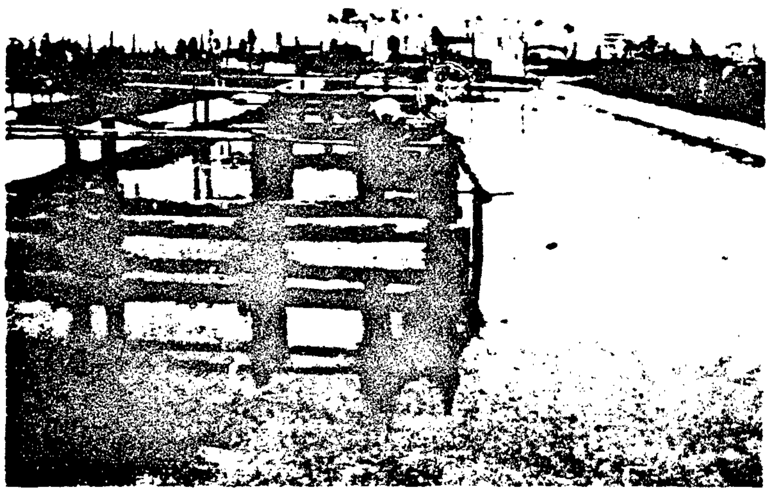


Photo 1. 30 days after reclaiming

Photo 2. Second trenching (120 days)

Photo 3. Fifth trenching (200 days)

Photo 4. Sixth trenching (240 days)

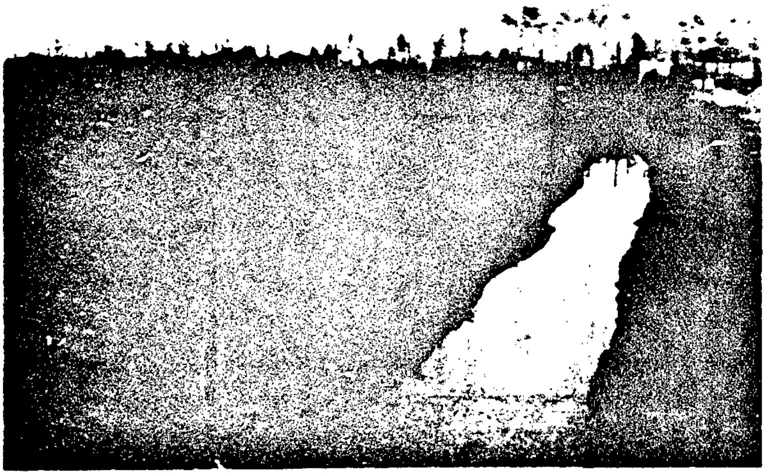


Photo 5. Condition after raining

The advantages of the powdery state are:

(1) The required quantities of material are small.

(2) Volume expansion is also small because no surplus water is added.

(3) Material such as quick lime, which cannot be used in a slurried state, can be applied.

On the other hand, the disadvantages of powdery materials are mostly in work difficulties, especially caused by:

(1) incomplete mixing

(2) dust during handling.

The powder jet injection and mixing method (DJM), which was developed to handle these problems, is now in practice in our country.

Figures 6 and 7 graphically depict compressive strength versus mixing ratio and mixing time, respectively.

Application of this DJM principle is now being tested in situ at a waste disposal site under the auspices of the Tokyo City Government.

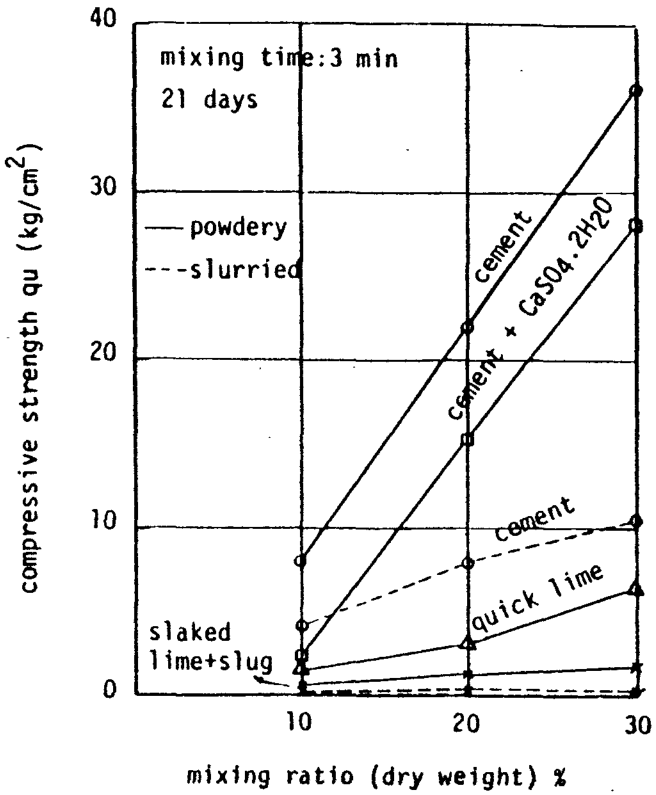


Figure 6. Compressive strength versus mixing ratio (example)

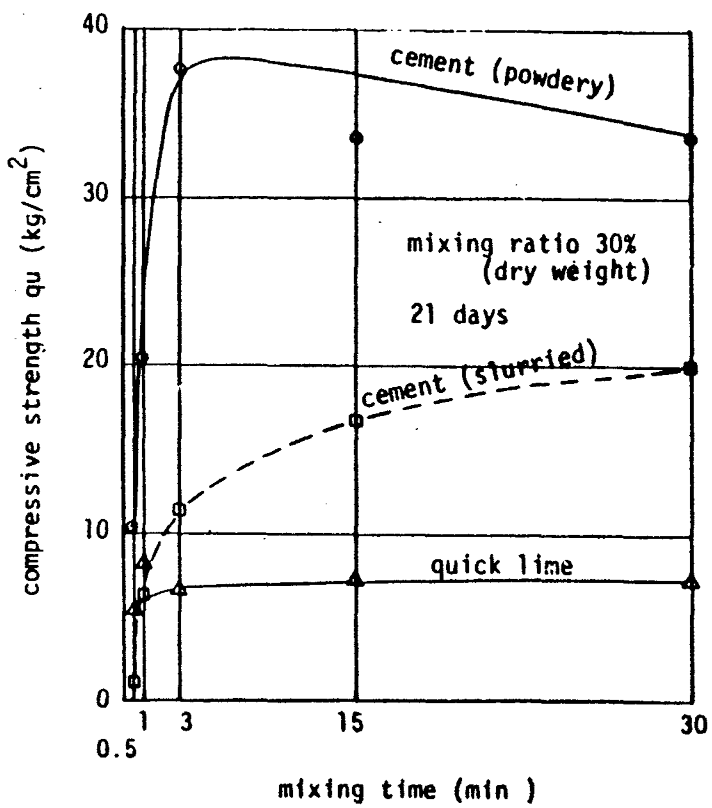


Figure 7. Compressive strength versus mixing time (example)

The laboratory test results, summarized in Fig. 8, show that:

(1) In the case of cement the required quantities of powdery cement are 1/1.5-1/2 of that of slurry for the same strength.

(2) The solidified strength from quicklime is more strongly affected by soil properties than that by cement and has a large deviation in strength, about 2 times for the same mixing ratio.

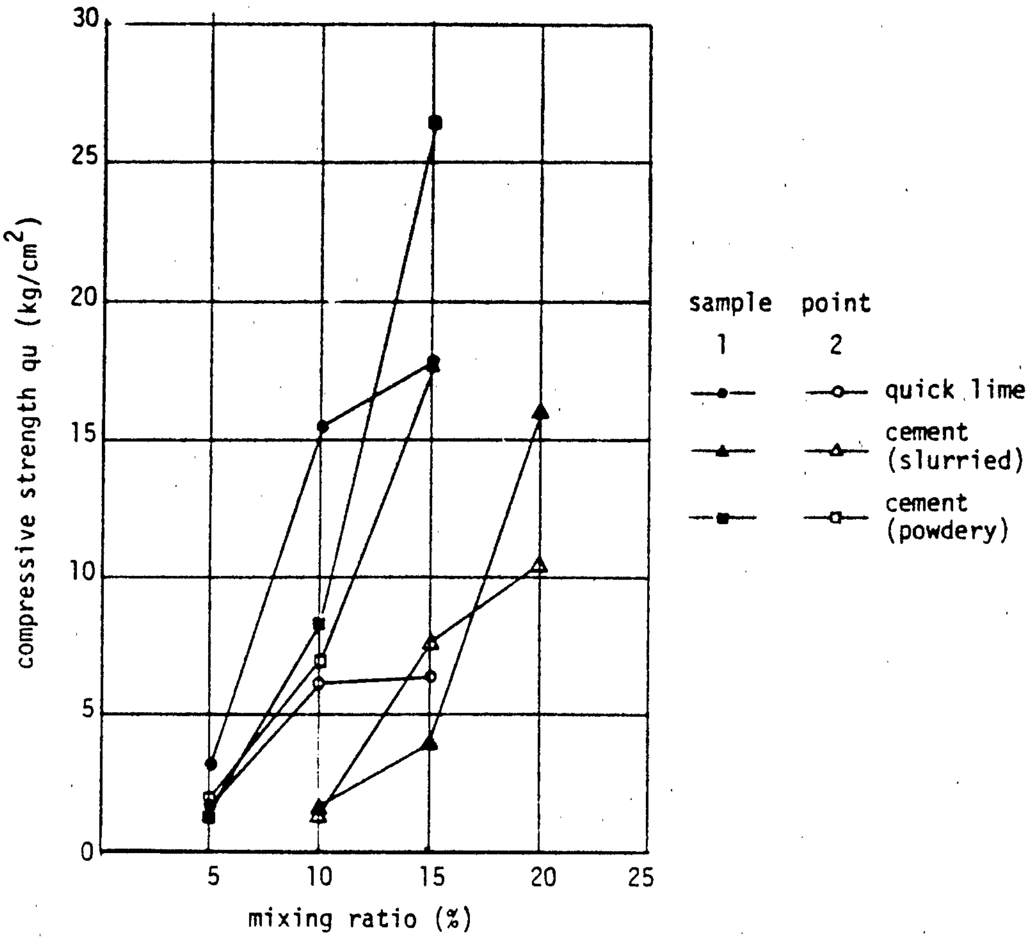


Figure 8. Laboratory test results

Test Results

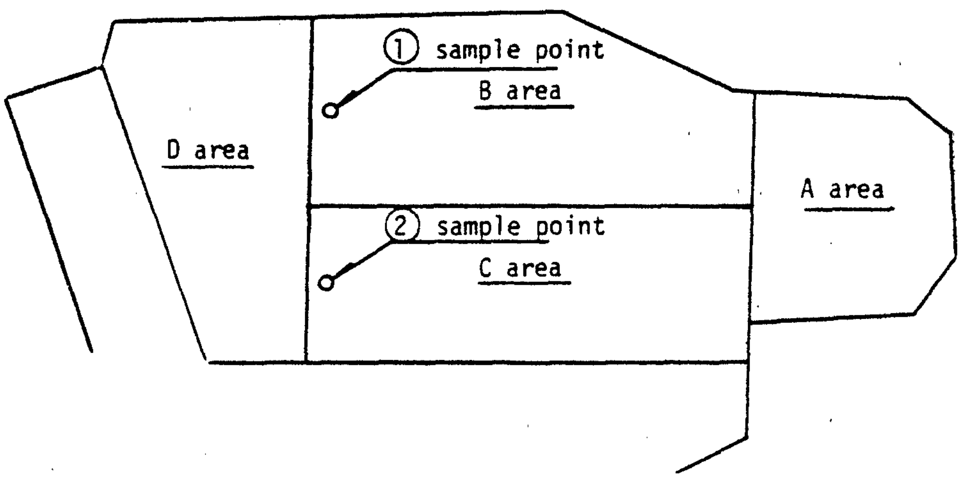
The site where the test was conducted is reclaimed land which was filled with dredged material from Tokyo Bay during the last 4-5 years.

The properties of the soil at the two sample points are shown in Table 4.

TABLE 4. PROPERTIES OF THE SOIL

Sample Point	Water Content ω (%)	Unit Weight γt (g/cm^3)	pH	Organic Content (%)
①	124.1	1.36	7.4	12.2
②	185.5	1.31	8.2	15.6

The locations of the two sample points are shown below:



Mixing tests of solidificants were made in the laboratory before the on-site test. Cement milk in a slurried state and cement and quicklime in a powdery state were used as solidifants (See Fig. 8).

In the site tests on reclaimed land, for surface layers of 3-m thicknesses, powdery solidificants were injected into the soil by compressed air, using stir vanes of 1.4-m diameters. The compressor had a delivery air volume of 40-150 m^3/hr with a maximum pressure of 5 kg/cm^2. The consumption of quicklime (under 1 mm) was 80-150 kg/m^3. The test scenes on the site are shown in Photos 6-8.

Fig. 9 shows a machine called the "Chemical Consolider-A," which will be put in operation this fall. This is the first device manufactured on the basis of the in situ test results, and it is expected to exhibit a good solidifying function of the surface layer.

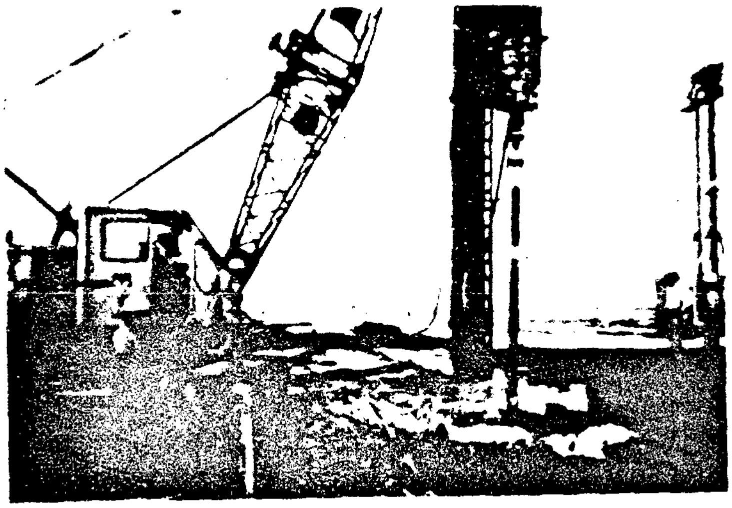


Photo 6. Scene of tests

Photo 7. Mixing device

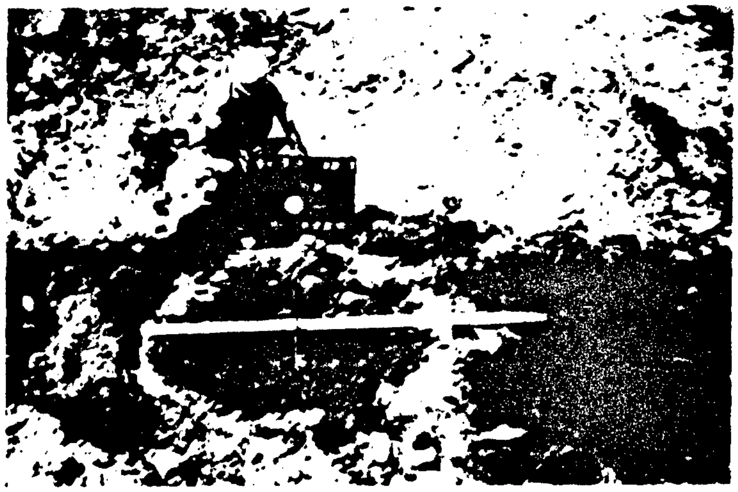


Photo 8. Pile after execution

SAND COMPACTION PILING

The sand compaction piling method was developed in 1956 in our country and has become a typical stabilization method for road banks, railroad embankments, tank foundations, etc. It is effective for preventing liquidation of the soil in case of an earthquake. After 1964, it has been used for sea work such as breakwaters and sea banks. In 1970, this method was also used in successfully developing a new large-scale method (the Mammoth Composer System) that forcibly replaces soft ground under the sea with many large-diametered sand piles.

Sand compaction piling turns sand piles into soil, with an increase in the relative density of the sand such as with vibroflotation for sandy soil and an improvement in soil strength due to stress-concentrating effects for the sand piles and sand drain effects for the clays.

The general procedure for sand compaction piling is indicated in Fig. 10.

As the figure shows, sand piles are formed by drilling down to the required depth and then drawing out hollow pipes. In order to ensure the separation of sand from the pipes when drawing them out, the insides of the pipes are kept under air pressure. In the application of this method (Dry Method) to sea work, the generated air blows create turbidity in the seawater. In previous methods (Wet Method) used in sea work, no air blows were generated, and the strength of sand piles was poor, resulting in limited utility.

In sand compaction piling (Dry Method) there is no problem with sand strength and workability, but there is a problem with air blowing.

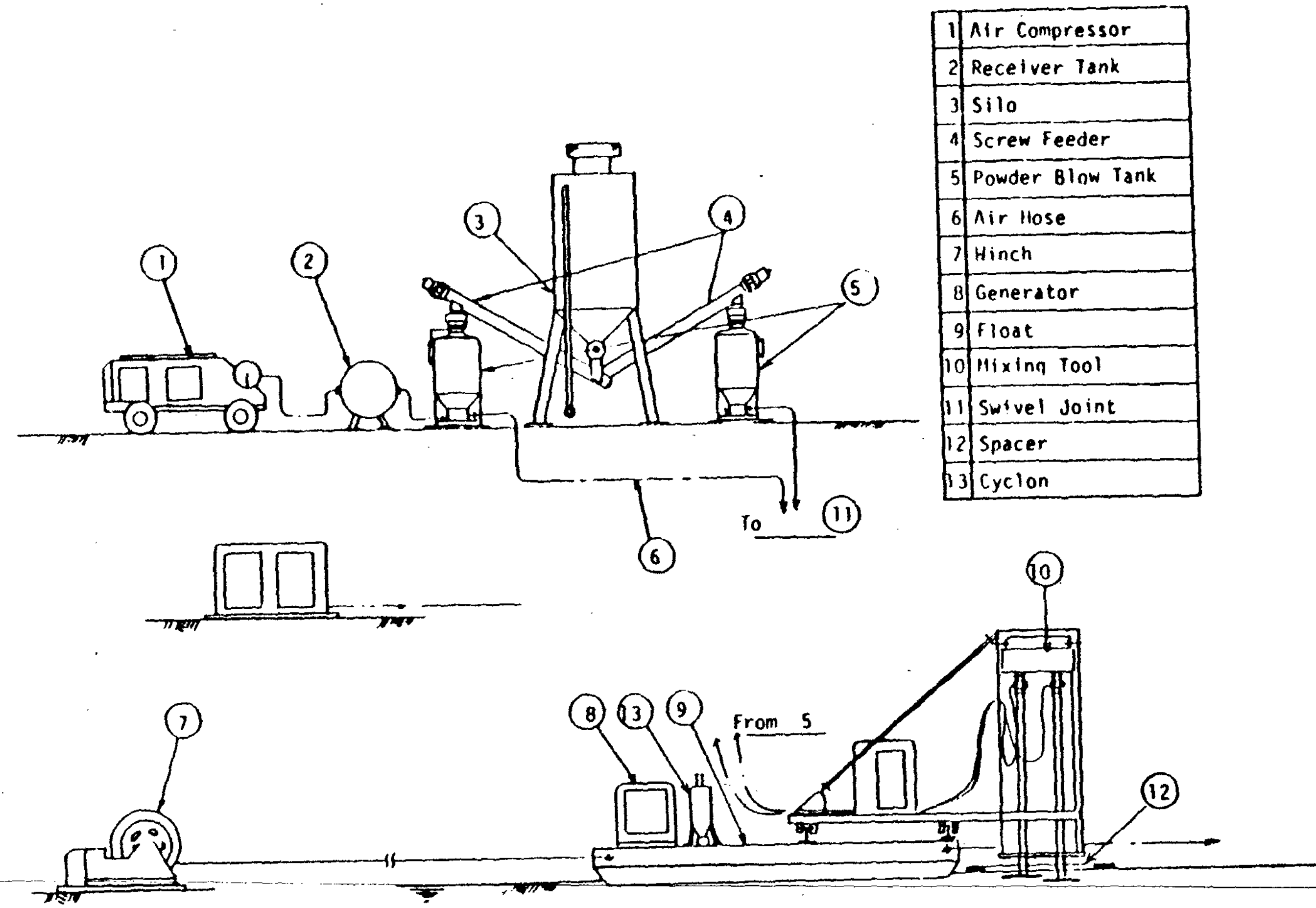


Figure 9. Chemical Consolider-S

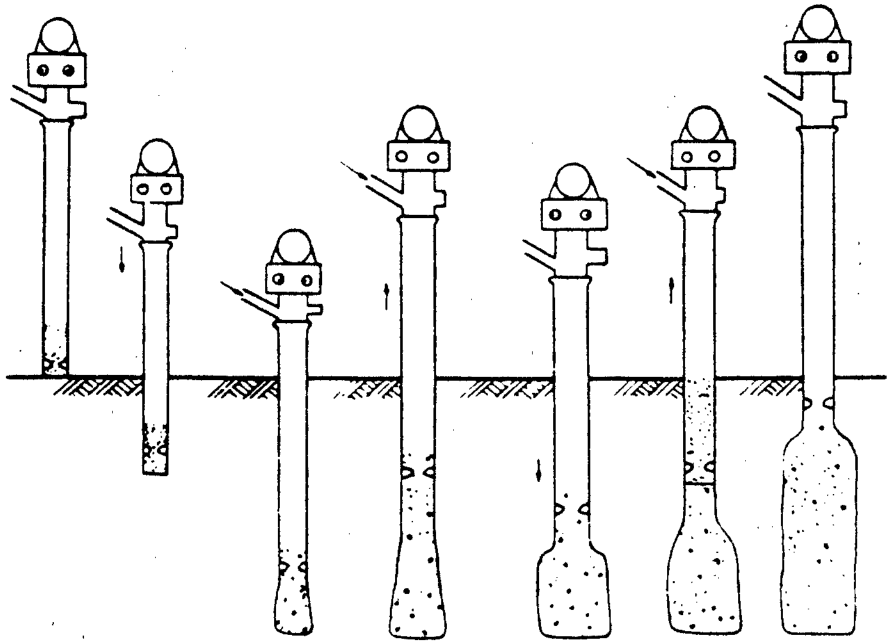


Figure 10. General procedure for sand compaction piling

A new method was developed in 1980 that displayed relatively good results in onsite tests conducted in north Kyushu (Fig. 11). This method has a mechanism by which the insides of the pipes are saturated by water added from the top end of the displaced sand in the drilling process and the air pressure is controlled automatically to prevent air flow in the drawing out process. As the water quantities and air pressure are both controllable in this method, the sand levels in the pipes can be held safely to prevent blowing back in repenetration.

The general scheme of sand compaction piling is shown in Photo 9, and the three methods are compared in Table 5.

Test Results

In the tests, sand piles of 2.0-m diameters with a pitch of 2.1 m were laid into unstable layers 4 m thick, at a sea bottom depth of 2.5 m and a seawater flow of 0-0.05 m/sec. The investigation point of turbidity is shown in Fig. 12.

Fig. 13 shows tests results for the measured values of turbidity at the layer 0.5 m below the surface water at points ①-⑦. The degrees of turbidity were 0-3 ppm for wet systems with a slurry material, 9-30 ppm (max. 60 ppm) for dry systems with a powdery material, and 3-8 ppm for the new system. The degree of turbidity for the New Method is about 1/3 of that for the Dry Method.

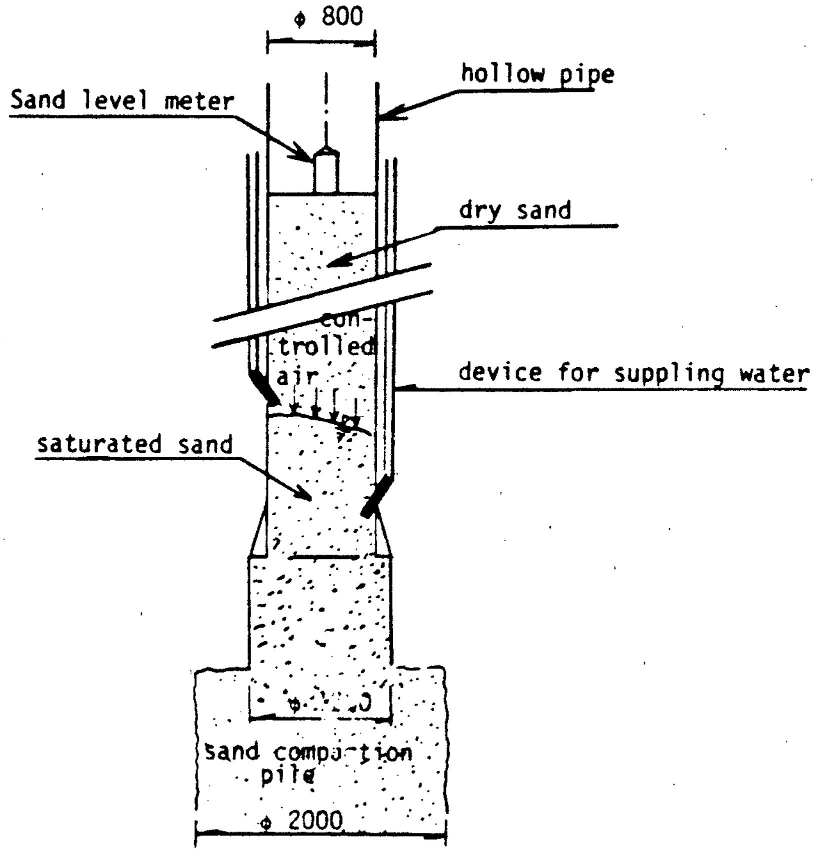


Figure 11. Mechanism of new method

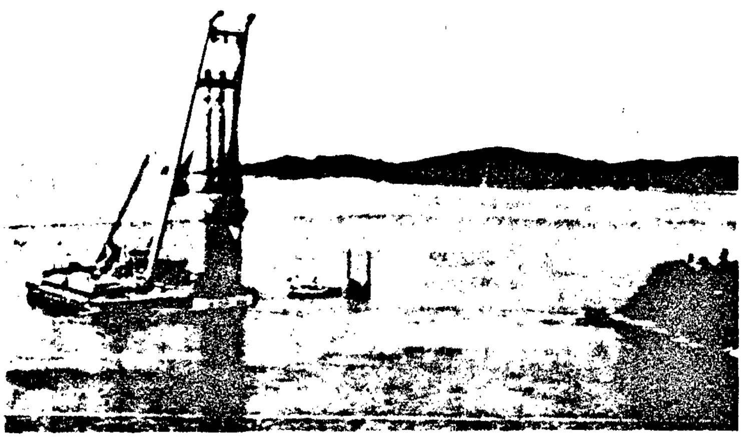
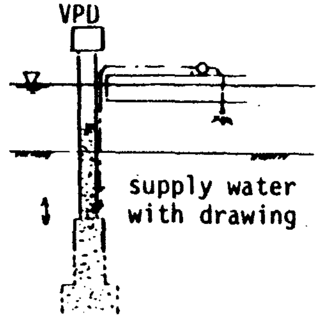
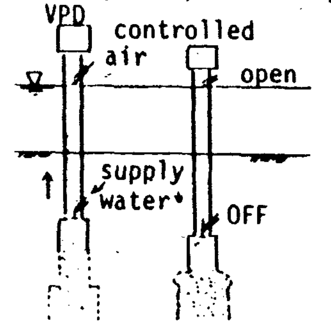
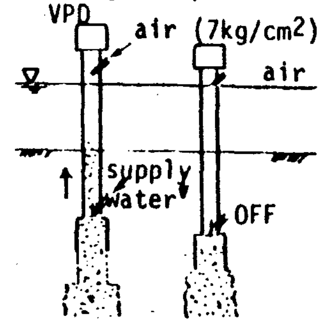


Photo 9. General scene of sand compaction piling

TABLE 5. GENERAL COMPARISON OF SAND COMPACTION PILING IN SEA WORK

	Wet Method	New Method	Dry Method
Execution			
Workability	○	○	○
Strength of Sand Piles	△	○	○
Turbidity	○	○	×

NOTE: VPD = Vibro Pile Driver
○ = Excellent
△ = Good
× = Fair

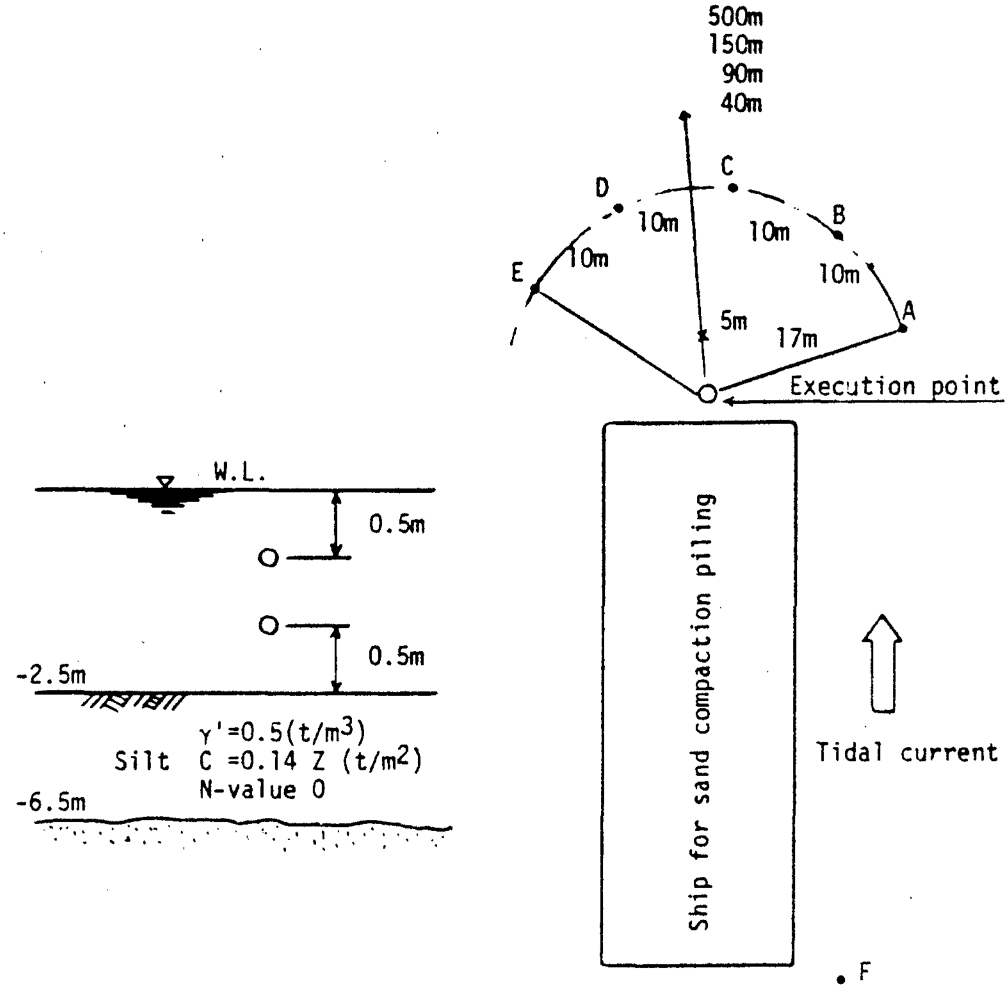


Figure 12. Investigation point of turbidity

The generating rates of turbidity were obtained as follows:

Wet Method	14.1 g/sed
Dry Method	42.6 g/sec
New Method	21.5 g/sec

The rate of turbidity generation with the New Method was about 1/2 of that with the dry method. From these data, it was demonstrated that the new method with water addition has an advantage in regards to turbidity.

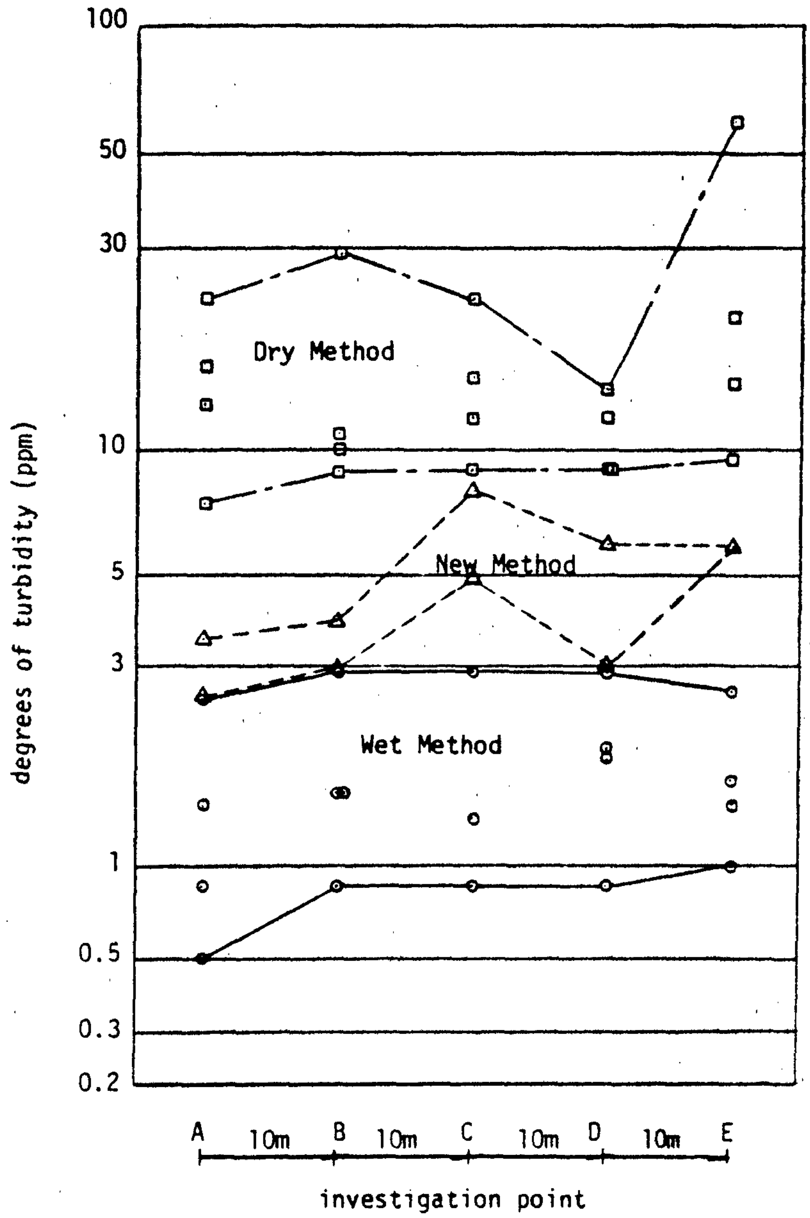


Figure 13. Measured values of turbidity

CONCLUSION

Several new methods for stabilizing sediments are reported herein. These tests were carried out at a field site to improve the existing conventional methods. These new methods are not yet in practice, but are expected to exhibit an improved function in practical application.

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AD P002401

PCB CLEANUP ACTIVITIES ON THE UPPER HUDSON RIVER

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INTRODUCTION

In the fall of 1979 at a similar gathering in New Orleans, I reported that the Hudson River was contaminated with polychlorinated biphenyls (PCBs). Unfortunately, the Hudson River remains contaminated with PCBs and very little has been done to correct this problem. A summary of the distribution of residual PCBs in the Hudson River Basin is presented in Table 1.

Anticipating that Federal funds would become available to New York State for the removal of PCB-contaminated sediments, engineering efforts were continued in an attempt to narrow down the dredging systems selections and to finalize the design report for the PCB containment site.

At the same time, scientific studies were also continued to focus on refining the extent of the PCB contamination and to evaluate the full impact of the PCBs on the ecology of the river.

DISCUSSION

In October 1980, Congress authorized the expenditure of wastewater treatment construction funds already allotted to New York State for the purpose of implementing the "Hudson River PCB Reclamation Demonstration Project." Due to the Federal involvement in the funding mechanism, the Environmental Protection Agency (EPA) became the lead Agency as required by the National Environmental Protection Act and prepared an Environmental Impact Statement (EIS). The EIS was to evaluate more fully a number of alternatives previously presented in a number of technical papers and reports.[1,2,3] The major alternatives were:

1. No action
2. In-river detoxification
3. In-river contamination

TABLE 1. DISTRIBUTION OF RESIDUAL PCBs IN THE HUDSON RIVER BASIN

Area	Estimated Total PCBs kg	Estimated Scourable PCBs kg	Calculated Loss Rate* kg/yr
River sediments			
Remnant deposits	63,500	20,400	3,900
Upper Hudson River bed (Ft. Edward damsite to Troy)	136,000	44,450	2,600
Lower Husdon River bed (Estuary-Troy to New York Harbor)	91,000	?	?
Dredge spoil areas			
(Upper Hudson)	72,600	?	77
Landfills and dumps			
(Upper Hudson)	240,000	--	365
Biota			
Lower River	91-910	--	0
Total	603,300		

* Does not include volatilization. (Based on April 1978 Data)

4. Complete or partial dredging with upland disposal

5. Remnant deposits evaluations

6. Various dredging and transport systems

7. Control of river flow, etc.

These major alternatives were evaluated for the short- and long-term impacts on the upper and lower Hudson River drainage basin and its inhabitants. The primary and secondary impact assessment objectives are summarized in Table 2. The major finding of the EIS[4] were as follows:

1. Disposal of PCB-contaminated dredged sediments in a secure encapsulation site would provide a much higher standard of protection of the health, safety, and welfare for the public.

TABLE 2. PRIMARY AND SECONDARY IMPACT ASSESSMENT OBJECTIVES

A. Public Health

1. Protection of downstream water supply
2. Protection of groundwater in the area of the containment site
3. Reduction of PCB volatilization from river bed/bank, and remnant deposits into the air
4. Reduction of containment site volatilization
5. Reduction of exposure through the ingestion of food

B. Fisheries

1. Permanent reopening of the commercial and recreational fisheries
2. Protection of endangered species (shortnosed sturgeon)
3. Reducing the bioaccumulation of PCBs through the food web
4. Protection of wetlands

C. Maintenance Dredging and Navigation

1. Mitigation of future maintenance dredging and disposal problems in the upper Hudson River as well as the estuary
2. Maintenance of a navigable waterway serving transportation needs of the upper and lower Hudson communities

D. Agriculture

Protection of livestock and their food sources through:

1. Reduction of river bed/bank and remnant deposit volatilization
2. Reduction of containment site volatilization
3. Protection of groundwater in the area of the containment site used for dairy industry purposes

E. Other Impacts

1. Evaluation of impacts of future hydroelectric dam construction and usage

2. The proposed encapsulation site is environmentally sound for the indefinite storage of PCB-contaminated sediments, and that the storage of these PCB-contaminated sediments does not present a long-term adverse environmental impact to the surrounding area.

3. The proposed dredging operation will not have significant adverse effects on the surrounding area nor on the ecology of the Hudson River.

4. Removal of large quantities of PCB-contaminated sediments should improve the rate of recovery of the Hudson River.

5. The removal of PCB-contaminated sediments will also reduce the major risk of contaminating downriver water supplies; damaging public health due to volatilization; and posing public health threats due to consumption of contaminated fish.

Dredging/Transport Systems

On September 1980, a report[5] prepared by Malcolm Pirnie Engineers was submitted to the New York State Department of Environmental Conservation further evaluating the various dredging/transport systems. These systems were evaluated based on technical, environmental, and economic feasibility of removing PCB-contaminated sediments from the hot spot areas in the upper Hudson River.

Three major systems were evaluated: clamshell dredging, mechanical unloading; clamshell dredging, hydraulic transport; and hydraulic dredging, hydraulic transport. The clamshell dredging, mechanical unloading was eliminated at this stage due to the much higher costs when compared to the other two systems. The other two systems proved feasible for the removal of the first 20 hot spots located nearest the proposed encapsulation site. A summary of the two systems is presented in Table 3.

Even though both systems are equal in costs, the PCB losses for the clamshell dredging, hydraulic transport are greater than for the hydraulic dredging, hydraulic transport. It is estimated that the removal efficiencies of hydraulic dredging should be 95.9 to 97.5 percent versus the 90.9 to 94.2 percent for the clamshell dredging.

The major difference between the two dredging systems is the treatment plant required at the encapsulation site. The hydraulic dredging will require a 10-MGD treatment system as compared to only a 1-MGD system with recycling for the clamshell dredging, hydraulic transport.

Once the removal systems were evaluated and narrowed down to two, a design report[6] for the encapsulation site was finalized and submitted by Malcolm Pirnie, Inc. This report defined the design, construction, and operation procedures for the containment of Hudson River PCB-contaminated sediments. Plans and specifications as well as contract bids could now be prepared based on the concept presented in this report.

TABLE 3. SUMMARY OF ALTERNATIVE SYSTEMS

Item	Clamshell Dredging, Hydraulic Transport Unloading	Hydraulic Dredging, Hydraulic Transport
Equipment List	Two 5-cu-yd clamshell dredges Five 1000-cu-yd hopper scows One work-deck barge One 800-HP towing tug Two 200-HP tender tugs One 16-in. pumpout plant One tie-up barge Shore pipeline and miscellaneous equipment Two bulldozers	One 16-in. hydraulic cutterhead dredge Two 16-in. booster pump units One 300-HP tender tugs One 160-HP supply tug One derrick barge One fuel barge One work-deck barge Pipeline and miscellaneous equipment Two bulldozers
Production Rate per Dredge	$\frac{120,000\ \text{cy yd}}{\text{month}}$	$\frac{170,300\ \text{cu yd}}{\text{month}}$
Time Required	2.9 months (Two dredges)	4.5 months
Treatment Plant Size	1 MGD recycle mode 10 MGD once-through process	10 MGD
Fuel Requirements	375,300 gal	554,400 gal

Design Concepts

The design concepts were based on a site capacity of approximately 1,800,000 cu yd. This material would contain 236,000 lb of PCB at an average concentration of 74 μg/g. A summary of the quantities is presented in Table 4.

TABLE 4. CONTAMINATED MATERIAL QUANTITIES FOR DISPOSAL AT CONTAINMENT SITE

	Volume cubic yards		PCB pounds	
Thompson Island Pool and Above Lock 7 (Hot Spots 1-10)	645,500		105,800	
Remnant Deposits (Areas 3 & 5)	212,500		41,200	
Subtotal, 1st Year		858,000		147,000
Lock 2 through Lock 6 Pools (Hot Spots 21-40)	807,200		64,100	
DOT Spoil Areas (Area 13 & Site 212)	149,400		25,600	
Subtotal, 2nd Year		956,600		89,700
Total		1,814,600		236,700

Due to the limited funds approved by Congress, the PCB Hudson River Reclamation Demonstration Project had to be rescoped. Approximately two thirds of the funds required to complete the entire project was approved; as a result, only a limited number of hot spots could now be removed. This reduced scope of work required a complete redesign of the containment site as shown by Figures 1 and 2.

The encapsulation site consists of various components that include the actual containment area for PCB-contaminated sediments, a roughing and storage pond, a surge pond, a flocculation basin, and a settling basin. The containment area consists of approximately 63 acres and is designed for the long-term storage of PCB-contaminated sediments. This material will be surrounded by impermeable clays with the hydraulic conductivity of 3 × 10-7 cm/sec. At least 10 ft of clay will be used at the bottom and sides and at least 18 in. of clay for the cap (Figure 3).

The roughing and storage pond is designed to minimize upsets in the treatment units as well as to provide additional settling once the main

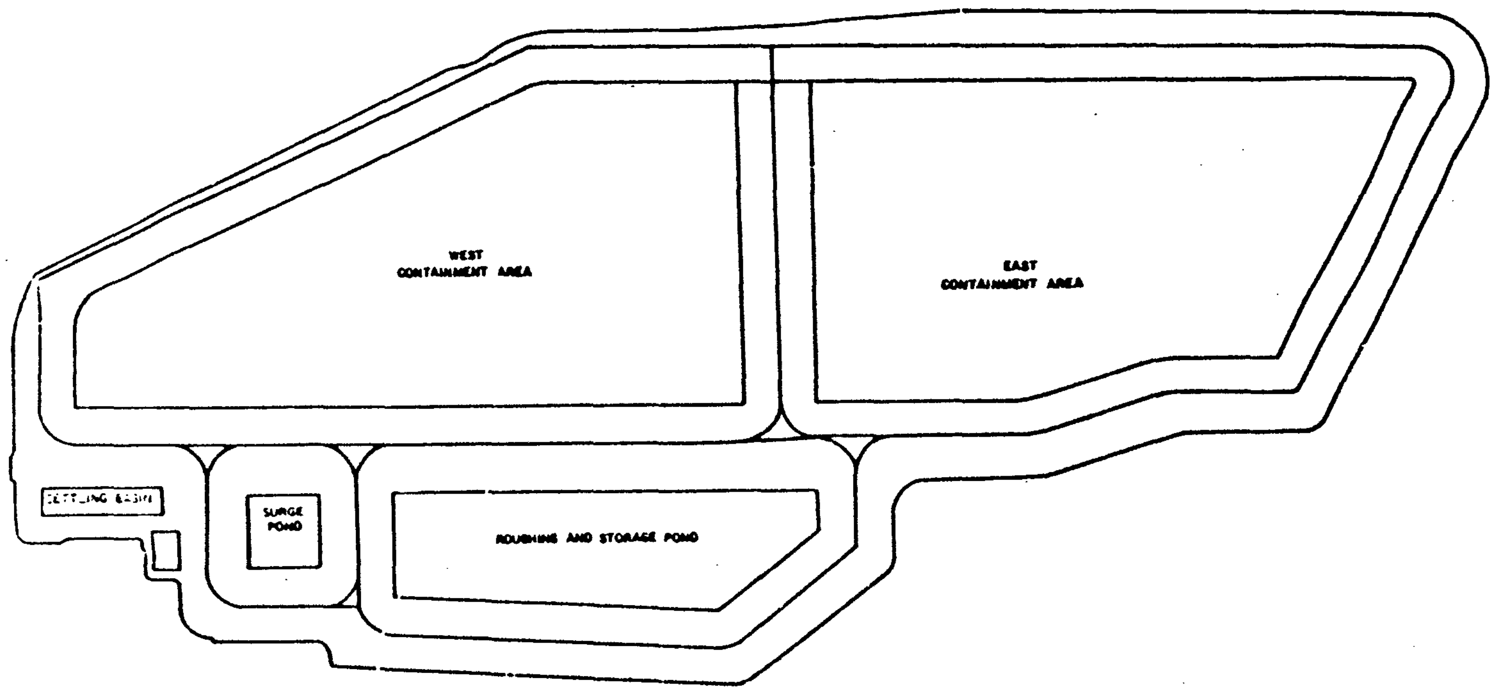

Figure 1. Containment site for full project

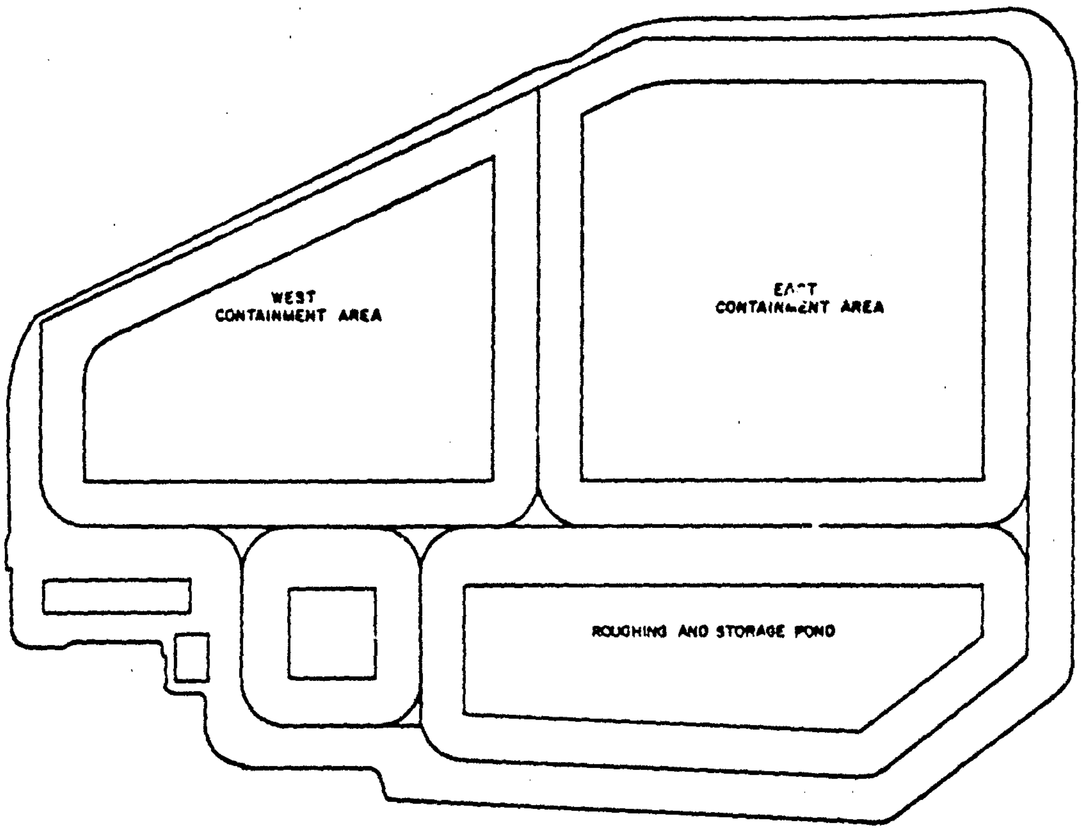

Figure 2. Containment site for rescoped project

containment area begins to fill up. The pond consists of 12 acres with a 340,000-cu-yd capacity. At the conclusion of the project, all of the PCB-contaminated material will be relocated within the main containment area of the encapsulation site.

The surge pond is a 24-acre area with an effective volume of 49,000 cu yd. Its main function is to buffer the flow of the treatment units from surges caused by recycling pumping demands.

The flocculation and settling basins are to permit the treatment of the return water by means of cationic polyelectrolytes as coagulation aids. The settling basin is designed for an overflow rate of 350 gal/day/sq ft. Likewise, these two basins are to be used only for the duration of the dredging operation. Afterwards, the two basins will be leveled and graded.

Operational Procedures

Thus far, the various components of the upland containment system have

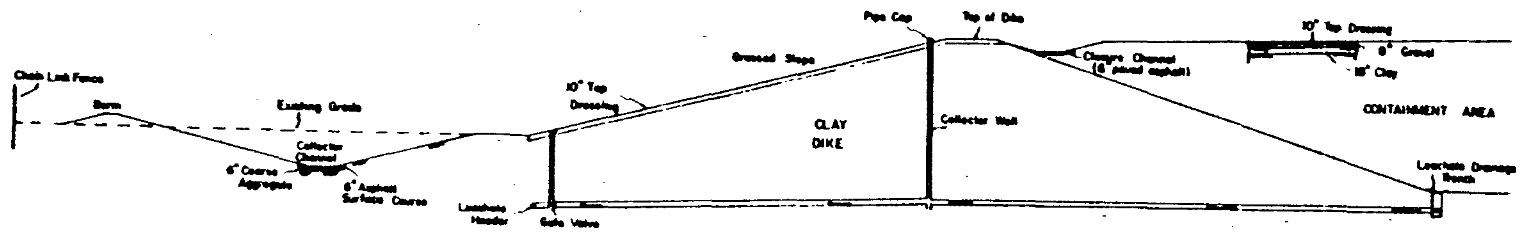

Figure 3. Disposal site construction and leachate collection system

been described. A most important aspect of this project is the actual operational procedures to be used to maximize the PCB removal efficiency and to minimize the impact of the operation on the surrounding areas.

PCB volatilization, storm water control, site closure, leachate collection and control, effect on groundwater, and PCB mass balance are the major components associated with the operation of the containment site. The PCB volatilization issue is of major concern to the surrounding community. During dredging, there is a potential for PCB losses at the dredge slurry inlet pipe, at the turbulent zone of the outlet weir, and at the bulk transfer areas of the containment, roughing and storage, surge, and water treatment units. A summary of predicted losses, including those due to volatilization, is given as Table 5.

TABLE 5. PCB LOSSES: HYDRAULIC DREDGING THE FIRST YEAR; CLAMSHELL DREDGING WITH RECYCLE THE SECOND YEAR

	Pounds PCB		
	First Year	Second Year	Total
Lost in Dredge Plume	2,100	2,600	4,700
Missed During Dredging	2,100	3,200	5,300
Volatilization Losses			
Containment Area	83	38	121
R&S Pond	33	17	50
Surge Pond	0.5	0.5	1.0
Treatment Plant	0.2	0.2	0.4
Remnant Deposits	10	--	10
DOT Spoil Areas	--	10	10
Treatment Plant Effluent	160	20	180
Total (Rounded)	4,490	5,890	10,380

The construction staging, including the closure plan, can best be described as one that ensures the least amount of PCB being lost to the environment. Figure 4 presents the various stages of construction. This plan incorporates the numerous environmental concerns as well as avoids unnecessary excavation beyond that required to contain the PCB-contaminated sediments.

Public Participation Program

We were mandated by Federal regulations to establish a public

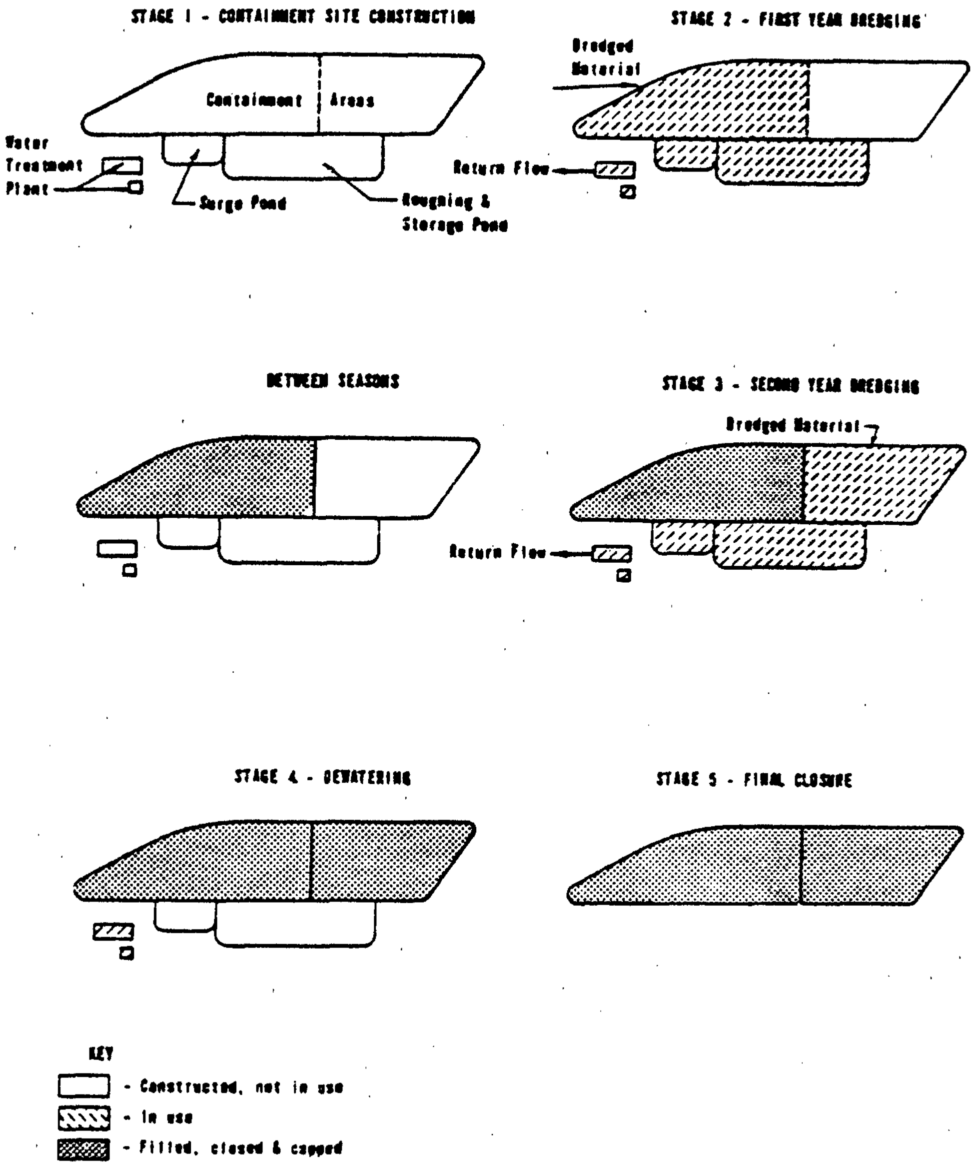

Figure 4. Containment site construction staging

participation program that had its major objective in establishing a public information plan[7].

This program had to encompass the entire Hudson River drainage basin from New York City to Fort Edward, New York. The public information included public meetings, newsletters, press releases, brochures, technical reports, meeting with various public interest groups, public hearings, etc. In addition, a Citizen Advisory Committee was organized with representatives from the upper, middle, and lower Hudson River areas. An extensive and expensive campaign was conducted in order to identify the members of the Committee.

The first meeting of this Committee was held in March 1981, and it has continued to meet on a regular basis. The Committee has reviewed various project material and has made numerous recommendations on important issues. The Committee has proven to be an effective tool in providing accurate information to the public sector, and it has also made valuable impacts in identifying various concerns that could be alleviated by minor modification in the implementation procedures of the project.

CONCLUSIONS

Since 1979 we have not removed additional quantities of PCBs from the hot spot areas. However, a funding mechanism has been established with the help of the U. S. Congress. The dredging systems have been refined to the extent that only two dredging options have proven to be technically, environmentally, and economically feasible.

Additional scientific and engineering efforts have also produced a plan capable of containing PCB-contaminated sediments in an environmentally safe encapsulation site. Extensive monitoring efforts will prevent PCB contamination of the surrounding areas, and will assist in the efficient operation of the disposal site during the actual river dredging.

We are still awaiting the final approval of the Environmental Impact Statement and a number of State and Federal permits. These final actions are expected to be completed within the next two to three months, and construction of the encapsulation site is expected to begin in May 1982.

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AD P002 402

PRODUCTIVE USE OF CALCINED SEDIMENT
(Calcination of Sediment for an Artifical Aggregate)

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ABSTRACT

In the case of sediment removal, the problem of how to discharge the dredged material is very important. The most popular methods are to dump it in water or on land. However, since this has environmental impacts, it is now being restricted by administrative limitations. Therefore, current demands are for measures that have no adverse effects on the environment. The idea of finding a productive use for dredged material has grown from such demands. As one of these, the calcination of sediment for artificial aggregates seems feasible. To investigate its feasibility, a calcination test was carried out on dredged sediment from Lake Suwa in Japan. This paper reports those test results.

INTRODUCTION

The purpose of calcination is to produce artificial, heavy aggregates instead of natural ones from rivers. The major processes of manufacturing aggregates from calcined sediment are drying, granulation or pelletizing, and calcination. The calcination in this study was done in a rotary kiln at a temperature of 1150-1190°C. The properties of concrete made with these aggregates were examined in comparison with river gravel. The test results demonstrated that the compressive strength of the concrete made of artificial aggregates was the same or a little higher than that of normal concrete.

MANUFACTURE OF ARTIFICIAL AGGREGATE

Chemical Composition and Properties of the Material

Chemical and Mineral Compositions

The results of chemical analysis and X-ray diffraction analysis of the sediment in Lake Suwa are listed in Table 1 and Figure 1. The ignition

TABLE 1. CHEMICAL COMPOSITIONS AND MINERAL COMPOSITIONS OF LAKE SUWA SEDIMENT

ig. loss	S_iO_2	$A\ell_2O_3$	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Total	Mineral composition
15.9	46.8	20.2	7.9	3.1	1.8	1.52	1.16	98.38	Quartz Feldspar group
--	56.8	24.5	9.6	3.8	2.2	1.8	1.3	100.00	Kaolinite Cristobalite

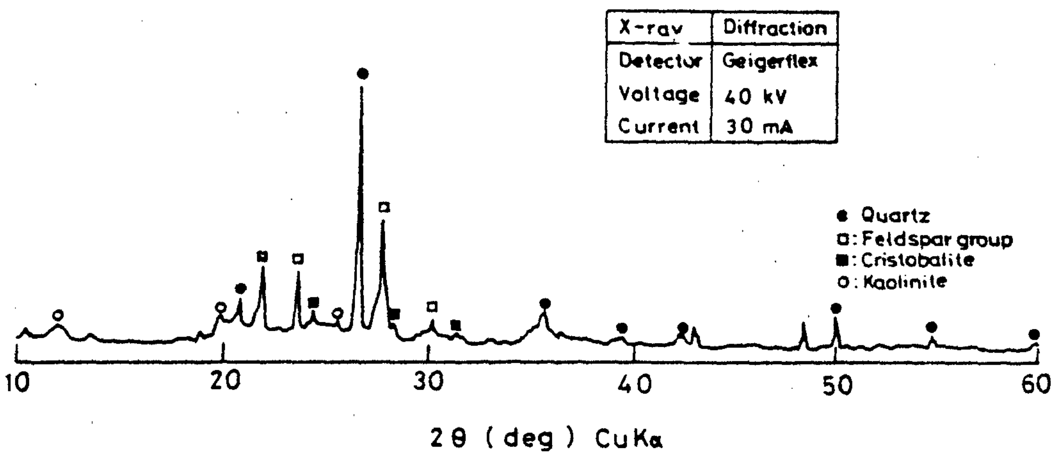


Figure 1. X-ray diffraction patterns of Lake Suwa sediment

loss amounted to about 16% indicating that this material contained a lot of organic substances and other combustible or decomposable components. The proportion of each component, as percentages, to the ignition loss residue is shown in Table 1. Figure 2 is a Riley diagram in which these values are plotted. Riley stdied the effervescent properties of shale, clay, and other minerals, and pointed out that a clay having a composition surrounded by the solid line in Figure 2 tends to effervesce when ignited. This material may be considered suitable as the raw material for the manufacture of lightweight aggregates because of the large amount of organic substances contained and

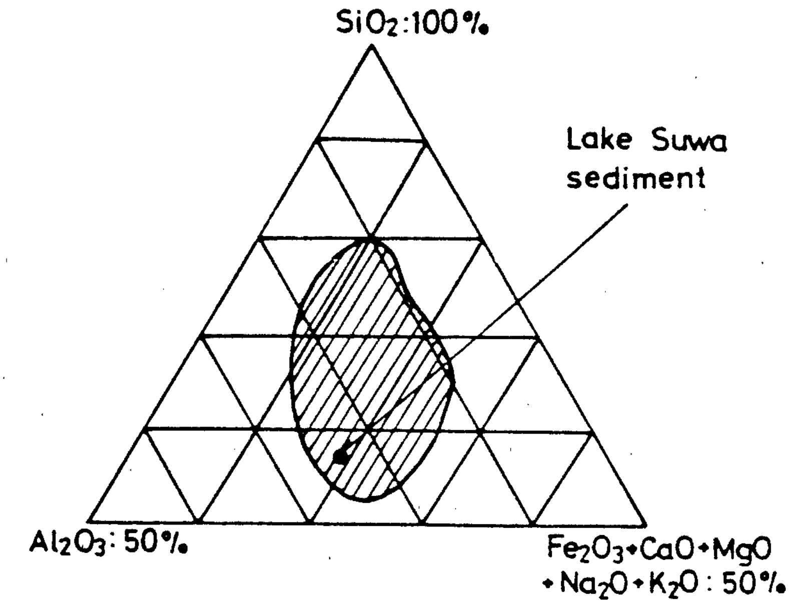


Figure 2. Chemical composition of Lake Suwa sediment in a Riley diagram

its chemical composition, which corresponds to the range specified by Riley. As a mineral, this material consists mainly of quartz, cristobalite, the feldspar group, and kaolinite as a clay mineral.

Thermal Properties as Measured by DTA and TGA

Figure 3 shows the differential thermal analysis (DTA) and thermogravimetric analysis (TGA) measurements for this material. The DTA curve shows an endothermic peak near 100°C due to dehydration, an exothermic peak at about 300°C ascribable to the combustion of organic substances, and an endothermic peak near 480°C due to structural changes in clay minerals. The TGA curve also shows a significant weight loss near 300°C.

Experiments on the Manufacture of Aggregate

Manufacturing Process

The aggregate manufacturing process consists of the following steps: sediment collection, drying, pulverizing, addition of water, granulation, drying of granules, calcination, and cooling.

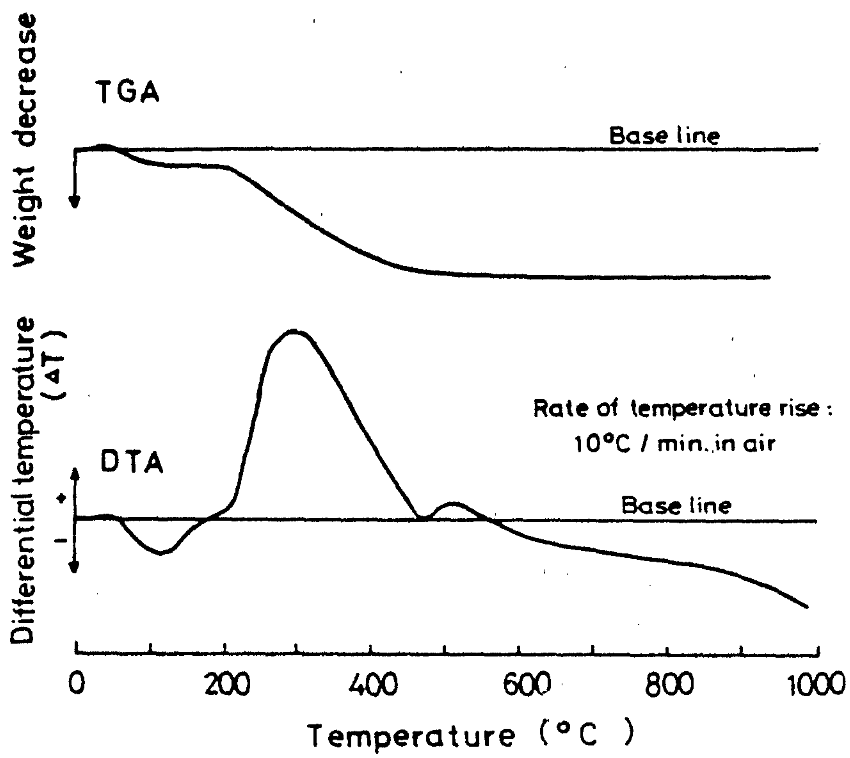


Figure 3. Differential thermal analysis curve and thermogravimetric analysis curve of Lake Suwa sediment

Description of Each Step

Drying

The dredged sediment was sun-dried from a water content of 45% to 27-36%.

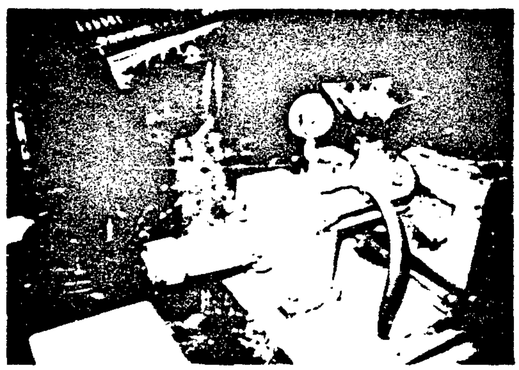
Pulverizing and Addition of Water

The dried material was pulverized, blended, and conditioned to a water content of 31-34% so that it could be extruded for granulation. The conditioned material is shown in Photograph 1.

Granulation

The conditioned sediment was then extruded into small cylindrical granules 10 mm in diameter and 10-15 mm in length, by means of a vacuum extruder (Photograph 2).

Photograph 1. Lake Suwa sediment



Photograph 2. Vacuum extruder

The granules thus produced are shown in Photograph 3.

Photograph 3. Produced granules

Drying of Granules

The granules were air-dried to a water content of 10% or less.

Calcination

Calcination was conducted in a rotary kiln (capacity: 40-60 kg/hr) whose specifications are shown in Figure 4. Two-stage calcination was

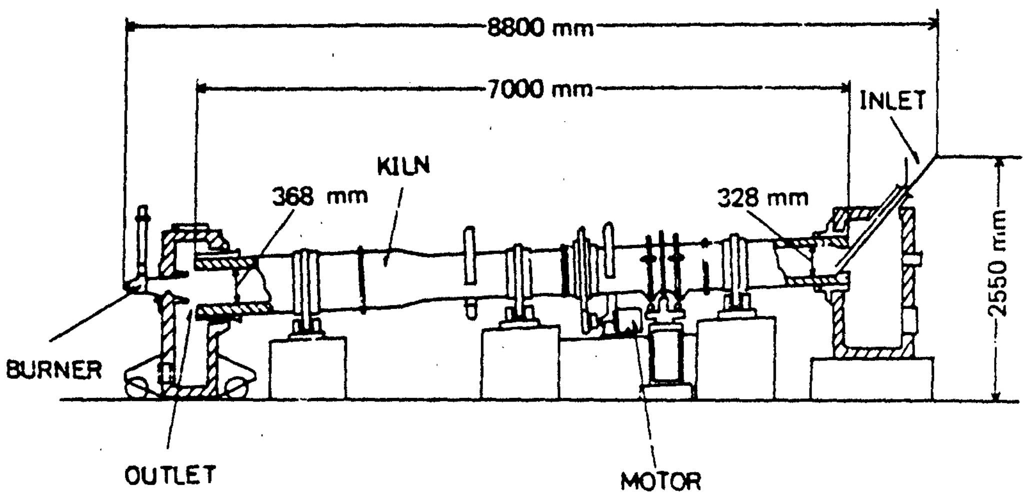


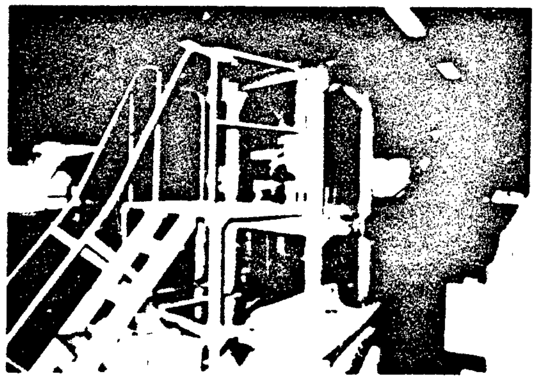
Figure 4. Specifications of rotary kiln

adopted to minimize extra effervescence due to combustion of the organic substances contained. In the first stage, calcination was carried out at 1030°C while supplying a sufficient amount of air to effect combustion of the organic substances. In the second stage, air supply was interrupted (exhaust gas fan stopped) and calcination was conducted at two temperature levels: 1150-1170° and 1170-1190°C. The fuel consumption (kerosene) was about 440 liters/ton for each stage. Photos 4 and 5 show the progress of calcination, and Photo 6 shows the final aggregate.

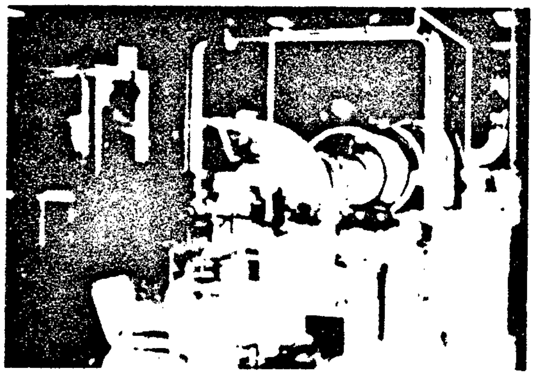
PROPERTIES OF AGGREGATE

Sieve Analysis

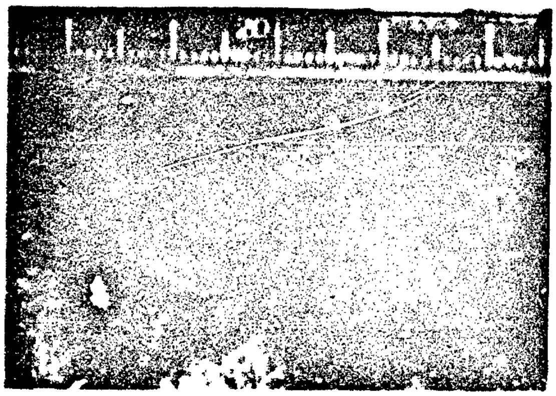
The sieve analysis was conducted according to the method defined in JIS A1102 (1). The results are shown in Table 2. The particle size of a substantial portion of the calcined aggregate was concentrated within the range of 5-10 mm. The river gravel used in this experiment was sieved to provide the same particle-size distribution as the calcined aggregate to ensure a reasonable comparison.



Photograph 4. Feeder



Photograph 5. Rotary kiln



Photograph 6. Calcined artificial aggregates

TABLE 2. SIEVE ANALYSIS TEST RESULTS

Kind of aggregate		Clear square opening of siev (mm)				Fineness modules
		10	5	2.5	1.2	
River gravel		0.2*	99.7	99.9	100	6.00
Calcination temperature	1170-1190°C	0.2	99.7	99.9	100	6.00
	1150-1170°C	0.5	99.2	99.5	100	4.00

* Percent retained.

Specific Gravity, Coefficient of Water Absorption, and Weight of Unit Volume

The specific gravity and coefficient of water absorption of the calcined aggregate were measured according to the methods specified in JIS A1110 (2), and the weight of unit volume was determined by the method given in JIS A1104 (3). The results are listed in Table 3. No significant difference in specific gravity was observed between the two kinds of aggregate calcined at 1170-1190°C and 1150-1170°C. However, the coefficient of water absorption was 18.45% for the aggregate calcined at the lower temperature, which is 6% larger than that calcined at the higher temperature. The calcined aggregate was lighter than the river gravel of the same particle size, its weight of unit volume being 68% for the calcination temperature of 1170-1190°C and 60% for the temperature of 1150-1170°C.

TABLE 3. SPECIFIC GRAVITY, COEFFICIENT OF WATER ABSORPTION, AND WEIGHT OF UNIT VOLUME OF AGGREGATES

Kind of aggregate \ Test item		Sp. gr.	Coefficient of water absorption(%)	Weight of unit volume (kg/m^3)
River gravel		2.64	0.68	1,660
Calcination temperature	1170-1190°C	2.04	12.41	1,130
	1150-1170°C	1.97	18.45	1,000

Leaching Test for Toxicants on the Calcined Aggregate

The leaching test for toxicants was carried out on the calcined aggregate according to the procedure defined in the Environment Agency Notification No. 22. The results obtained are shown in Table 4. No toxicants were detected by this experiment, and the calcined aggregate was confirmed to be harmless.

TABLE 4. LEACHING TEST RESULTS OF THE ARTIFICIAL AGGREGATE

Name of toxicants	T-Hg	Pb	Cd	As	CN	Cr(VI)
The limit of detection for toxicants in case of the reclamation, appointed by Environment Agency, Japan (mg/ℓ)	0.005	3	1.5	1.5	1	1.5
Results	UD*	UD	UD	UD	UD	UD

* Undetectable.

APPLICATION TO CONCRETE

Materials and Apparatus

Materials

Cement

Normal portland cement was used. Its chemical composition is listed in Table 5, and physical properties are shown in Table 6 and Table 7.

TABLE 5. CHEMICAL COMPOSITIONS OF NORMAL PORTLAND CEMENT

	ig. loss	In sol.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	(%) Total
Normal portland cement	0.4	0.0	22.4	5.3	3.1	64.9	1.5	1.7	99.3
JIS 5201 (-)	<3.0						<5.0	<3.0	

Fine sand

Fine sand collected from River Sagami was used. Its specific gravity was 2.59, coefficient of water absorption was 2.12%, and fineness module was 3.20.

River gravel used as reference

River gravel as listed in Tables 2 and 3 was used for comparison with the calcined aggregate.

TABLE 6. PHYSICAL PROPERTIES OF NORMAL PORTLAND CEMENT

Item	Sp. gr.	Fineness: Specific surface area (m^2/g)	Fineness: Residual (%)	Water content (%)	Setting: Initial setting time (m/h)	Setting: Final setting time (m/h)	Setting: Temperature (°C)	Setting: Humidity (%)	Soundness
Normal portland cement	3.16	3,280	1.0	26.4	2-43	3-53	21	83	Good
JIS 5210 (5)		>2,500			>60	<10	20 ± 3	>80	Good

TABLE 7. PHYSICAL PROPERTIES OF NORMAL PORTLAND CEMENT

Item	Flow	Strength (kg/cm^2) Bending 3d	Bending 7d	Bending 28d	Compressive 3d	Compressive 7d	Compressive 28d
Normal portland cement	266	32	49	70	132	236	408
JIS 5210 (5)					>70	>150	>300

Apparatus

A 100-ℓ capacity forced mixer was used.

Dimensions of Test Pieces

Compressive and Tensile Strength Tests

The size of the test pieces used for the compressive and tensile tests was ϕ10 × 20 cm.

Bending Strength Test

The size of the test pieces used for the bending test was 10 × 10 × 40 cm.

Curing and Testing Methods

Curing of Concrete

Concrete samples were removed from the forms two days after casting, and then cured in water at 20 ± 1°C to the respective testing ages.

Testing Methods

The compressive, bending, and tensile strength tests were conducted according to the methods specified in JIS A1108 (6), A1106 (7), and A1113 (8), respectively.

Mix Proportions of Concrete

In order to determine the effect of the type of aggregate on fresh concrete and hardened concrete, mix proportions were set so that the weight of cement per unit volume of concrete, weight of water per unit volume of concrete, and S/a ratio would be maintained constant, as shown in Table 8.

TABLE 8. PROPORTION OF CONCRETE

Kind of aggregate		Maximum size (mm)	Slump (mm)	W/C (%)	S/a (%)	Air (%)	Quantity of material per unit volume of concrete (kg/m³) Water	Cement	Sand	Gravel	Admixture
River Gravel		10	12	50	50	5	182	350	851	867	0.875
Calcination Temperature	(1170-1190°C)	10	12	50	50	5	182	350	851	670	0.875
	(1150-1170°C)	10	12	50	50	5	182	350	851	647	0.875

Test Results

The test results on fresh and hardened concrete are shown in Table 9.

In fresh concrete, the calcined aggregate gave a slump 4.4-7.6% smaller than that given by the river gravel and showed 34-48% increases in air entrainment. In hardened concrete, on the other hand, the same level of compressive strength as the river gravel concrete was obtained with the artificial aggregate calcined at 1170-1190°C, for both samples cured for 7 and 28 days; that is, the sample cured for 28 days showed a compressive strength of 400 kg/cm^2. The concrete using the aggregate calcined at 1150-1170°C, however, showed a compressive strength about 85% of that of the river gravel concrete.

In the bending test, as compared with the river gravel concrete, the artificial aggregate calcined at 1170-1190°C gave a higher strength for both

TABLE 9. TEST RESULTS OF FRESH CONCRETE AND HARDENED CONCRETE

Kind of aggregate \ Test item		Fresh concrete Slump (cm)	Fresh concrete Air (%)	Compressive 7d	Compressive 28d	Bending 7d	Bending 28d	Tensile 7d	Tensile 28d	Static elastic modulus (28) × 10^5
				Strength of hardened concrete (kg/cm²)						
River gravel		15.8	5.8	256 (1.00)*	405 (1.00)	42.5 (1.00)	50.3 (1.00)	24.3 (1.00)	26.6 (1.00)	3.51 (1.00)
Calcination Temperature	(1170-1190°C)	15.1	7.8	251 (0.98)	400 (0.99)	45.9 (1.08)	52.1 (1.04)	22.4 (0.92)	30.8 (1.16)	2.58 (0.74)
	(1150-1170°C)	14.6	8.6	219 (0.86)	345 (0.85)	42.0 (0.99)	48.4 (0.96)	22.3 (0.92)	21.7 (0.82)	2.20 (0.63)

* Index.

the two age groups, and nearly the same level was observed for the aggregate calcined at 1150-1170°C.

The tensile strength was about 10% higher when the aggregate calcined at higher temperatures was used, but was about 20% lower with the calcination temperature of 1150-1170°C.

PRODUCTION COST OF CALCINED AGGREGATE

The quantity of sediment to be dredged for clarifying the water of Lake Suwa amounted to about 530,000 m^3. If a new aggregate calcination plant with a capacity of 10 t/h (240 t/d), including a dryer, rotary kiln, power station, and other necessary facilities is built, the production cost of the calcined aggregate is estimated at approximately 9800 yen/t product (2200 yen/m^3 sediment).

CONCLUSION

The manufacture of artificial aggregates from calcined sediment requires no pulverizing and no bonding agents for granulation or pelletizing because the sediment is originally made of very fine particles and has a bonding property due to the organic materials contained. Therefore, the manufacturing processes are simpler than ones for natural rock. This is an advantage in production costs.

The most important points regarding production are the heating rates and the calcination temperature. These are carefully determined by pre-calcining tests in the laboratory. In this case, the former is 5°C/min and the latter is 1150-1190°C. It has been demonstrated that the compressive strength of the concrete made of artificial aggregates is the same or a little higher than that using natural aggregates.

This means that the calcined sediment can be applied to civil engineering practices. It is found that the trial cost of production is not as high as might be expected. Therefore, it can be said that the calcination of sediment is a promising way of using resources.

REFERENCES

(1) JIS*A 1102 Method of Test for Sieve Analysis of Aggregate

(2) JIS A 1110 Method of Test for Sieve Gravity and Absorption of Coarse Aggregate

(3) JIS A 1104 Method of Test for Unit Weight of Aggregate and Solid Content in Aggregate

(4) JIS A 5201 Classification Standard of Tile for Exportation

(5) JIS A 5210 Hollow Clay Building Blocks

(6) JIS A 1108 Method of Test for Compressive Strength of Concrete

(7) JIS A 1106 Method of Test for Flexural Strength of Concrete

(8) JIS A 1113 Method of Test for Splitting Tensile Strength of Concrete

* JIS: Japanese Industrial Standard.

SEVERAL SOLIDIFIED SEDIMENT EXAMPLES

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ABSTRACT

The treatment of bottom sediments by solidification has increased in Japan in recent years. This paper describes the state of the art in our country, citing some examples. The applications of this method can be divided into four cases, which are discussed in this paper.

INTRODUCTION

Solidification of bottom sediments is similar in principle to the soil-cement and soil-lime methods in soil stabilization on land. However, the properties of the bottom sediments and the places where work is done differ considerably from work on land. Accordingly, solidification of bottom sediments is different from conventional soil-cement and soil-lime methods in many respects such as the purposes, effects, and applications of solidification, work execution equipment, and solidificants. This paper describes the results of investigations and tests carried out regarding these points.

PURPOSES AND EFFECTS OF SOLIDIFICATION

The purposes of solidifying bottom sediment are to increase the mechanical strength of sediment and to prevent the release of toxic components into the overlying water.

Increase of Strength

Bottom sediments possess large quantities of very fine particles, have high water contents, and are extremely soft. Therefore, from the standpoint of soil mechanics, bottom sediments comprise one of the worst kinds of soil. For example, the softness of sediments is a great obstacle to work in cases such as the following:

(1) Effective use as land of the dredged sediment containment area.
(2) Hauling of dredged sediment to the containment area by dump truck.

(3) Utilization of dredged sediment for civil work materials such as embankment and fill materials.

Therefore, it is extremely important to increase the strength of sediments.

Methods of increasing sediment strength are based on stabilization methods for soft ground. Stabilization methods for bottom sediment may be broadly divided into the three categories: sun-drying, consolidation drainage, and solidification. Of these methods, solidification is often adopted since it makes it possible for sediments to be stabilized in a shorter time and to a higher strength compared with the other two methods.

Prevention of the Release of Toxic Components

Bottom sediments, especially sediments at the bottom of water fronting urban areas, often contain large quantities of heavy metals, PCB, nitrogen compounds, and phosphorus compounds as toxic substances. When preventing release of these toxic substances by solidification, the mechanism may be divided into physical and chemical aspects.

Physical Mechanisms of Release Prevention

When solidificants are mixed into bottom sediments, the sediment particles are mutually bonded together, while voids between the particles are filled to a considerable degree by hydration products of the solidificants so that the permeabilities of the sediments are substantially decreased.

Consequently, churning up sediment particles due to the disturbance of overlying water is prevented, while further, for practical purposes, the contact area of sediment particles with overlying water is decreased. It is in such a manner that heavy metals, PCB, nitrogen compounds, and phosphorus compounds are physically restrained from being leached out from sediments into water. It may be considered that such a physical mechanism is more important than the chemical mechanism in preventing release.

Chemical Mechanisms of Release Prevention

Since cement and lime are used as solidificants, solidified sediments show fairly high pH values, particularly values immediately after mixing solidificants that reach 11 to 12. This rise in pH has great significance in the chemical mechanism, with the influences being different for heavy metals than for nitrogen and phosphorus compounds.

Heavy metals generally form hydroxides of low solubility under alkaline conditions. This may chemically stabilize the heavy metals in the sediments. However, the sediments are in a reductive condition and contain large amounts of sulfur componds, while the heavy metals are in the form of sulfides. The solubilities of these metal sulfides are much lower than those of hydroxides of the metals. Also, there are some hydroxides of heavy metals which produce complex ions when their pH values are higher than about 10 and become more soluble. Further, in the case of mercury compounds, although sulfides are extremely stable, hydroxides are unstable. In these respects, it cannot be said that solidification will chemically suppress the release of heavy metals.

It is conceivable that when bottom sediments are dredged and oxidized through exposure to air at containment areas, the sulfides will be transformed into sulfates, pH values will change to the acidic side, and the solubilities of heavy metals will increase. Solidification with the objective of preventing acidification will be chemically effective.

Most of the nitrogen and phosphorus compounds in bottom sediments, along with carbon compounds, comprise components of organic matter in the sediments. Generally speaking, organics in soil are decomposed into humus and soluble organic matter under alkaline conditions. Similar phenomena have been recognized in cases of the solidification of bottom sediments. When sediment is solidified with cement or lime, the organics in the sediment are decomposed by alkali and a part becomes soluble so that the nitrogen concentration and COD of the overlying water are increased. However, phosphorus compounds in sediment react with calcium ions in the solidificant to form calcium phosphate which is low in water solubility, and there is practically no leaching of phosphorus. In view of the above, in order to suppress nitrogen compounds in sediments from being released and COD from being increased, it will be advantageous to use a solidificant which raises pH as little as possible.

Therefore, it cannot necessarily be said that solidification contributes greatly to chemically preventing leaching, and it is considered that physical release prevention effects are more significant. It should be mentioned, however, that several varieties of solidificants containing additives to enhance chemical release prevention effects have been marketed in recent years. In any event, further investigations will be necessary regarding the matter of preventing leaching out of toxic substances by solidification.

APPLICATIONS OF SOLIDIFICATION

Cases in which solidication would be applied to treat bottom sediments may be divided into the four categories as discussed below.

Case A: Bottom sediments are dredged and transferred to containment areas where effluent is treated and then discharged. When the bottom sediments have been filled to the planned height and have settled to an extent, they are subjected to solidification (Figure 1). The extents and forms of solidification may be divided into the three kinds shown in Figure 2.

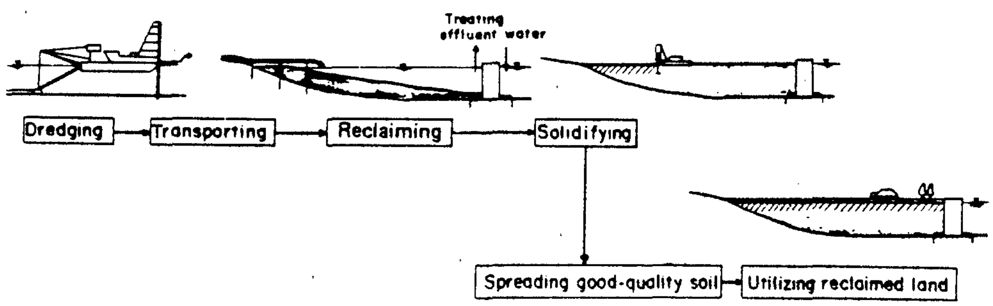
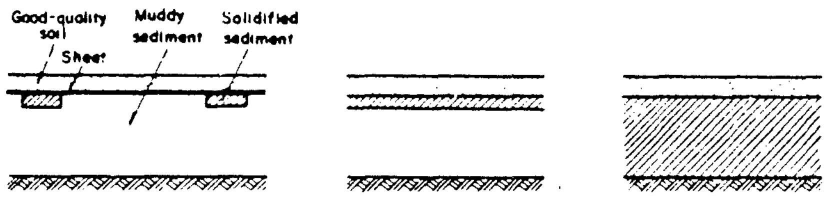


Figure 1. Typical diagram of Case A



(a) Solidifying surface layer of sediment in stripes

(b) Solidifying entire layer of sediment

(c) Solidifying entire layer of sediment

Figure 2. Extents and configurations of solidification in Case A

Case 3: Sediments are dredged and solidified on the way to the final containment area. This is an effective method when dredging by grab dredger or suction dredger which is capable of dredging at high solids concentration (Figure 3).

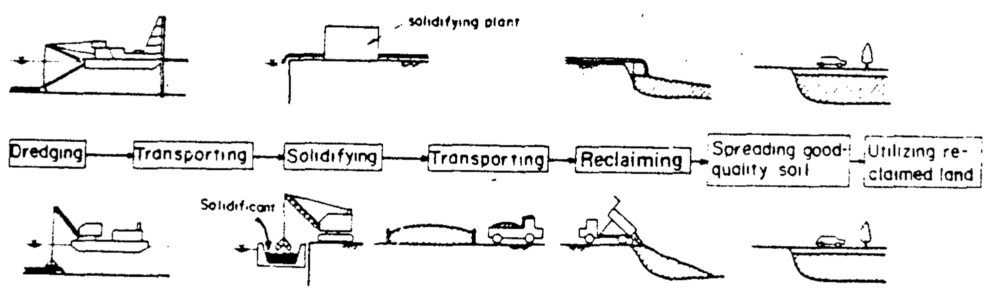


Figure 3. Typical diagram of Case B

Case C: A part of the water body is cofferdammed and dewatered, and, after lowering the water level, the bottom sediments are solidified in situ. Upon completion of solidification, the water level is restored directly over the solidified sediment or after providing an overlay of concrete. There are also cases when the solidified sediment is removed, after which the water level is restored (Figure 4). This method is often applied in treating bottom sediments in rivers.

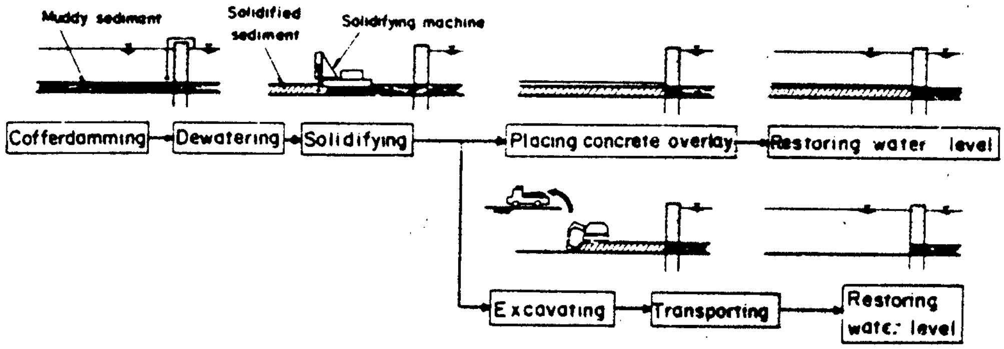


Figure 4. Typical diagram of Case C

Case D: Bottom sediments are solidified in situ from a treatment vessel at the surface of the water with hardly any change in the water level (Figure 5). This method is applied at times when dredging cannot be done and lowering the water level is difficult. However, there are very few examples of implementation of this method. The chief reasons for this situation are the three below. Firstly, water is contaminated by agitation of sediments and solidificant when performing solidifying work. Secondly, the solidified strength is not increased very much since part of the surface layer of the sediments is drawn in large quantity. Thirdly, adverse effects on benthos are of concern.

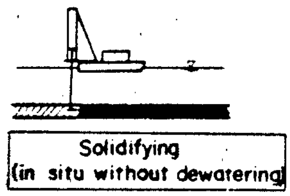


Figure 5. Typical diagram of Case D

EQUIPMENT AND SOLIDIFICANTS FOR SOLIDIFICATION

Equipment

The equipment for solidification will differ depending on the method of solidification. The equipment used in Cases A, C, and D described above consists of machines for solidifying ground comprised of bottom sediments. The equipment used in Case B consists of machinery for solidifying dredged sediments in transit to the containment area.

Solidifying Equipment for Sediment

Equipment for treating sediment generally consists of a plant for supplying solidificant made into a slurry by mixing solidificant powder and water in ratios of 1:1 to 1:3 by weight, and an agitator-mixer for mixing the supplied solidificant with bottom sediments. Agitator-mixers may be classified as ship-type (Figure 6) and crawler-type (Figure 7).

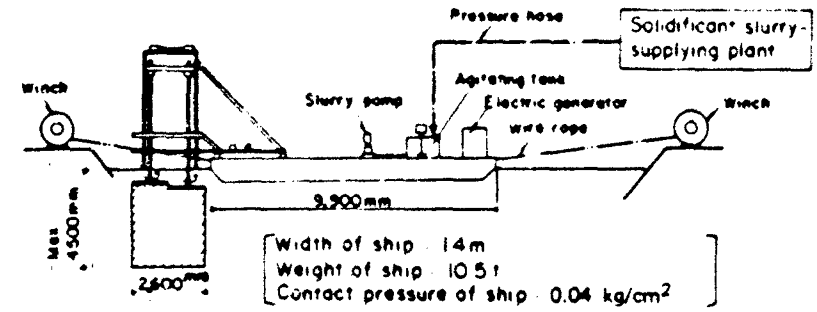


Figure 6. Example of ship-type agitator-mixer

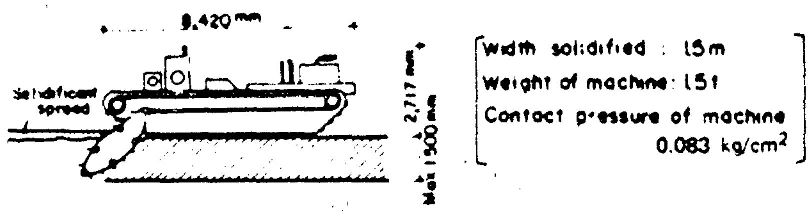


Figure 7. Example of crawler-type agitator-mixer

The ship-type equipment is a machine which travels on the surface of bottom sediments forcing solidificant slurry pumped from the solidificant-supplying plant into the sediments and performs agitation and mixing. The speed of the agitating propeller of the ship is 40 to 60 rpm. This type of agitator-mixer is capable of accurate travel on the surface of even very soft sediment, work can be executed even on water, and the thickness of the treatment is large.

On the other hand, a crawler-type is a self-propelled machine having a pontoon-type body equipped with extra-width treads. Solidificant is pumped from the solidificant-slurry-supplying plants in cases similar to the ship-type, but there are cases in which solidificant is spread in the path of the crawler-type equipment. The crawler-type cannot move about freely when the bottom sediment is very soft, while the thickness of solidification is approximately 1.5 m at maximum. A feature of this type is easier traveling and work efficiency is good if the strength of the sediment-ground is higher than a certain level.

Solidifying Equipment for Sediment in Transit

Equipment for solidifying bottom sediments which have been dredged and are on the way to the containment area may be divided into agitating-blade types, pipeline-mixer types, and bucket types.

The agitating-blade type is represented by the pugmill mixer. The pipeline-mixer type has blades attached inside a pipe, and sediment to which solidificant has been added passes through to become mixed. Further, clamshells and backhoes are typical of bucket type equipment.

Solidificants

Solidificants may be divided into cement types and lime types. Since the former are hydraulic, it is possible for bottom sediments of high water contents to be solidified. As for the latter, quicklime or lime are used, and, although there is a dehydration effect, the degree of solidification is inferior to cement types. Therefore, cement type solidificants are chiefly used to solidify sediments of high water content and very weak strength.

A typical solidificant of the cement type is ordinary portland cement. Ordinary portland cement is frequently used in solidification of bottom sediments. Meanwhile, in recent years, in order to further increase solidified strength, cases of using special cement type solidificants with chemical and mineral compositions adjusted have increased. However, there were many unknown aspects regarding the effects and conditions for applications of these special solidificants. Accordingly, comparison tests were performed on 14 varieties of cement type solidificants. The results of the tests are described in outline below.

TABLE 1. PROPERTIES OF SOIL SAMPLES

	Clay (%)	Silt (%)	Sand (%)	Atterberg limits LL (%)	PL (%)	PI	Specific gravity Gs	Ig loss (%)	Natural water content (%)	Liquidity index LI
Ohtemachi	50	49	1	114	52	62	2.61	6	250	3.19
[illegible]	38	[illegible]	5	113	35	78	2.52	11	250	2.76
[illegible]	36	51	13	120	43	77	2.49	23	230	2.43
[illegible]	[illegible]	12	11	268	54	214	2.34	43	510	2.13

Fourteen representative varieties of solidificants, (A, B, ... , N) were used in the tests. The four varieties of soils shown in Table 1 were used as soil samples. Of the four varieties of soil, three, (not including Ohtemachi) were bottom sediments, while Ohtemachi was a cohesive soil excavated in a foundation project.

Chemical Compositions of Solidificants

Solidificants, as shown in Figure 8, contain CaO, SiO_2, Al_2O_3 and SO_3, and may be divided into six groups according to the contents of the above. Solidificants B to N contain larger amounts of SO_3 compared with A (ordinary portland cement)

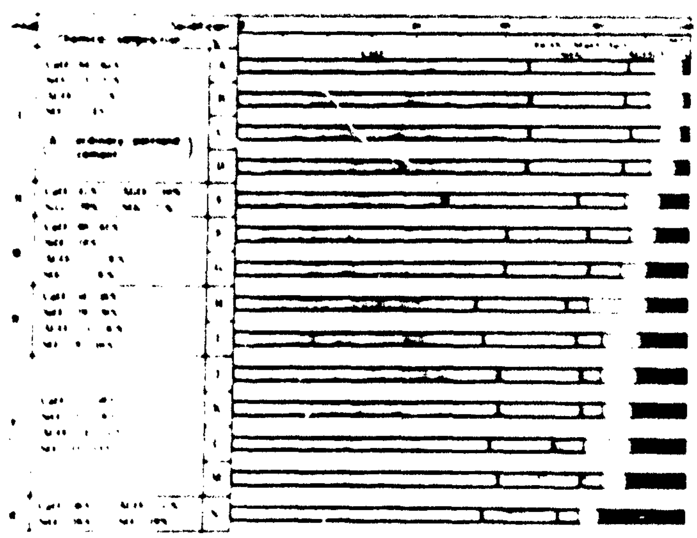


Figure 8. Chemical compositions of 14 varieties of solidificants

Relations between Varieties of Solidificants and Solidified Strengths

The unconfined compressive strengths after 28 days of curing the four varieties of soil treated with the solidificants are shown in Figure 9. It may be seen that strengths were similar within groups of solidificants. The group indicating high strength on the average was V, followed in order by III, VI, IV, I and II. Therefore, the relations between chemical compositions of solidificants and solidified strengths were examined, and as a result, as shown in Figure 10, strengths were found to be considerably influenced by the CaO and SO_3 contents of solidificants. High strengths were gained when CaO contents of solidificants were 58 to 60% and SO_3 contents 9 to 13%.

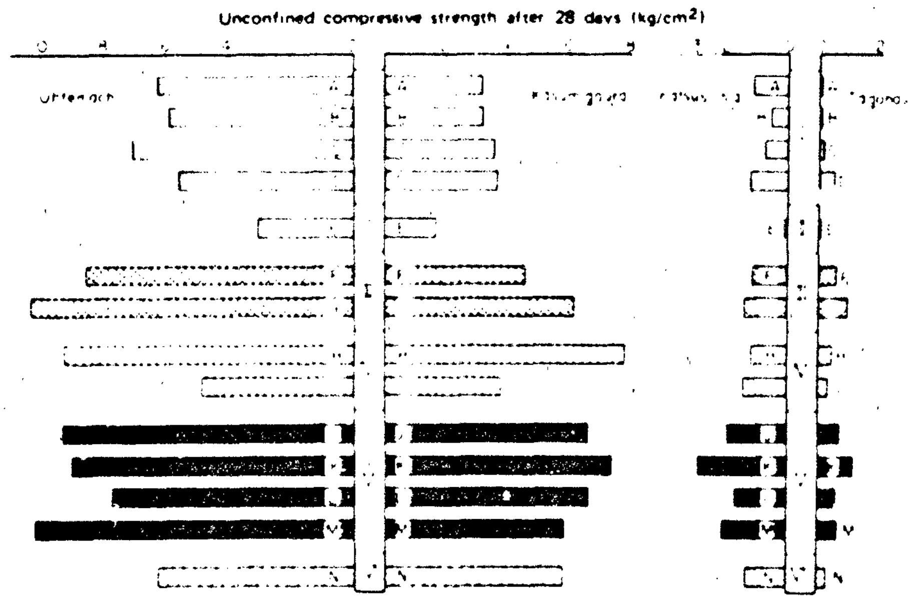


Figure 9. Unconfined compressive strengths of soils solidified with 14 varieties of solidificants

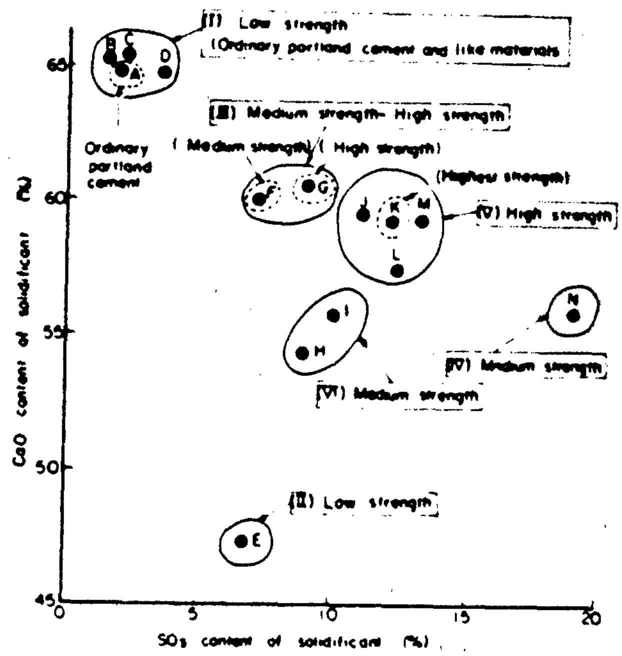


Figure 10. Relations between chemical compositions of solidificants and solidified strengths

Examination of Solidified Strength by X-ray Diffractometer

Examples of X-ray diffraction charts are shown in Figure 11 for sediments from two locations. Both sediments showed peaks for quartz, feldspar and clay minerals before solidification. And, after solidifying with solidificant K, peaks not seen prior to solidification appeared at 9.1° (9.37Å), 15.8° (5.61 Å), and 22.9° (3.88 Å). These peaks were identified as a mineral, ettringite, whose formula is $3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$.

As shown in Figure 12, strength has a tendency to increase as the amount of ettringite in the solidified sediment increases. The solidificant N, in spite of producing a large amount of ettringite, does not show very high strength, and the reason for this is not clear.

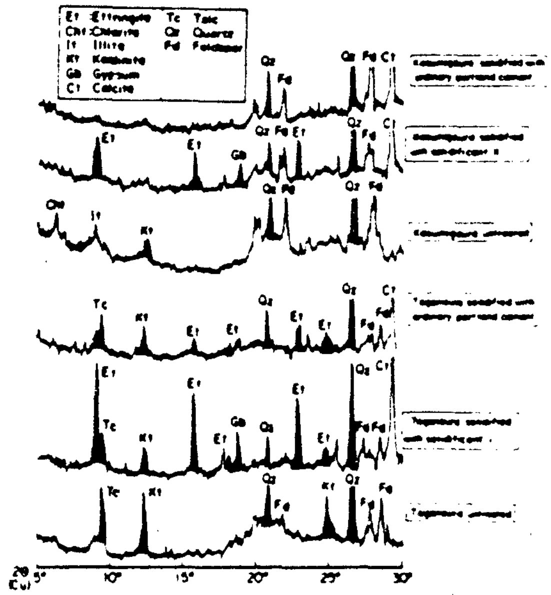


Figure 11. X-ray diffraction charts for sediments and solidified sediments

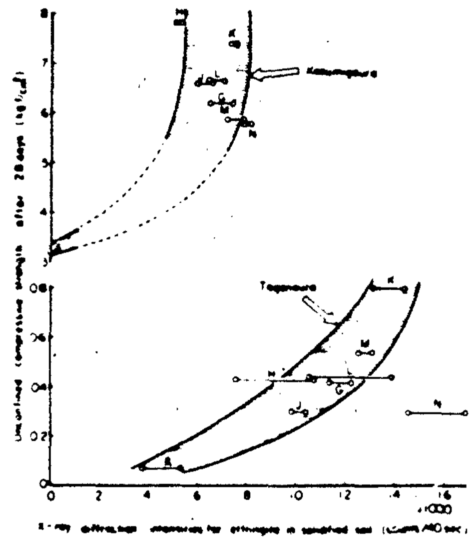


Figure 12. Relations between quantities of ettringite formed in solidified sediments and solidified strengths

Examination of Solidified Strength of Scanning Electron Microscope

Photos 1 to 6 are scanning electron micrographs of Tagonoura and Kasumigaura sediments before and after solidification. It may be seen that aggregates of cement hydrate minerals are formed in the solidified sediments with interstices filled by acicular crystals of ettringite to form bridges between the aggregates. It may be surmised from this that formation of ettringite, in a similar way to the formation of other cement hydrate minerals, contributes greatly to strength gain of solidified sediment.

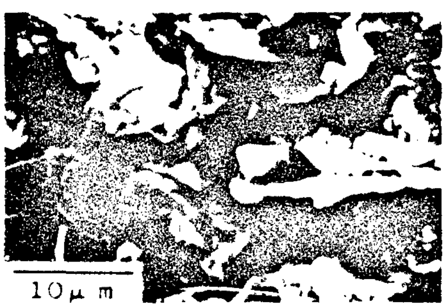


Photo. 1 Scanning electron micrograph of Tagonoura bottom sediment (untreated)

Photo. 2 Scanning electron micrograph of Tagonoura bottom sediment (solidified with solidificant K)

Photo. 3 Scanning electron micrograph of Katsushima bottom sediment (untreated)

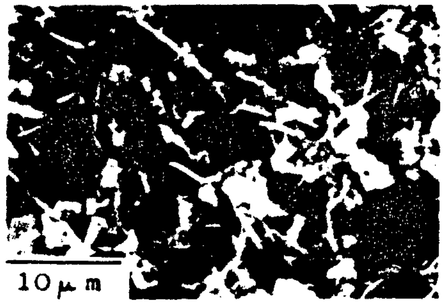


Photo. 4 Scanning electron micrograph of Katsushima bottom sediment (solidified with solidificant K)

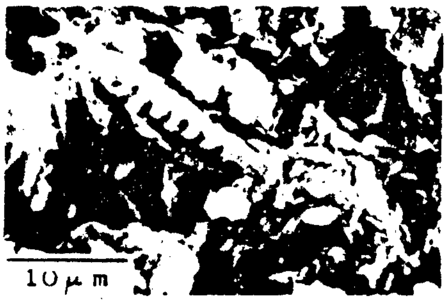


Photo. 5 Scanning electron micrograph of Kasumigaura bottom sediment (untreated)

Photo. 6 Scanning electron micrograph of Kasumigaura bottom sediment (solidified with solidificant H)

FACTORS INFLUENCING STRENGTH OF SOLIDIFIED SEDIMENT

Various factors influence solidified strength, the principal ones being the following:

(1) Factors regarding properties of bottom sediments:
water content, grain-size distribution, organic contents

(2) Factors regarding solidificants:
varieties of solidificants, quantities of solidificants added

(3) Factors regarding mixing of bottom sediments and solidificants:
mixed condition

(4) Factors regarding curing:
curing temperature, curing time

Although all of the these factors are important, the mixed condition and curing temperature are of particular importance in estimating solidified strengths in the field from laboratory tests and designing the quantities of solidificant added.

Accordingly, investigations were conducted on the degree of influence the mixed condition and curing temperature have on the differences between laboratory tests and field strengths, and examples of the investigation results are described below. These investigations were carried out in the solidification project example of Fushigi-Toyama described later in this paper.

Method of Testing

Specimens of solidified soil were prepared by the four methods shown in Figure 13. Since samples were collected simultaneously from a small area, all were thought to be of the same properties with the cement addition quantities roughly identical. The strength according to ② in Figure 13 is the strength in laboratory tests performed in general; that is, the strength for bottom sediment to which solidificant had been added and was thoroughly mixed and cured in a 20°C constant temperature room. The strength according to ④ is the field strength, in effect, the strength of sediment ground solidified by solidifying equipment.

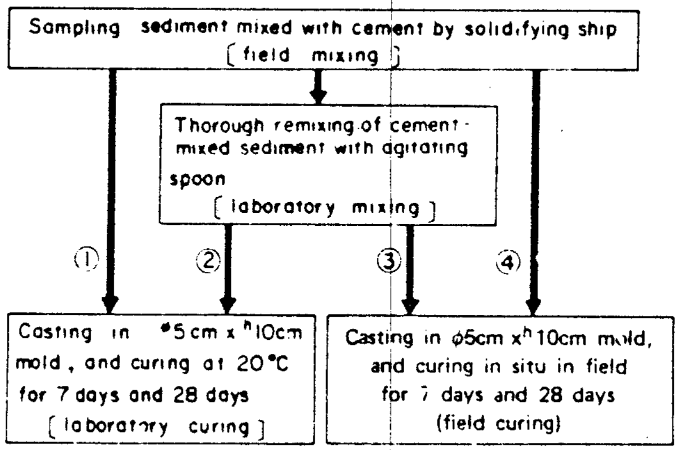


Figure 13. Four methods of preparing solidified specimens

Influences of Differences in Mixed Condition and Curing Temperature on Solidified Strength

The results of unconfined compressive strength tests for the methods of ① through ④ are given in Figure 14. Solidified strength is highest with ②, followed in order by ①, ③, and ④.

The relations of unconfined compressive strengths between the cases ① to ④ are shown in Figures 15 through 17. From the relation between ② and ④ in Figure 15, the following is obtained:

$$\gamma = \frac{qu - fm \cdot fc}{qu - lm \cdot lc} = 0.20 \sim 0.35 \text{ (av. 28\%)}$$

where

l_m : laboratory mixing
l_c : laboratory curing
f_m : field mixing
f_c : field curing
qu : unconfined compressive strength

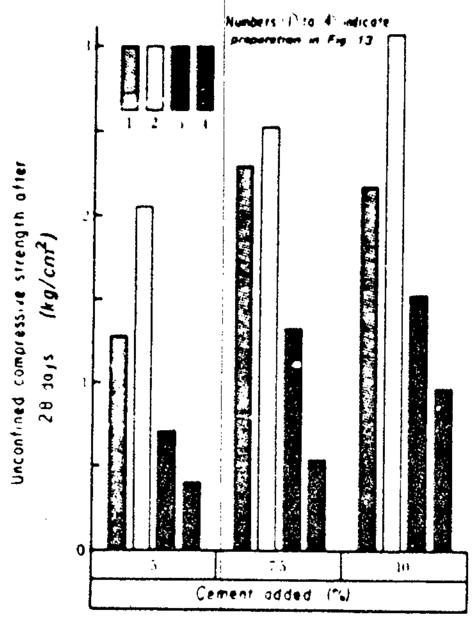


Figure 14. Unconfined compressive strengths of solidified specimens prepared by four different methods

The symbol γ expr sses the ratio between field strength and laboratory strength, and it is suggested that field strength in this project is no more than about 20 to 35% (average 28%) of the strength in ordinary laboratory tests. These figures are extremely important when designing the addition quantity of solidificant in a solidification project based on laboratory test results.

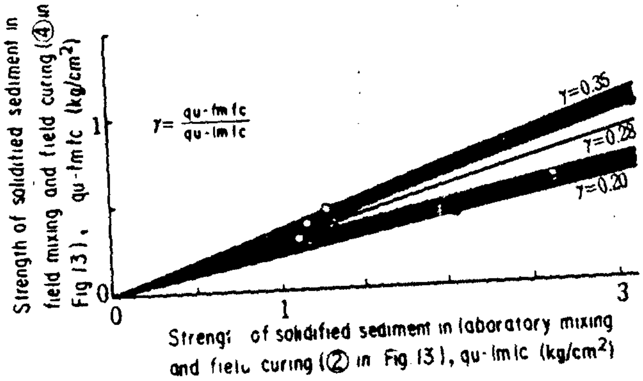


Figure 15. Relations between laboratory and field strengths

The differences in mixed conditions and curing temperatures greatly influence the difference between field and laboratory strengths, and a question arises as to the degree of contribution by each factor. Figure 16 shows the influence of the mixed condition:

$$\alpha = \frac{qu - fm}{qu - lm} = 0.41 - 0.94 \text{ (av. 67\%)}$$

Figure 17 shows the influence of curing conditions:

$$\beta = \frac{qu - fc}{qu - lc} = 0.23 - 0.67 \text{ (av. 44\%)}$$

As indicated above, field strengths, compared with laboratory strengths, were found to be reduced to an average of 67% due to poorer mixing conditions and an average of 44% due to a low curing temperature. The mixing condition is affected by the configurations and rotating speeds of the agitating propellers of the equipment, mixing times, etc. Meanwhile, curing temperature is influenced by factors such as meteorological conditions.

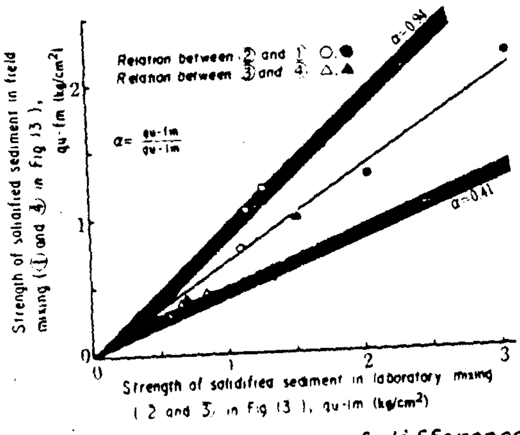


Figure 16. Influences of differences in mixing conditions

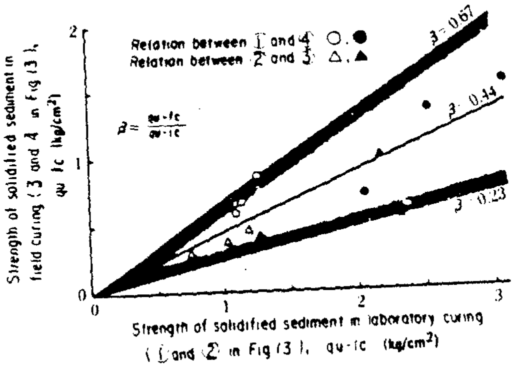


Figure 17. Influences of differences in curing conditions

Curing Temperature in the Field and Its Influence on Strength

The investigations were carried out in the wintertime during December and January, and the surface of the solidified bottom sediments was oftem covered by snow. Figure 18 shows the results of investigations of temperatures inside the sediments in the direction of depth 4 to 5 days after solidification treatment in the field. The temperatures in untreated ground were 11 to 13°C. On the other hand, although solidified ground was not very much different from untreated ground down to 20 cm from the surface, the temperature rose to 20°C at around 50 cm, the center of the solidified portion, so that the temperature was 7 to 8°C higher than at untreated ground. It was ascertained that such a temperature difference continued to exist for approximately one week after solidification, but subsequent measurements were not made.

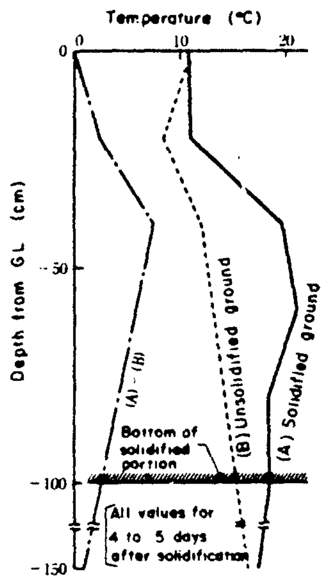


Figure 18. Underground temperatures in solidified and unsolidified sediment ground

Based on the above, it was found that the field curing temperature in the vicinity of the surface layer was approximately 10°C. Thereupon, separate tests were carried out in the laboratory regarding the influence on solidified strength of the difference between curing temperature in the field (10°C) and curing temperature in the laboratory (20°C). The results are given in Table 2. Solidified strength was reduced to approximately one half by lowering the curing temperature from 20°C to 10°C. This agrees more or less with the influence of curing conditions, β=0.44 (av.), described before, suggesting that the influence of temperature was important among curing conditions.

Table 2. RELATION BETWEEN CURING TEMPERATURE AND SOLIDIFIED STRENGTH (LABORATORY TEST)

	qu 7 days kg/cm²	qu 28 days kg/cm²	qu28days/qu7days ratio
10°C	0.33	0.50	1.52
20°C	0.61	1.06	1.74
qu20°C/qu10°C ratio	1.85	2.12	*

cement 75 % added

EXAMPLES OF SOLIDIFICATION PROJECTS

Sediment Containment Area in Fushigi-Toyama Harbor

This is an example of Case A. At Fushigi-Toyama Harbor in Toyama Prefecture, an area of 70 ha has been reclaimed by filling with bottom sediments brought up by a pump dredger. This ground is very soft since it has only recently been filled. The surface layer sediment stabilization of a portion of the area, 10.5 ha, was carried out for the purpose of land use, and strips of the surface layer were solidified as part of the work. The equipment used was a ship-type machine.

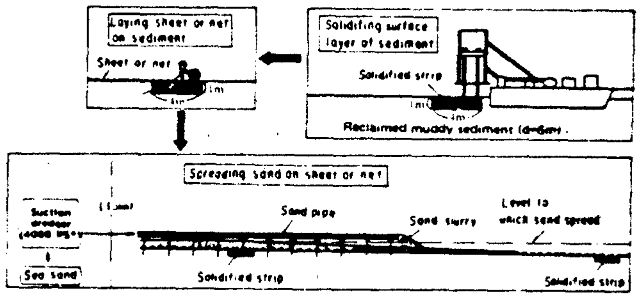


Figure 19. Flow of work

The flow of the work is shown in Figure 19. The extent and configuration of the solidification and the strengths of the sheets and nets laid are indicated in Figure 20.

The objective of the solidification in this project was to secure a foothold for the manual laying of sheets and nets and to improve work efficiency in the spreading of the soil.

Properties of sediment: Water content 136%, liquid limit 80%, plastic limit 28%, ignition loss 9.2%
Solidificant: Ordinary portland cement at 100 kg/m^3
Target solidified strength: Unconfined compressive strength 0.5 kg/cm^2 (28-day curing)
Solidified sediment volume: Approx. 11,000 m^3
Period of work: December 1979 - January 1980

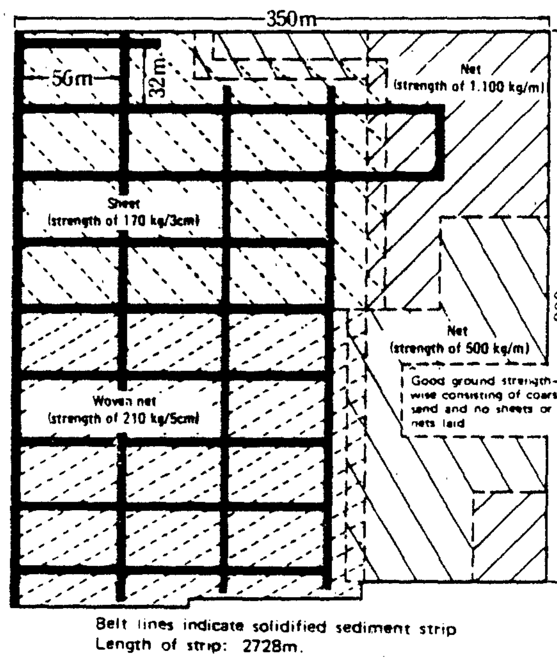


Figure 20. Arrangement of solidified strips and material strengths of sheets and nets laid

Kasumigaura (Test Works)

This is an example of Case B. Bottom sediments were dredged at a high solid content with a negative-pressure suction and pneumatic-pumping dredger

* 1 PS = 75 kg · m/sec.

barge (dredging capacity 100 m^3/hr) with the pipeline branched part way to provide solidification of the sediment. Mixers of the pipeline-mixer type were used for solidifying. A solidificant slurry was injected into the sediment in the branched pipe, the sediment was passed through the mixer, and the sediment intermixed with solidificant was discharged at the disposal area.

Properties of sediment: Water content (at time of solidification) 29%, liquid limit 127%, plastic limit 48%, ignition loss 12.4%
Solidificant: Ordinary portland cement at 116 kg/m^3
Solidified strength: Unconfined compressive strength 0.4 kg/cm^2 (28-day curing), unconfined compressive strength 3.0 kg/cm^2 (180-day curing)
Solidified sediment volume: 40 m^3
Period of work: 1980

Tagonoura Harbor

This is also an example of Case B. Bottom sediment brought up by grab dredger (bucket 6 m^3) was transferred to a soil transport barge (capacity 300 - 500 m^3) and hauled to a wharf. Mixing was performed upon adding solidificant slurry from the solidificant-supply plant using a clamshell at the wharf. The mixing time was approximately 2 hours per transport barge.

Bottom sediment given solidification on the barge was left untouched for 24 hours and then placed on land by clamshell, left another 24 hours at a stockpile, loaded on dump trucks, and hauled to a containment area at the Fuji River channel approximately 5 km distant.

Example sediment properties: Water content (at time of solidification) 180%, liquid limit 120%, plastic limit 55%, ignition loss 27%
Solidificant: A special cement-type solidificant of 144 kg/m^3
Target solidified strength: Unconfined compressive strength 0.3 kg/cm^2 (2-day curing)
Solidified sediment volume: 120,000 m^3 (part of 4th-phase works)
Period of work: February - May 1979 (part of 4th-phase works)

Hama River

This is an example of Case C. The Hama is a river in the city of Nobeoka in Miyazaki Prefecture.

The river with a width of approximately 40 m was cofferdammed in half by double steel sheet-piling in the direction of flow. The interior of the cofferdammed area was dewatered by pump, and bottom sediments were solidified in situ by a ship-type treatment machine. The solidified sediment was dug up by backhoe after approximately one month of curing, and hauled by dump truck to a containment area. At this time, a part of the solidified sediment was left in place to secure the level of the improved river channel cross section. An overlay of concrete was provided on the bottom after excavation and the bed was restored as a water channel. The other half of the cofferdammed river was filled with soil after the solidification of the sediment to build up land which was utilized for a park.

Properties of sediment: Water content 174%, liquid limit 82%, plastic limit 36%, ignition loss 11%
Solidificant: Ordinary portland cement at 100 kg/m^3
Target solidified strength: Unconfined compressive strength 0.6 kg/cm^2 (28-day curing)
Solidified sediment volume: 35,000 m^3

Period of work: 1974-1976

CONCLUSIONS

Four examples of solidified sediment are discussed. From these experiences, it was found that the aims of solidification such as (1) increasing soil strength and (2) preventing the leaching of toxic substances, could be attained on a practical scale. However, further research on the solidified sediment, with respect to solidification practices, is still needed.

AD P002404

JAMES RIVER, VIRGINIA
DREDGING DEMONSTRATION IN CONTAMINATED MATERIAL
(KEPONE)
DUSTPAN VERSUS CUTTERHEAD

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ABSTRACT

The James River, Virginia, is a tributary of the Chesapeake Bay polluted with the toxic pesticide Kepone. The Norfolk District, Corps of Engineers, will conduct a dredging demonstration project as part of the maintenance of the James River Channel. The goals of the demonstration are to achieve containment of a layer of polluted sediment; to minimize resuspension of pollution at the dredge head; and to remove the sediment at in situ density. In order to achieve these goals, a dustpan suction head will be specially adapted and fitted on a typical hydraulic pipeline dredge. The dredge will be operated in the dustpan mode using a dredging method designed to obtain precise positioning of the suction head within the specified layer of polluted sediment. ~~The~~ dredge will also be operated as a conventional cutter suction dredge for comparison with the dustpan arrangement. Monitoring of operating parameters on board the dredge, and of water quality parameters around the perimeter of the operation, will be accomplished with appropriate instrumentation to document the effectiveness of the two dredging methods. It is anticipated that the dredging demonstration will result in a method of adapting readily available cutterhead dredge plant for the cleanup of polluted sediments.

INTRODUCTION

The waterways within the Norfolk District of the Corps of Engineers are generally free of hazardous substances. Where dredging is required to maintain navigable channels, pollution normally does not impede this activity. The James River, however, where the toxic pesticide Kepone has polluted the waterway, the dredging of the channel has became a major issue. The Kepone pollution has also directly resulted in the Norfolk District's dredging demonstration for Kepone removal.

BACKGROUND

The James River is a tributary of the Chesapeake Bay and is located in the State of Virginia about 400 miles (640 kilometers) south of New York (Figure 1). Its sources are in the Allegheny Mountains of West Virginia and Virginia. Between the City of Richmond and the mouth at Hampton Roads, a distance of 90 miles (145 kilometers), the James is tidal and navigable. In this portion of the river, a navigation channel 25 feet (7.6 meters) deep is maintained to serve the ports of Richmond, Hopewell, and the industries between these cities. These industries and port activities depend on the James River Channel for the economical transport of many commodities and raw materials. As is the case on many of the world's waterways, local industries have created pollution. In particular, the Allied

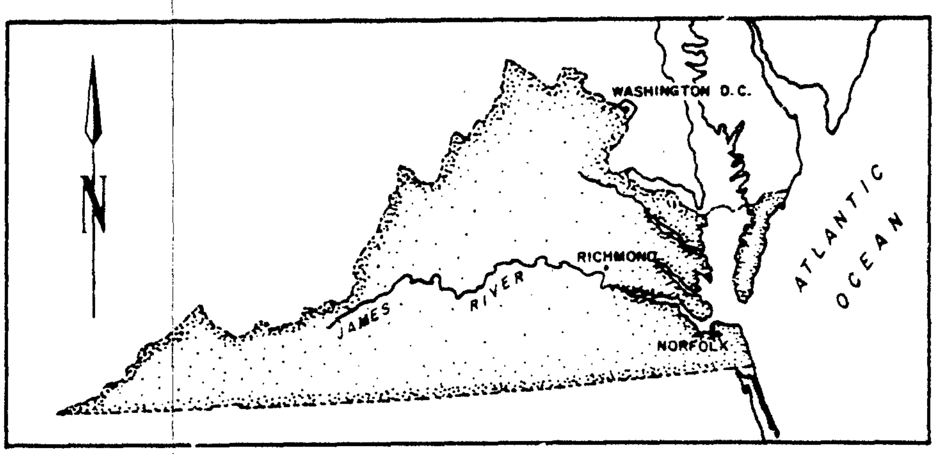

Figure 1. Location of the James River, Virginia

Chemical Corporation, at plants in the vicinity of Hopewell, Virginia, was responsible for the release of Kepone into the James River system. Between 1967 and 1975 it is estimated that as much as 65,000 pounds of the highly toxic chemical were discharged into the James River basin.

The extent of the Kepone pollution was not fully discovered until 1975, and the production and resultant discharge of the chemical was ceased that year. The closing of the James River to fishing and shellfishing was ordered by the Governor of Virginia in December 1975. Since that time the State has periodically sampled the river and its seafood in order to monitor Kepone levels, and promulgated regulations pertaining to seafood harvesting in the James River. In recent years, Kepone levels have decreased in organisms to the extent that, for most species, commercial harvesting is again permitted within certain geographic and seasonal limits. However, Kepone data obtained during the summer and fall of 1981 by the State show that this trend has reversed, perhaps only temporarily, and that Kepone levels in certain fish have risen. While the now relaxed fishing regulations have not been made more restrictive, it is apparent that the Kepone problem will persist for years. Following discovery of the extent of Kepone pollution, and formation of State and Federal task forces, the U.S. Environmental Protection Agency (EPA) conducted the Kepone Mitigation Feasibility Study. As part of this effort, the Norfolk District was requested to evaluate alternatives for the removal of Kepone-contaminated sediments, and to investigate all potential dredging technology and methods to control resuspension and secondary pollution. During this mitigation study, a delegation from EPA and the Norfolk District visited Japan to observe specialized methods of handling toxic sediments. The group was favorably impressed with the Oozer Dredge because of its alleged ability to achieve a high solids to water ratio and minimize resuspension. As a result of the Japan visit, the Norfolk District recommended that a demonstration project be conducted on the James River to evaluate the Oozer Dredge in comparison with a conventional cutter suction dredge. The basis for the recommendation was that there would be a need to know the best method of removing pollutant "hot spots", whether consisting of Kepone in the James River or toxics in other areas of the country if the Corps were assigned a cleanup mission.

The recommendation to conduct a demonstration project was made to higher authority in early 1979, and resulted in much discussion among dredging experts both within and outside the Corps. Informally, it was suggested that a dustpan dredge, appropriately modified, could perform as well as the Oozer Dredge in removing polluted sediments. The dustpan type dredge uses hydraulic transport, as do cutter suction dredges, and is extensively employed by the Corps for navigation dredging of granular materials on the Lower Mississippi River. Furthermore, it was suggested that parts from retired Corps dustpan dredges, available in the St. Louis District, could be adapted to available cutterhead dredge plant. As a result of these discussions, Amalgamated Dredge Design, Incorporated, presented a formal proposal to modify an available dustpan suction head and adapt the dustpan to a contractor's cutter suction dredge. The effectiveness of this arrangement for dredging polluted sediment would then be tested and compared to the conventional cutterhead arrangement. The dredging would be accomplished as part of the maintenance of the James River Channel. This proposal was the basis for the dredging demonstration project in the James River.

PROBLEM DESCRIPTION

The problem is not just to dredge the contaminated sediments--it is to attempt total containment at the dredge head of a specified layer of material as near in-place density as possible. This will involve minimizing resuspension of material at the head, minimizing the volume of the specified material left behind, and minimizing the amount of water added during the dredging process.

To achieve total containment, the problems discussed in the following paragraphs must be solved.

Entry Design

The entry design of the dustpan head must ensure that there is no escape of polluted material. The entry design must also be based on the characteristics of the channel sediments to be dredged, which are shown on Table 1.

TABLE 1. SEDIMENT PROPERTIES

Property	Value
Classification (USCS)*	Silty-clay (CH)
Moist Unit Weight (Avg.)	84 pounds per cubic foot (1300 grams per liter)
Moisture Content (Avg.)	144 percent
Liquid Limit	100 percent or greater
Plastic Index	60 percent or greater
Kepone Content (Avg.)	0.1 parts per million

* Unified Soil Classification System.

The material to be dredged from the James River Channel exists in a fluid state. Therefore, it is not necessary to have any means to agitate or fluidize the material; in fact, this would be undesirable since the goal is to minimize dilution and resuspension of the material.

An existing dustpan suction head from the retired Corps Dredge KENNEDY will be used for the demonstration project. Since dustpan dredges normally operate in granular materials, the head was equipped with digging teeth and water jets at the mouthpiece to enhance the flow of material. This mouthpiece section was removed from the head and will be replaced with a newly fabricated section without water jets or teeth.

The KENNEDY dustpan head is 28 feet (8.5 meters) wide and 8 inches (20 centimeters) deep. In order to overcome the entry losses of the flat, rectangular mouthpiece, and to accelerate the material through the dustpan, it will be necessary to build up a layer of material above the top edge of the entrance. A rollover plate, shaped like a bulldozer blade, will be installed on the top of the dustpan to artifically create the needed head of material (Figure 2).

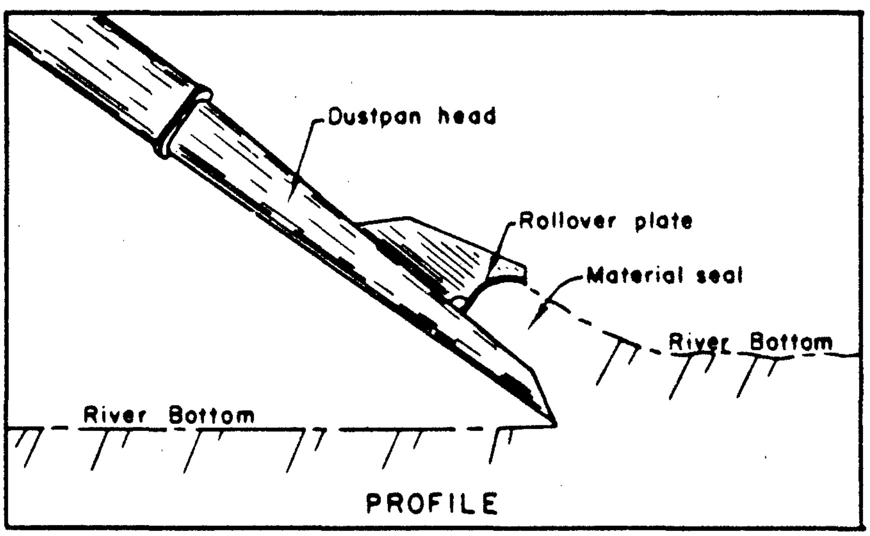

Figure 2. Dustpan head with rollover plate

The layer of material created above the entrance may have a tendency to spill over the sides, leaving some of the specified material undredged. To prevent this condition, wing plates will be attached to either side of the dustpan head and a splitter plate will be attached in the center, as shown in Figure 3.

These wing plates and splitter plate will keep the layer of material above the entrance and provide some stability for the head as it advances into the cut. The wing plates will also prevent the ingress of dilution water at the sides.

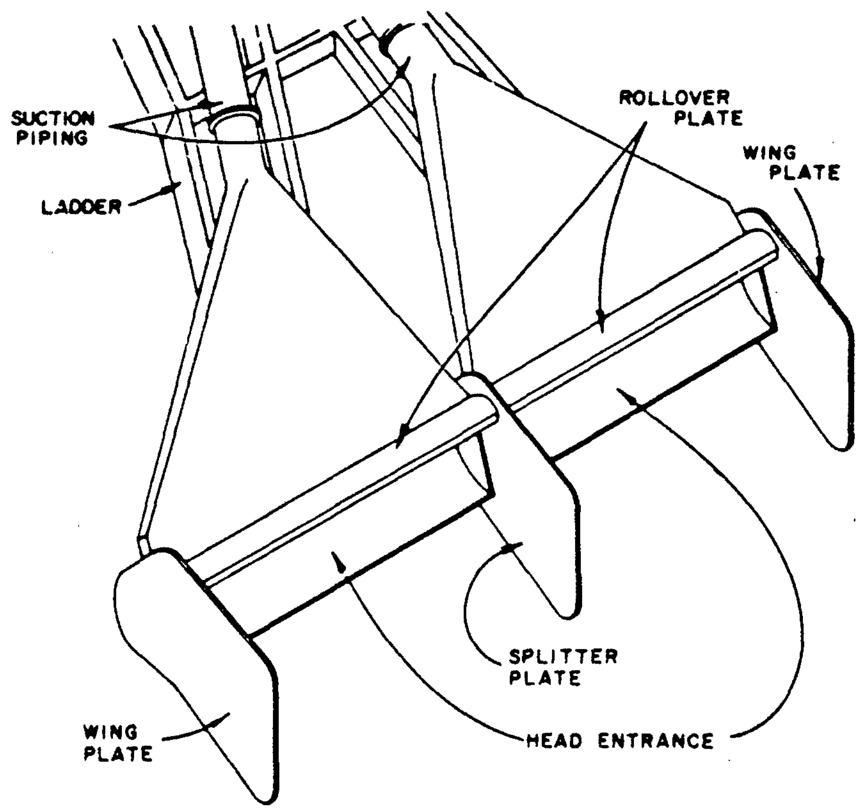

Figure 3. Modified dustpan head

Dredge Positioning

Positioning of the dredge will be another problem which must be solved in order to achieve total containment of the polluted material.

Dustpan dredges normally operate by anchoring two crossed headwires upstream of the dredge, and advancing on these wires into the cut. The strong river currents of the Mississippi or Missouri Rivers and the crossed headwires keep the dredge in position within limits acceptable for channel maintenance dredging.

On the James River, this system would not work well. The river currents vary in strength and direction with the tidal cycle as compared to the strong, steady current in one direction on the Mississippi. Greater positioning accuracy, estimated to be ± 1 foot (0.3 meter), must be achieved for the goal of total containment. The lack of a strong, steady current on the James, coupled with the need for greater accuracy, requires that other methods of dredge positioning be investigated.

Electronic positioning systems were explored as a means of positioning the dredge. It was determined that there is no commercially available system which can guarantee the desired degree of accuracy. The most accurate system available, which utilizes measurements from three separate shore stations and a computerized least squares adjustment of these measurements (Figure 4), can guarantee precision of ± 3 feet (1 meter).

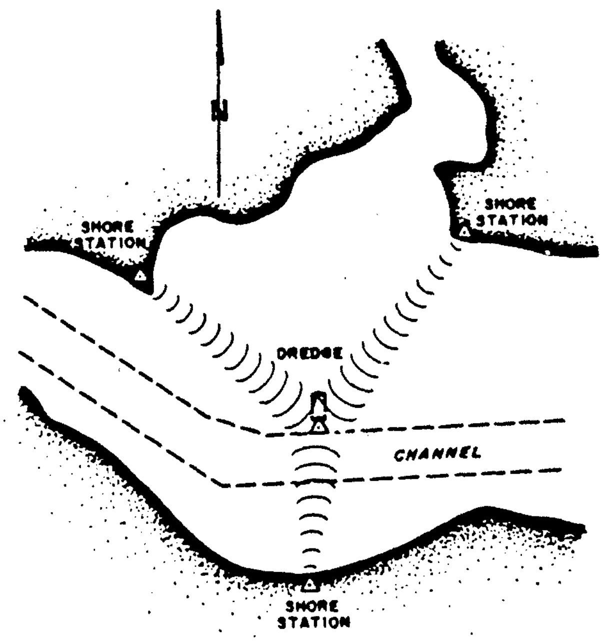

Figure 4. Electronic positioning system

This system will be used in the demonstration project to delineate the specified areas to be dredged. The problem of positioning the dredge with the required degree of accuracy, however, cannot be solved with electronic equipment, but must instead be solved by the choice of an appropriate dredging method.

DREDGING METHOD

The method of dredging by dustpan chosen for the project is unorthodox, but will enable accurate and positive positioning of the dredge. Rather than working along the length of the navigation channel, the dredge will be working across the channel and perpendicular to the tidal currents.

Five wires will be used to position and maneuver the dredge in the dustpan mode (Figure 5).

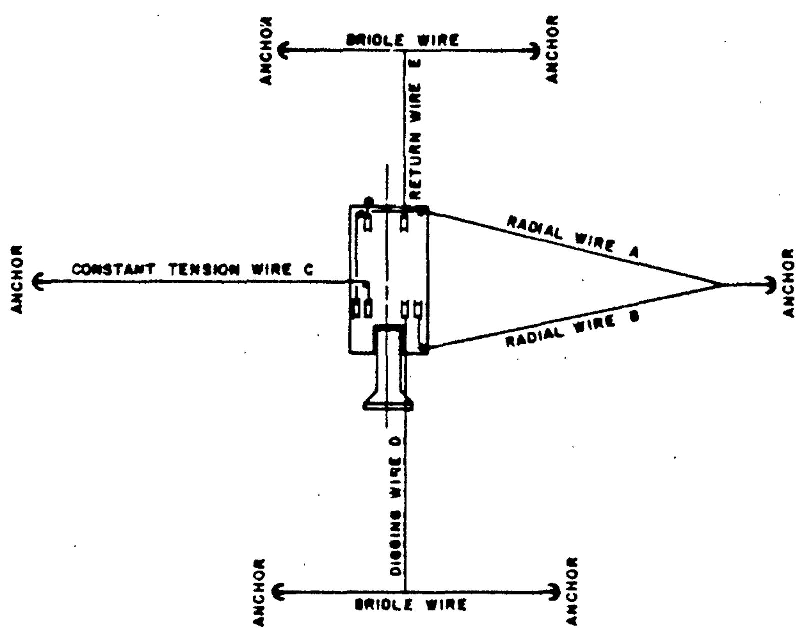

Figure 5. Dredging wire diagram

Radial wires A and B with a common anchor point will maintain the dredge on a slightly curved path across the channel. Wire C will maintain a constant tension in wires A and B with the use of an in-line tensiometer having a remote display in the dredge lever room. Digging wire D will pull the dredge into the cut, and return wire E will bring the dredge back to the beginning of the cut.

The step from one cut to the next is 28 feet, the width of the dustpan head. This step will be accomplished by paying out an equivalent amount of wire on the calibrated radial wires and adjusting the constant tension wire. The desired accuracy of ± 1 foot (0.3 meters) for dredge positioning will be obtained by accurate calibration and measurement of the amount payed out on the radial wires.

CUTTER SUCTION DREDGE

During May 1981, the Norfolk District advertised for bids for lease of a cutter suction dredge to be used in the James River demonstration project. A contract was subsequently awarded to Norfolk Dredging Company, the low bidder, for lease of the 18-inch cutter suction dredge ESSEX. It was at this time that Amalgamated Dredge Design, under a separate contract with the Norfolk District, began detailed engineering and design work for the project based on the characteristics of the ESSEX. The principal characteristics are shown in TABLE 2.

TABLE 2. CUTTER SUCTION DREDGE ESSEX
PRINCIPAL CHARACTERISTICS

Characteristics		Value
Hull -	Length	140 feet (42.7 meters)
	Breadth	36 feet (10.0 meters)
	Depth	10 feet (3.0 meters)
Cutting Power		300 horsepower (225 kw)
Dredging Depth		40 feet (12.2 meters)
Pump -	Suction	21 inches (53 cm)
	Discharge	18 inches (46 cm)
	Power	2250 horsepower (1680 kw)
Ladder and Swing		75 horsepower (56 kw)
Winch Power		≈ 400 rpm

Upon close inspection it was determined that the dredge ESSEX is well equipped to accommodate the installation of the dustpan from the dredge KENNEDY, with a minimum of modifications. The winches on board can also be easily modified to enable the dredge to operate in the dustpan mode as proposed.

MONITORING OF DREDGING OPERATIONS

In order to compare the operation of the dredge ESSEX while tests are carried out in the dustpan mode with the operation of the dredge in the conventional cutterhead mode, several parameters will be closely monitored.

On Board Instrumentation

Dredge output will be continuously monitored through the use of a package of automatic instrumentation. The package consists of vacuum indicator, pressure indicator, density meter, velocity meter, production calculator, and yield indicator. A ladder depth indicator will enable accurate control of the dredging depth. Continuous tidal information will be provided by a radio tide transmitter, in order that the dredging depth may be accurately adjusted for the height of tide.

The efficiency of removal at the dredge head will be monitored in order to determine if the goal of total containment is being achieved. This will be accomplished by taking water samples with a series of tubes mounted around the head and measuring the turbidity of the samples with a transmissometer mounted on a sampling tank.

Off-Dredge Monitoring

Around the perimeter of the dredge and disposal sites, the Norfolk District will monitor water quality. Parameters to be measured include turbidity, suspended solids, dissolved Kepone, total water column Kepone, and current speed and direction. The monitoring program is designed to detect significant changes in Kepone levels resulting from the dredge operation. The Virginia State Water Control Board will also be monitoring the bioaccummulation of Kepone in local species of marine organisms. The effectiveness of a submerged discharge diffuser developed by the Waterways Experiment Station will be tested at the disposal site as well.

POTENTIAL PROBLEM AREAS

The testing of the modified dustpan arrangement for dredging contaminated sediments may potentially present operational problems.

Crew training will be essential in overcoming these problems. The dredge crew of the cutter suction dredge ESSEX is not familiar with the dustpan method of dredging, much less the unorthodox adaptation of this method for dredging in the James River Channel. Comprehensive crew training sessions are being planned and will be conducted prior to start-up of dustpan operations in order for the crew to become familiar with the dredging method.

Prior to start-up of dredge operations, but following the successful alteration of the ESSEX and installation of the dustpan head and test equipment, a series of tests will be run. These tests will ensure that each of the systems on board the dredge is functioning properly, and that the dredge as outfitted is capable of conducting the dredging tests. An adequate supply of spare parts will be kept on hand so that downtime of the instrumentation package will be kept to a minimum.

Much time will be required during the demonstration project for moving the dredge to start each new cut since the cuts will be no more than 350 feet (107 meters) in length. There will also be considerable time spent resetting the various anchors for each new series of cuts. While production is not a primary goal of the demonstration project, excessive nonpumping time would nonetheless be undesirable. Accordingly, procedures will be developed, and the crew properly trained, so that the maneuvering and resetting time of the dredge between cuts will be minimized.

One minor problem is the possibility of the choking or blocking of the dustpan head. It is anticipated that this condition will seldom occur; however, procedures will be developed to unblock the head should it become choked or blocked with debris.

CONCLUSIONS

Design drawings and specifications for the modifications to the ESSEX are in the process of finalization, and detailed plans for crew training and accomplishment of the dredging tests are in preparation. The dustpan head and dredging ladder from the dredge KENNEDY have been removed and delivered to the contractor's yard. The demonstration project as a whole is about to make the transition from design phase to the construction and operation phases.

A great deal of effort has gone into the project up to this stage by the Norfolk District, our contractors, and the many technical advisors within the Corps. Environmental coordination of the project with the various regulatory agencies has also been a monumental task. While it is believed, at this stage, that the technical phase of design and environmental coordination is behind us, the construction and operation phases may pose additional hurdles to overcome. The Norfolk District is optimistic, however, that the successful completion of the project will result in resumption of full maintenance of the James River and a proven method of adapting readily available dredge plant for cleanup of polluted sediments.

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AD P002405

TEST DREDGING OF BOTTOM SEDIMENTS IN OSAKA BAY

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ABSTRACT

Test dredging was carried out with cutterless dredges in Osaka Bay where bottom sediments contain severe organic contamination. The Oozer pump dredge was also studied in this test work. The following results were obtained:

a. The sludges may be efficiently dredged with the suction mouth of the dredge swinging back and forth along the seabed.

b. By setting the swing speed for dredging from 6 to 7 m/min. or less, little contamination in the vicinity of the suction mouth occurs.

c. The efficiency of the dredge is approximately 250 m^3/hr on the average, with a concentration of 30 to 40 percent by volume.

d. The sludge dredged may be efficiently disposed of by transporting it on a barge to the disposal site.

e. The advantage of the Oozer pump dredge lies in that little excess water is sucked in while dredging which facilitates disposal of the slurry.

INTRODUCTION

The Inland Sea is rich in marine resources and has long supplied the Japanese with quality proteins. Along with a rapid increase in the population on the coast in recent years, however, a eutrophication phenomenon of the seawater has occurred in this sea area and the fish and other marine products have died due to the so-called "red tide." If this problem is left unsolved, a critical problem could occur in Japan's protein sources. To cope with the problem, the Japanese Government has executed legal restrictions on the quality of the wastewater that may be discharged into the Inland Sea, but the occurrence of the red tide has not been so easily eliminated. It is believed that the red tide is caused by the load from organic sludges that has built up over a long period in the bottom sediments of the Inland Sea. Accordingly, it would doubtlessly be one of the most effective methods to dredge and remove the accumulated sludge in order to completely eliminate the damage caused by the red tide. However, since the quantities of organic sludges are enormous, the expense of the dredging work to remove such sludges would be equally huge. It is, therefore, significant to determine the most rational method of dredging. Osaka Bay is situated at the far east end portion of the Inland Sea, where a vast organic contamination load from Osaka, one of the largest cities in Japan has accumulated and the occurrence of the red tide is greatest. Hence, Osaka Bay was chosen for the case study. The authors of this article participated in the sediment removing test work executed by the Japanese Government; their observations of the test work are reported herein.

SUMMARY OF TEST WORK

Site of Execution

Organic sludge extends over a vast region of the Inland Sea, and the contamination near large cities such as Osaka and Hiroshima is of a particularly high level.

Figure 1 shows chemical oxygen demand (COD) and sulfides contained in the surface layer sediment of Osaka Bay and the proportion of ignition loss. Regions with a high concentration extend along the coast and the bayhead for three items, and a region about 2 km away from the Nishinomiya Breakwater of Osaka Bay was selected as the site of execution (Figure 2).

Test Condition

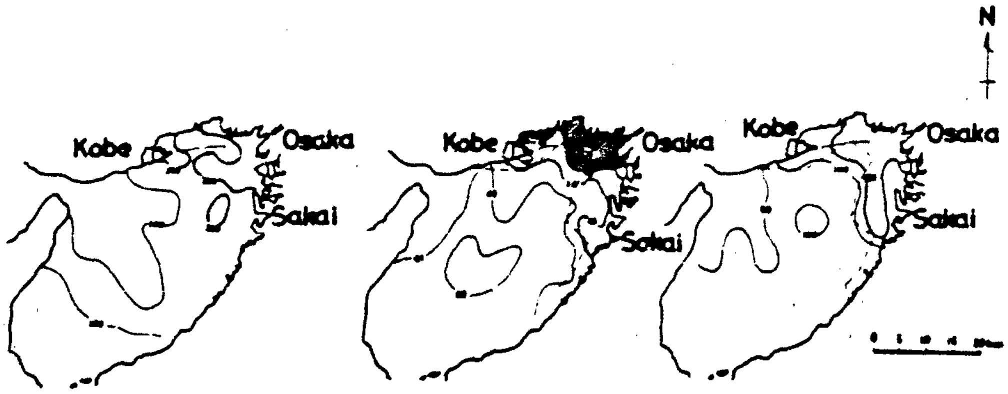
The principal test conditions are shown in Table 1. In this table, water content represents a weight percentage obtained by dividing the weight of the water contained in the sediment by the weight of dry soil.

Execution Method

The dredging study was carried out as indicated in Figure 3. The principal ships and equipments used for the study are given in Tables 2 and 3.

(1) Dredging Work

The sludge was dredged and then loaded into a pusher type box barge via a sludge discharge pipe.



(A) COD(mg/kg) (B) Sulfide(mg/kg) (C) Ignition loss (%)

Figure 1. Substance distribution of the sediment surface layer of Osaka Bay (summer)

(Note): From "Osaka Bay Sediment Purification Study," 1976 and 1978, The 3rd District Port & Harbour Construction Bureau, Ministry of Transportation

(2) Transportation Work

The dredged sludge and water were transported to the unloading base site of the disposal area about 5 km from the dredging site by the pusher type box barge.

(3) Dredge Unloading Work

At the unloading site, the dredged sludge and water were discharged to the dispo al site using a barge unloader ship.

The processing plant at the disposal site had a maximum processing capacity of 2,000 m^3 per day and processed the disposal area effluent by the simple aeration process system and the flocculation-sedimentation process. The effluent water quality was up to 20 mg/ℓ for biochemical oxygen demand (BOD) and 70 mg/ℓ for suspended solids (SS).

Test Results

In this dredging test, the following five items were examined:

a. Dredging operation method

b. Dredging efficiency

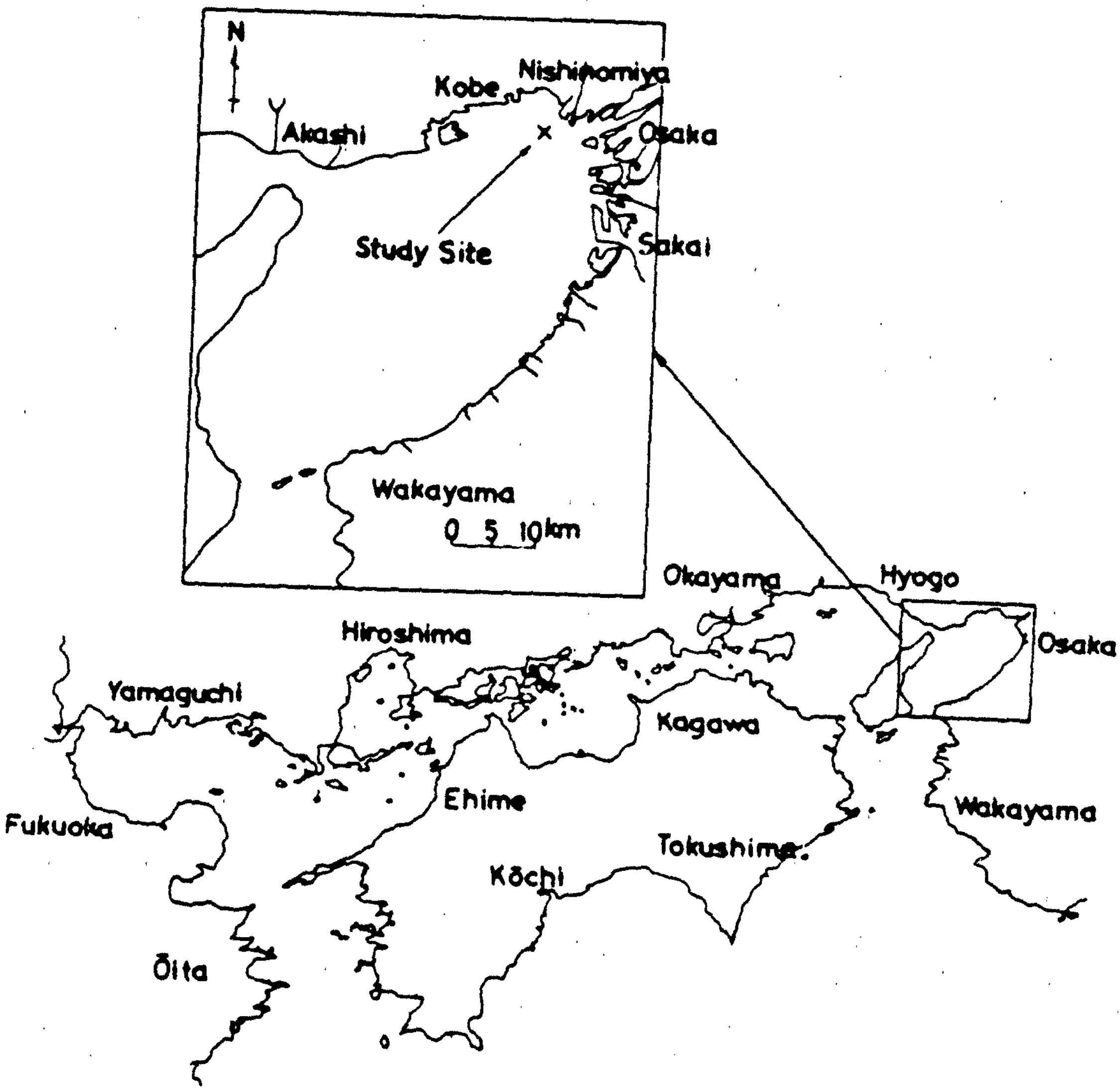
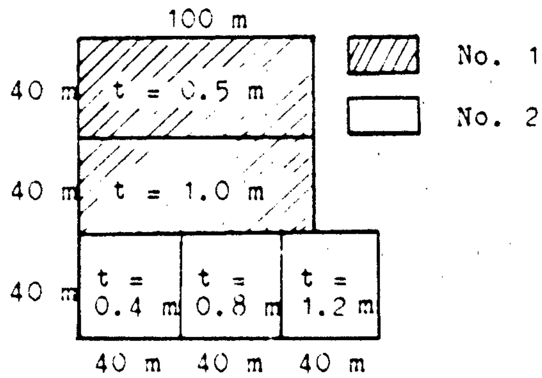


Figure 2. Location map for study

TABLE 1. CONDITION OF EXECUTION

Item / Period / Study	No. 1	No. 2
	March 1980	August 1960
Dredging area	8000 m^2 (100 m x 80 m)	4800 m^2 (120 m x 40 m)
Water depth	-16 m	
Soil (typical example)	Specific gravity 2.57 Water content about 150 ~ 250 % Grain-size distribution cobble 0 %, sand 1 %, silt 50 %, clay 49 %	
Work zone		

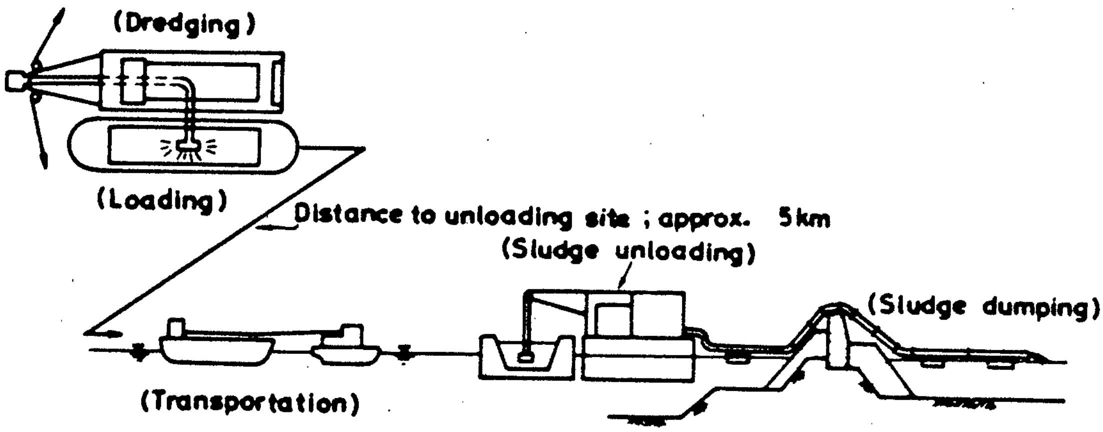


Figure 3. Execution flow sheet

c. Efficiency of transportation and sludge unloading works

d. Accuracy of dredging work

e. Contamination during dredging work

The results are discussed below.

Dredging Operation Method

Contamination during the dredging work was primarily caused by movement of the suction mouth. Hence, the swing speed must be adjusted in order to cope with this problem.

This test was carried out in the No. 1 study under the conditions shown in Table 4. In this table, dredging soil thickness represents the thickness of the soil that must be removed. "Dredging times" is the number of times the suction mouth was moved planewise per one time advance.

Table 5 represents the test results concerning the evaluation of the dredging operation method. In this table, under removal efficiency, dredge quantity represents the soil capacity removed at the seabed, and concentration represents a volume percentage obtained by dividing the sludge quantity by the slurry quantity.

Efficiency of Dredging Work

As shown in Table 5, the swing speed may be set to 6 m/min. to efficiently dredge the organic sludge of Osaka Bay. Accordingly, the efficiency of the dredging work is studied in the subsequent study by setting the swing speed to 6 m/min. and changing the soil thickness to be applied to the suction mouth (Table 6). (The swing speed was set decreasing to 5 m/min. in Zone C in the No. 2 study (effected in August) since the soil thickness excavating each time was as great as 0.6 m compared with that in the other cases.)

TABLE 2. PRINCIPAL SHIPS AND EQUIPMENTS (CARRIED OUT IN MARCH)

Work	Item	Specification	Quantity
Dredging work	Dredge	Oozer pump system 1000 m^3/hr type	1
	Windlass	240 ps* 15-ton suspension	1
	Loader	2500 tons	1
	Discharge pipe	560 mm in dia. by 6 m in length/pipe	375 m
	Traffic	50 ps	1
	Patrol	50 ps	1
Transportation work	Box barge	3000 m^3	1
		1200 m^3	1
	Pusher	3000 ps	1
		2000 ps	1
Unloading work	Unloader	610 ps	1
	Windlass	240 ps 15-ton suspension	1
	Transportation	300 m^3	1
	Crawler bed	150 tons 35-ton suspension	1
	Tug	300 ps	1
	Submersible sand pump	50 ps	3
		100 ps	1
	Generator	115 KVA	1
		200 KVA	2
	Pumping equipment	Centrifugal pump ø300 x 180 ps	1
	Discharge pipe	ø410 x 6.0 m/pipe	300 m

* ps means metric horse-power; and 1 ps = 75 kg · m/sec.

TABLE 3. PRINCIPAL SHIPS AND EQUIPMENTS
(CARRIED OUT IN AUGUST)

Work	Name	Specification	Quantity
Dredging work	Dredge	Clean up system	1
	Windlass	240 ps 15-ton suspension	1
	Traffic	280 ps	1
	Patrol	35 ps	1
	Traffic	12 ps	1
Transportation work	Box barge	700 m^3	3
		500 m^3	1
	Tug	1000 ps	1
		600 ps	3
Unloading work	Unloader	610 ps	1
	Windlass	240 ps 15-ton suspension	1
	Traffic	280 ps	1
	Pumping equipment	Centrifugal pump ø300 x 180 ps	1
	Generator	200 KVA	1
	Discharge pipe	ø410 x 6.0 m/pipe	300 m

On the basis of Table 6, the dredging efficiency results were approximately the same in both the No. 1 study and the No. 2 study, as illustrated in Table 7.

The sludge quantity in Table 7 is the value obtained by dividing the dredged soil quantity by the sum of the dredging time and the advancing time required for advancing work.

TABLE 4. OPERATING CONDITION OF DREDGE
(NO. 1 STUDY ONLY)

Dredge zone	Test case	Swing speed (m/min)	Dredging soil thickness (m)	Dredging times
A	A - 1	4	0.5	1
	A - 2	6		
	A - 3	8		
B	B - 1	4	1.0	2
	B - 2	6		
	B - 3	8		

TABLE 5. EVALUATION OF OPERATION METHOD

Item	Swing speed (m/min.)	4	6	8
Contamination	Sampling, SS analysis	○	○	○
	Underwater television observation	○	○	×
	Sonar recording	○	○	×
Removal Efficiency	Dredge quantity, Concentration	×	△	○
Overall evaluation		△	○	×

○: good, △: fair, ×: bad

TABLE 6. OPERATING CONDITION OF DREDGE (EFFICIENCY STUDY)

Study	Dredging zone	Dredging soil thickness (m)	Swing speed (m/min.)	Dredging times
No. 1	A	0.5	6	1
	B	1.0		2
No. 2	A	0.4	6	1
	B	0.8		2
	C	1.2	5	2

TABLE 7. EFFICIENCY OF DREDGING WORK

Study	Dredging zone	Dredging sludge quantity per hour (m^3/hr)	Dredging slurry quantity per hour (m^3/hr)	Concentration (%)
No. 1	A	177	576	31
	B	237	709	33
No. 2	A	251	534	47
	B	227	731	31
	C	335	984	34

Efficiency of Transportation and Sludge Unloading/Works

The cruising speed, operation time, and fuel consumption of the pusher barges and the operation time and fuel consumption of the sludge unloading ship were examined and general results were obtained.

Accuracy of Dredging Work

When compared with the work by conventional cutterhead dredges, the sludge dredging work calls for a higher level of accuracy because:

(1) The sludge to be removed cannot be left unexcavated.

(2) If the uncontaminated layer is also dredged and removed, the dredging quantity as a whole increases, causing problems with the capacity of the reclaimed land and the secondary treatment (such as solidification).

The soil thickness and the advancing distance of the suction mouth (length of advance once the spud is changed for repiling) were within the range of 10 to 20 cm, and the accuracy was within about 10% of a target set value.

Contamination During Dredging Work

To examine the quantity of contamination occurring from around the suction mouth and its diffusing range during the dredging work, observation boats measured the direction and velocity of the tidal currents flowing, measured the contamination in the vicinity of the dredge, and analyzed the SS of collected water samples. Almost all the measured SS values were within the range of 5 to 10 mg/ℓ, which is within the mean SS background value of 9 to 10 mg/ℓ in this sea zone (Figures 4 and 5).

The dredging operation in this study was effected at a swing speed that does not cause contamination on the basis of Table 5; it was confirmed that, throughout a series of examinations, no contamination problem occurred at all.

OOZER PUMP DREDGE STUDY

The Oozer pump dredge was used in the No. 1 study of this dredging test work.

Photo 1 and Figure 6 illustrate an overall view of the Oozer pump dredge.

Dredging Equipment

For this test work, we designed the dredging mechanism as shown in Figure 7; the outline is as follows:

6th day of March Condition after second hour from beginning of dredging.

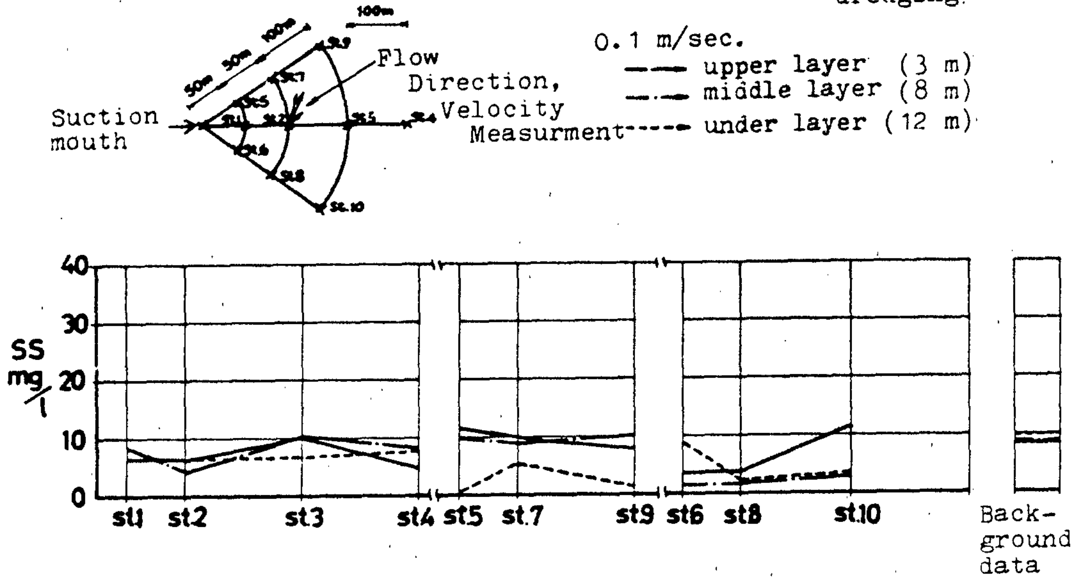


Figure 4. Muddiness in A Zone

8th day of March Condition after second hour from beginning of dredging

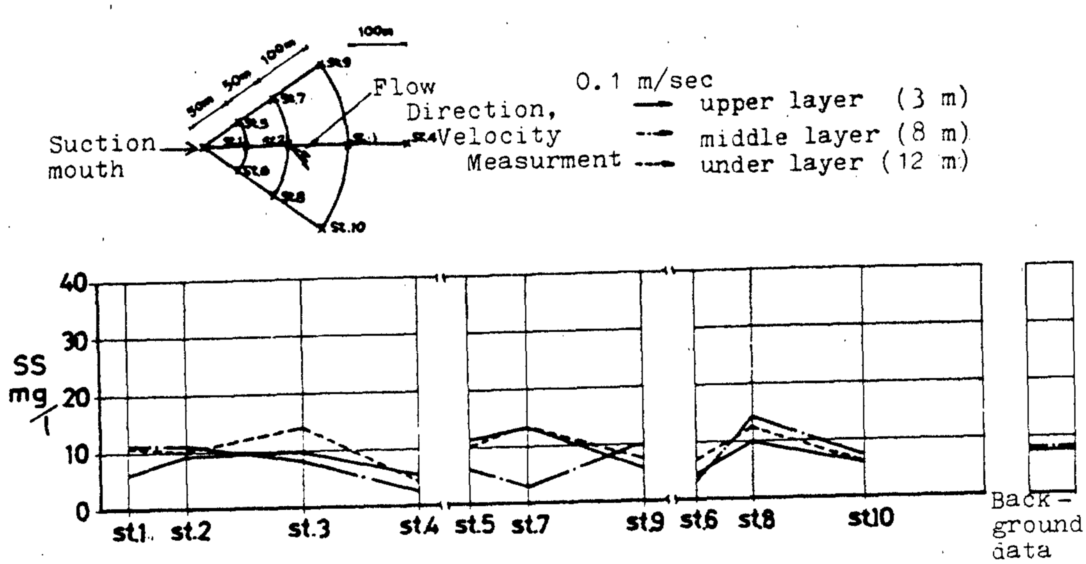


Figure 5. Muddiness in B Zone

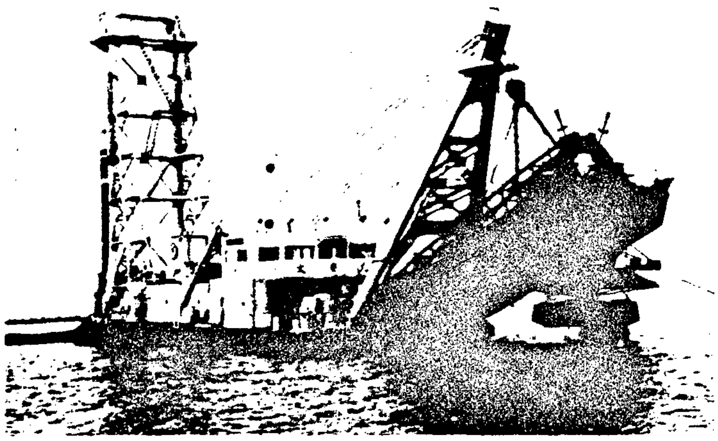


Photo 1. View of dredge

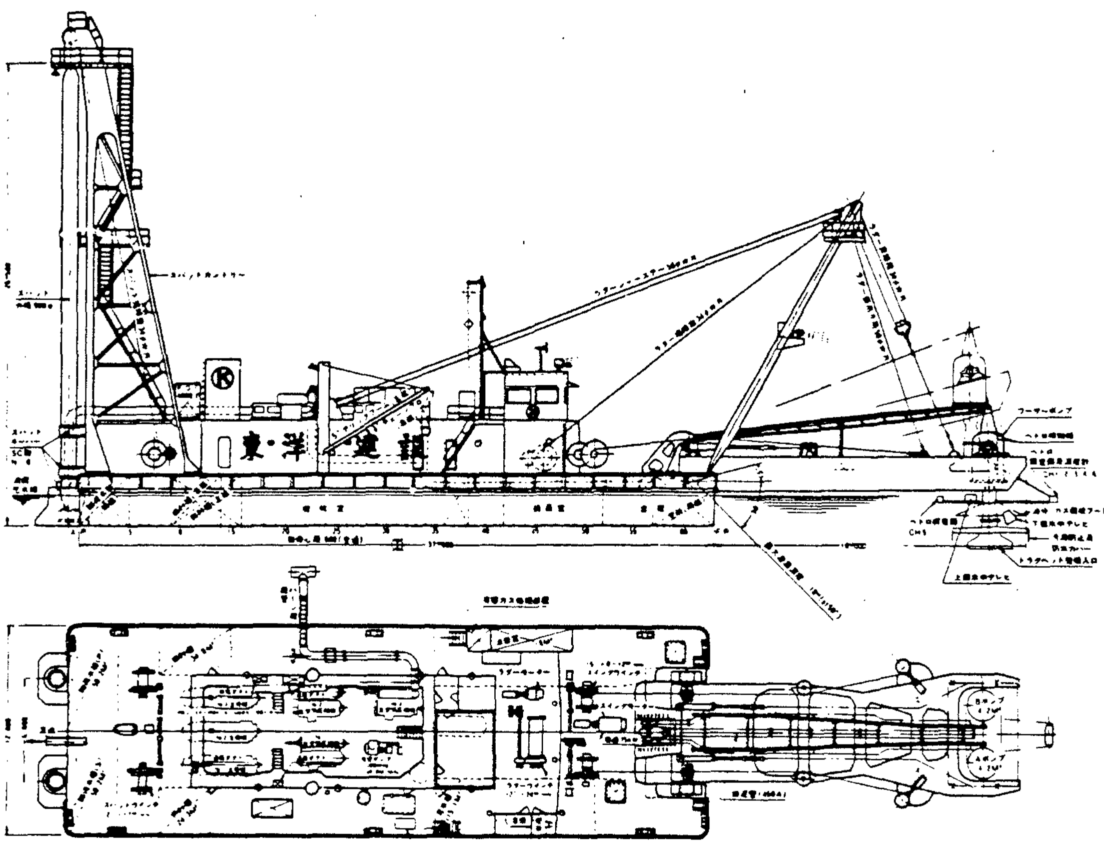


Figure 6. Arrangement of dredge

a. The Oozer pump was used for dredging because it delivers the sludge by means of pneumatic piston operation as shown in Figure 8; with this operation an excessive amount of water is not sucked in when stopping the pump before and after dredging work and during replacement of spuds.

b. It is thought that dredging can be carried out without agitating the sludge if a cutterless suction mouth is used.

c. A speed changeable winch is used that can freely adjust the swing speed within the range of 0 to 12 m/min. so that the dredging can be matched to the properties of the sludge.

d. Contamination during dredging can be constantly supervised by an underwater television fitted to the upper part of the suction mouth.

e. The purpose of sludge dredging is to remove the contaminated layer, not to dredge the seabed to a constant depth (Figure 9). To enable the dredge to move along the ups and downs of the seabed, three sonars are fitted to the upper side of the suction mouth. The seabed that has not been dredged and that has been dredged are continuously recorded while dredging and the suction mouth can be constantly moved up and down so that the sucked-in sediment thickness will match the planned value.

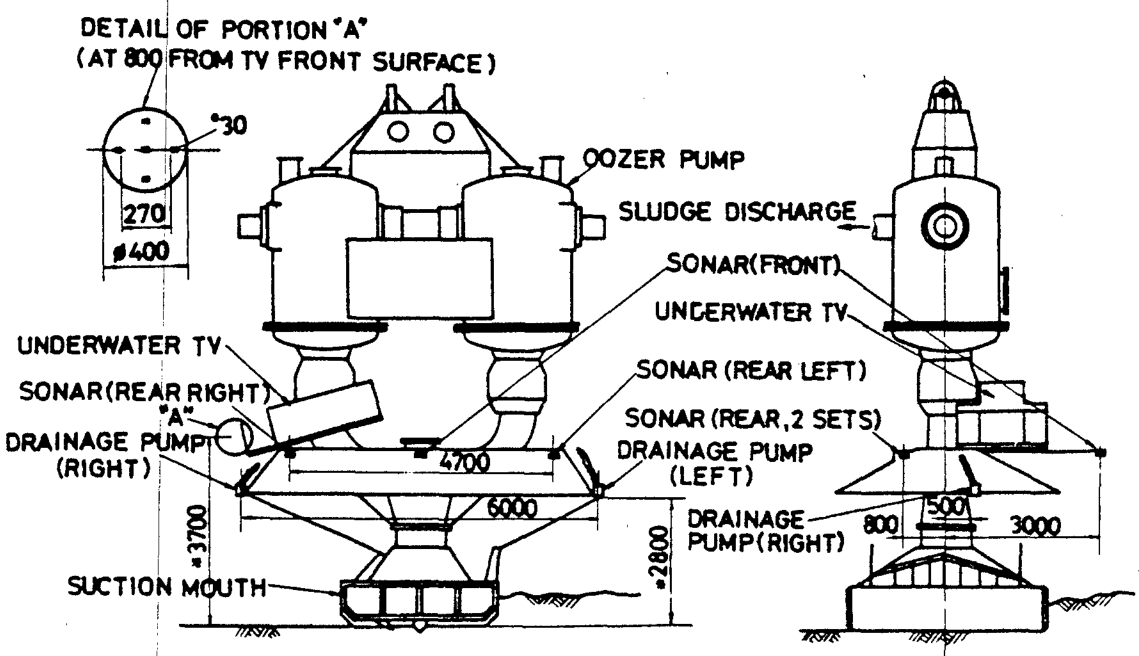


Figure 7. Dredging mechanism (lengths are measured in millimeters)

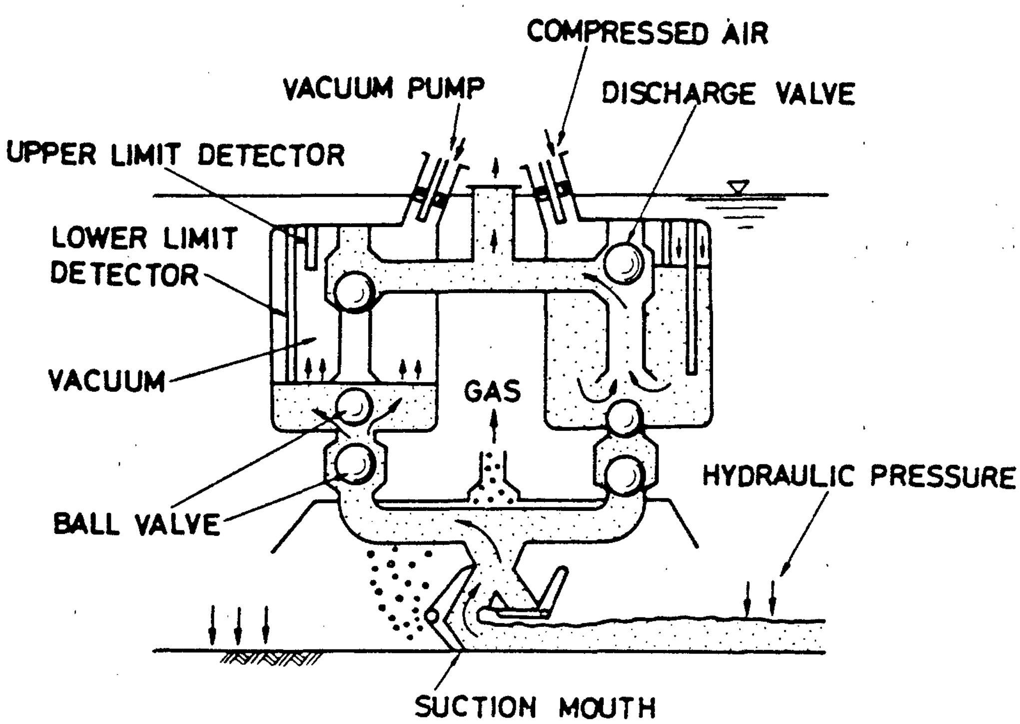


Figure 8. Oozer pump operation

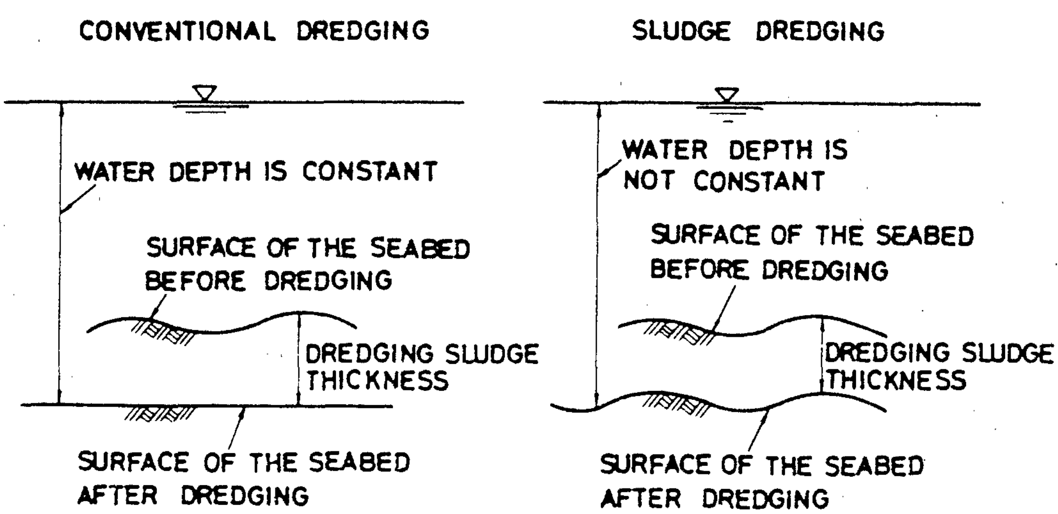


Figure 9. Explanation of dredging sediment thickness

Effective Operation Method

Operation Method of the Dredge

The operation method of the dredge selected was the same as that of the conventional cutter pump. In this method, the dredging work is carried out while the spuds are piled to fix the hull and the suction mouth is moved to left and right by the swing winch. The operator is accustomed to this operation and the organic sludge is such that it is equally piled up along the surface of the seabed. In view of these reasons, the cutter pump method is considered to be a rational dredging method.

Figure 10 illustrates the method of operation; the outline is as follows:

a. The order of operation is different to some extent between the first excavation and the second. First, we will explain the order of the first excavation. The sludge is dredged at ① → ② ; when it reaches ②, the suction mouth is raised and the pump is stopped and returned to ② → ③ . The temporary spud is piled at ③ and the working spud is removed. It is advanced to ③ → ④ in this state and, at ④ , the working spud is piled and the temporary spud is removed and swung to ④ → ⑤ . At ⑤ , the suction mouth is lowered into the sludge again and the pump is operated and the sludge is dredged in the order of ⑤ → ⑥ . In the second excavation, the sludge is dredged at ① → ② , the suction mouth is lowered at ② , and the sludge is dredged at ② → ① again. Then the suction mouth is raised at ① to hold it away from the surface of the seabed and the pump is stopped to return to ① → ③; at ③, temporary spud is piled and the working spud is removed. Subsequent advancing operations are carried out as indicated for the first excavation.

b. In both the first and second excavations, the position of the suction mouth is overlapped with the side of the trace of dredging so that the sludge may not collapse and fall down into the trace and remain there.

c. While the advancing operation is carried out, the ladder is wound up and the suction mouth is held away from the surface of the seabed. This action prevents the sludge from being stirred by the suction mouth when the hull rocks due to the repiling action of spuds.

The operation method when applied to the area of the test work is shown in Figure 11. ① - ⑦ in Figure 11 represent the order of the dredging operation.

① and ② represent the work zones of operation method study, (3) - (7) represent the efficiency study zones, and → represents the direction of dredging and advance.

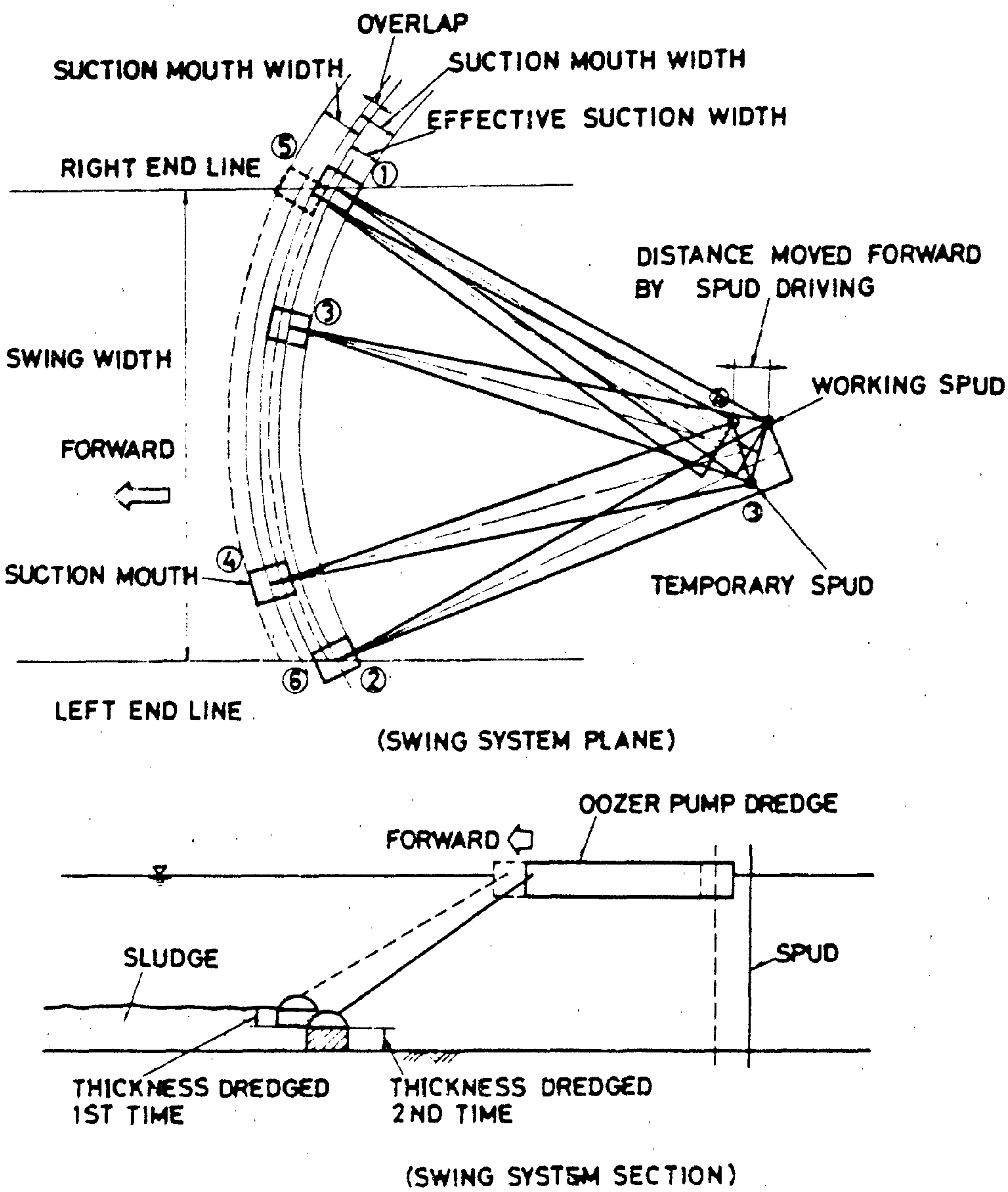


Figure 10. Dredging operation method

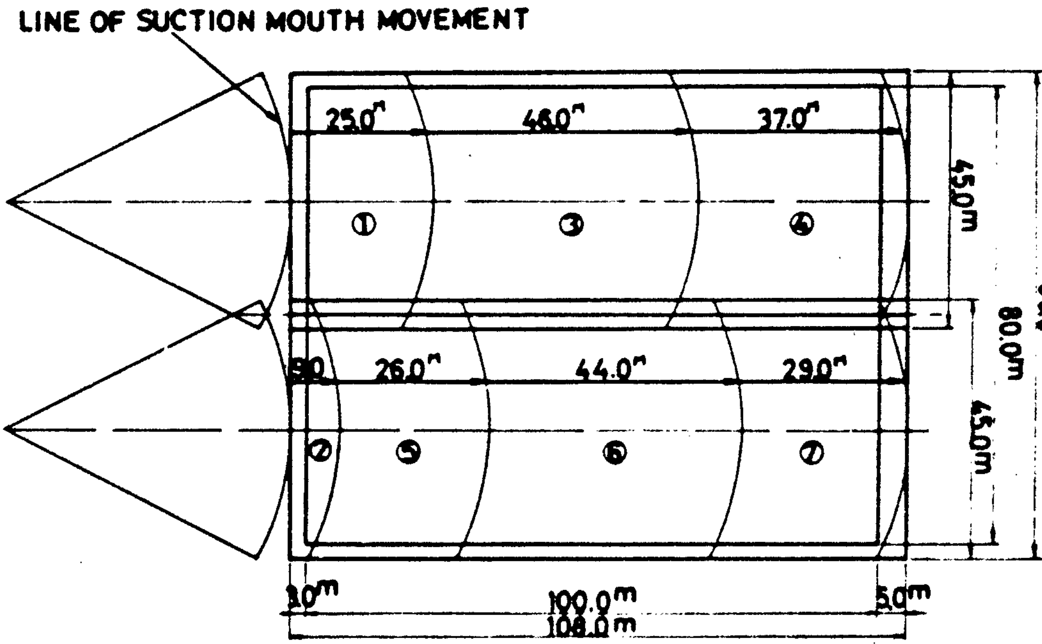


Figure 11. Dredging advance in No. 1 test work

Efficiency and Accuracy of Dredging Work

According to our study, the work efficiency of the Oozer pump dredge can be expressed by the formula in Equation 1 in accordance with the cutterless suction mouth model shown in Figure 12.

$$q_o = q \cdot \eta \qquad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

where q_o: quantity of sludge dredged per operation time $[m^3/hr]$

q: quantity of sludge dredged per dredging time $[m^3/hr]$

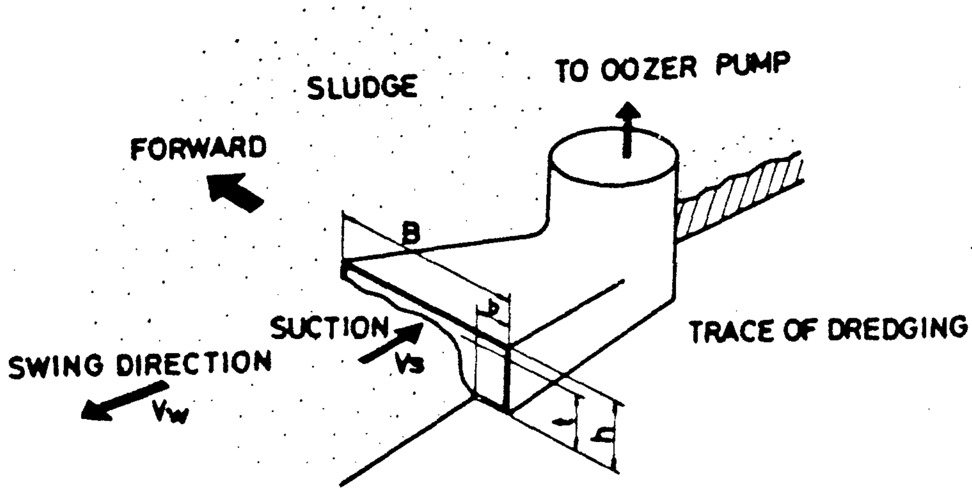
$q = 60(B - b) \cdot V_w \cdot t$

B: suction mouth width $[m]$

b: suction mouth overlap width $[m]$

t: sucked sludge thickness $[m]$

V_w: swing speed $[m/min]$



Symbols

B: suction mouth width

b: overlap width of suction mouth

V_W: swing speed

h: height of suction mouth

t: sucked soil thickness

V_S: suction velocity

Figure 12. Cutterless suction mouth model

η: time efficiency of work

$$\eta = n \cdot W/V_w/(n \cdot W/V_w + W'/V_w' + T_s)$$

n: number of excavations

W: swing width [m]

V_w: swing speed during dredging [m/min.]

W': moving distance of suction mouth during advance [m]

V_w': swing speed during advance [m/min.]

T_s: time required for elevating spuds during spud replacing operation [min.]

Here the operation time is the sum of the actual dredging time for excavating the sludge and the advance time in which the excavation is stopped for advancing.

The term W' represents the moving distance of the suction mouth from ① → ③ → ④ → ⑤ in the second excavation shown in Figure 10, for example.

T_s is the sum of the time required for pulling out and piling the spuds at the points ③ and ④ in Figure 10.

According to Equation 1, in order to increase the dredging efficiency, the suction mouth width B, the sucked sediment thickness t, the swing speed V_w, and the operation time efficiency η must be increased while the overlap width b of the suction mouth must be decreased. With respect to Equation 1, however, there is a limit of application and if the values of B · h, etc., are increased excessively, the suction flow velocity V_s in Figure 12 decreases and the sludge chokes up the suction mouth. According to our experiences, we believe the suction velocity should be not less than 0.5 m/sec when the suction mouth sucks sludge up. The size of the suction mouth B · h is determined so that said condition may be met and the sucked sediment thickness t and the overlap width b are determined by Equation 1.

In addition to the above-mentioned factors associated with the work efficiency, the sediment property, the size and shape of the work site, the thickness of the sludge to be dredged, the kind of detrimental substances contained in the sludge, etc., should be mentioned. These factors are summarized in Table 8.

In this test study, the size of the suction mouth and the thickness of sediment to be sucked were determined as follows:

suction mouth width B	. . . 3.4 m
suction mouth height h	. . . 0.5 m
suction mouth overlap width b	. . . 0.4 m
sucked sediment thickness t	. . . 0.5 m

The dredging operation was carried out following Table 6.

The results of the test study are shown in Tables 9 and 10 and Figure 13.

The work time in Table 10 is the sum of the dredging operation time and the rest time required for the contamination study and for moving the dredge to another work zone by a tug, in which dredging is stopped. It is the total restrictive time required for the dredging work.

Figure 13 shows the work result of the Oozer pump dredge. Plotting the efficiency of the study of Osaka Bay in Table 9, it is found that both the surface layer (water content 250%) and the lower layer (water content 150%) are positioned in an area of better condition and higher efficiency was obtained in comparison with the sludge dredging work in general. This fact has proved that our study is suitable.

TABLE 8. FACTORS AFFECTING DREDGING EFFICIENCY

Item \ dredged sediment q'ty q_o	small ←	→ great
(1) Water depth	shallow	deep
(2) Soil quality	sand, cobble (hard)	silt, clay (soft)
(3) Condition of site a. sludge thickness (small) b. topography (complicated) c. obstacles (much) d. navigating ships (many)	becomes worse in proportion to the degree of ( )	becomes better in inverse proportion to the degree of ( )
(4) Prevention of contamination (swing speed)	severe (slow)	mild (rapid)
(5) Inspection of excavated site	severe	mild

In comparison with the work efficiency of the cutterhead dredge, the dredged sludge quantity q_o of the Oozer pump dredge is about 50% of that of the cutterhead dredge, but the concentration is about 150 to 200% of the latter, provided that the dredged sludge thickness is equal. The reason q_o is small is because the swing speed V_w of 6 m/min is about 50% of the swing speed of the conventional cutterhead dredge. The concentration becomes higher even though q_o is small because the Oozer pump is stopped during advance so as not to suck excessive water. Therefore, the Oozer pump dredge is believed to be suited for dredging and removing the sludge.

To show the accuracy of the dredging, Figure 14 provides the sonar record of the depth before and after dredging. The sonars were fitted to the upper part of the suction mouth and the thickness t of the sucked sludge was confirmed while the work was carried out. As a result, the seabed of the excavated pit with a shape such as shown in Figure 15 was obtained. Using the data in Table 9, the accuracy of the dredged sludge thickness is found to have

TABLE 9. DREDGING EFFICIENCY

Study	Dredging zone	Dredging order	Swing speed (m/min.)	Dredging sludge thickness (m)	Number of times of dredging (time)	Suction mouth overlap width (m)	Dredging sludge quantity (m^3/hr)	Dredging slurry quantity (m^3/hr)	Concentration (%)
Operation method	A	①	5.6	0.68	1		253	723	35
			6.6	0.72	1	0.65	235	500	47
			8.2	0.58	1		167	388	43
	B	②	5.4	0.96	2		244	976	25
			6.8	0.99	2	0.40	314	872	36
			7.8	0.90	2		324	753	43
Efficiency	A	③, ④	5.7	0.58	1	0.54	177	576	31
	B	⑤,⑥,⑦	7.1	0.92	2	0.49	237	709	33

TABLE 10. BREAKDOWN OF WORK TIME

Date	Work time	Operation time	Breakdown of operation time		Rest time	Breakdown of rest time						
			Dredging time	Advance time		Anchor shifting	Ship shifting	Study and measurement	Engine	Waiting for transportation ship	Obstacles	Others
	H* M	H M	H M	H M	H M	H M	H M	H M	H M	H M	H M	H M
Mar. 4	12 00	4 56	2 15	2 41	7 04	0 00	1 25	1 20	0 43	1 51	0 00	1 45
5	12 00	6 52	2 24	4 28	5 08	0 00	1 30	1 17	0 38	0 00	0 00	1 43
6	12 00	8 45	3 44	5 01	3 15	0 00	0 49	0 41	0 0C	0 00	0 32	1 13
7	12 00	6 56	3 51	3 05	5 04	0 00	0 00	3 06	0 00	0 12	0 00	1 46
8	12 00	5 19	2 57	2 22	6 41	0 00	0 00	1 45	0 00	0 28	0 00	4 28
Total	60 00	32 48	15 11	17 37	27 12	0 00	3 44	8 09	1 21	2 31	0 32	10 55
Average	12 00	6 34	3 02	3 32	5 26	0 00	0 45	1 38	0 16	0 30	0 06	2 11
Ratio		To work time	To operation time		To work time	To rest time						
		54.7 %	46.2 %	53.8 %	45.3 %	0 %	13.8 %	30.1 %	4.9 %	9.2 %	1.8 %	40.2 %

* H = hours; M = minutes.

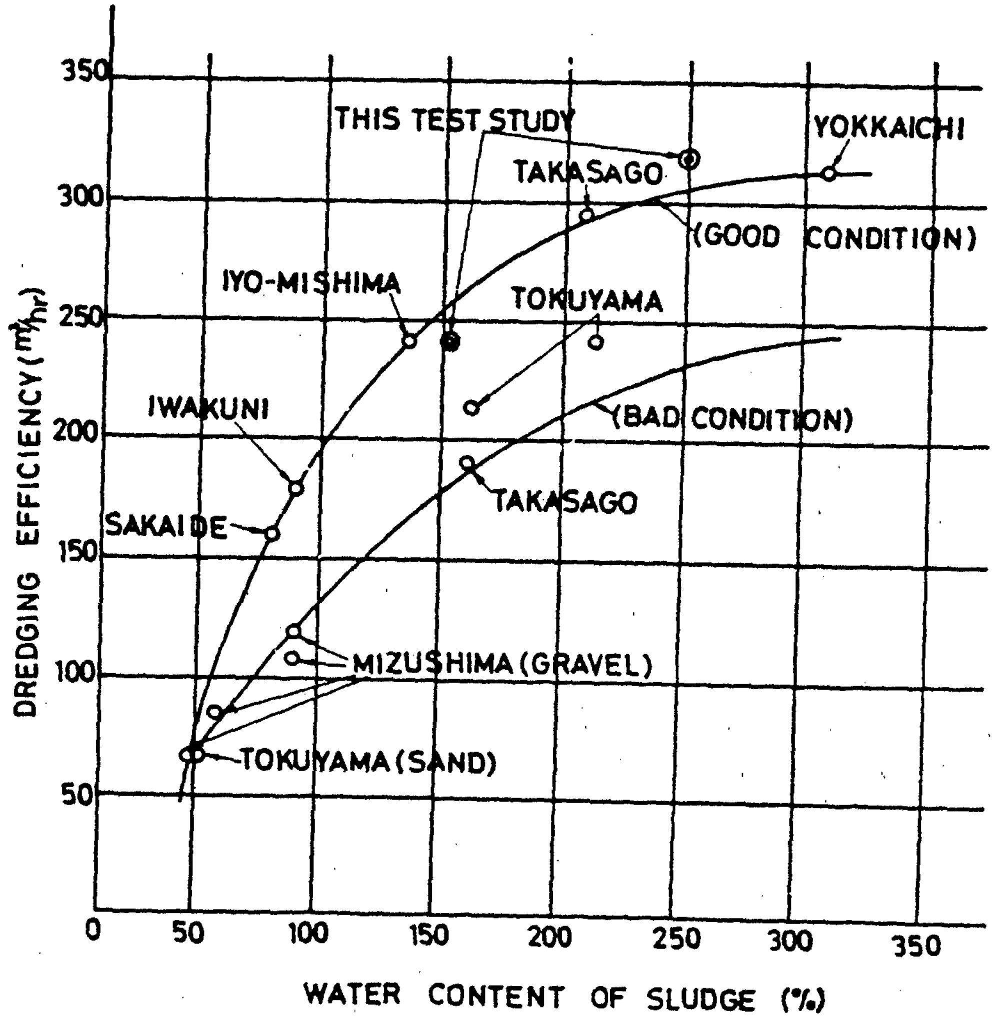


Figure 13. Result of dredging efficiency

errors of 16 and 8 percent for the given values of 0.5 m (zone A) and 1.0 m (zone B) in the zones of the efficiency study, respectively, after the operators were familiarized with the operation procedures.

Figure 15 shows measurement and recording data obtained by an investigation ship carrying the sonars cruising on the survey lines.

Therefore, in order to completely remove the given thickness of sediment to be dredged, it is necessary to remove about 20% more than said thickness of sediment. Such a high dredging accuracy can be attained because the dredge has a dredging mechanism that keeps the suction mouth parallel to the seabed during dredging as shown in Figures 10 and 12, unlike the cutterhead dredge which slants to the seabed though this may vary depending upon the method of management shown in Figure 14.

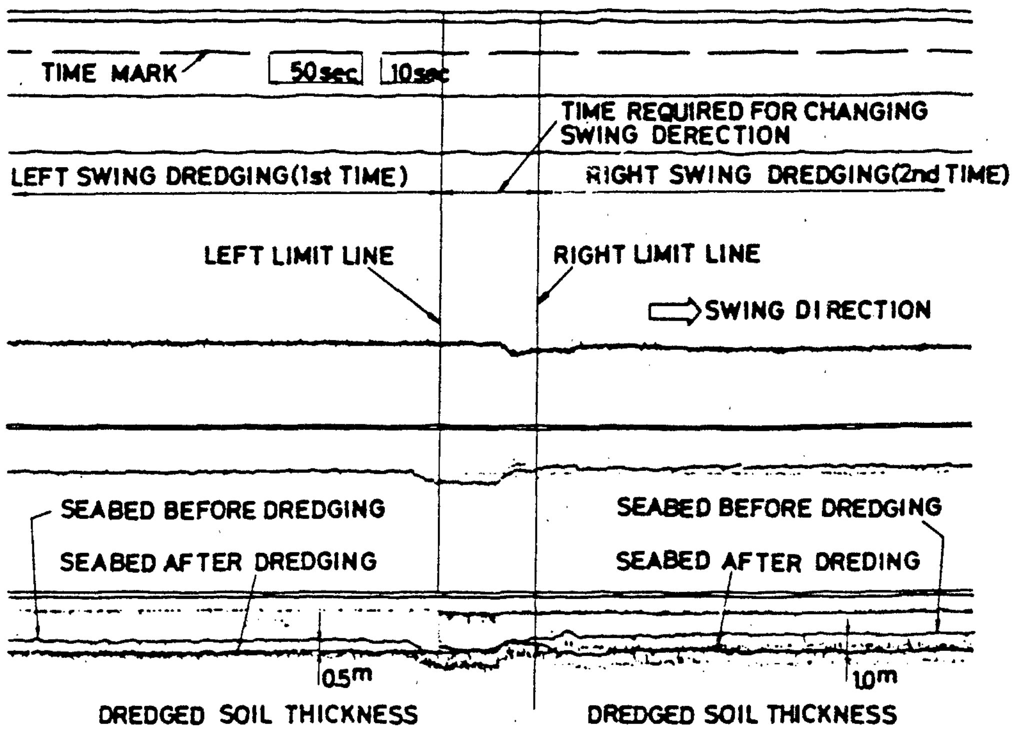


Figure 14. Sonar record (Zone B)

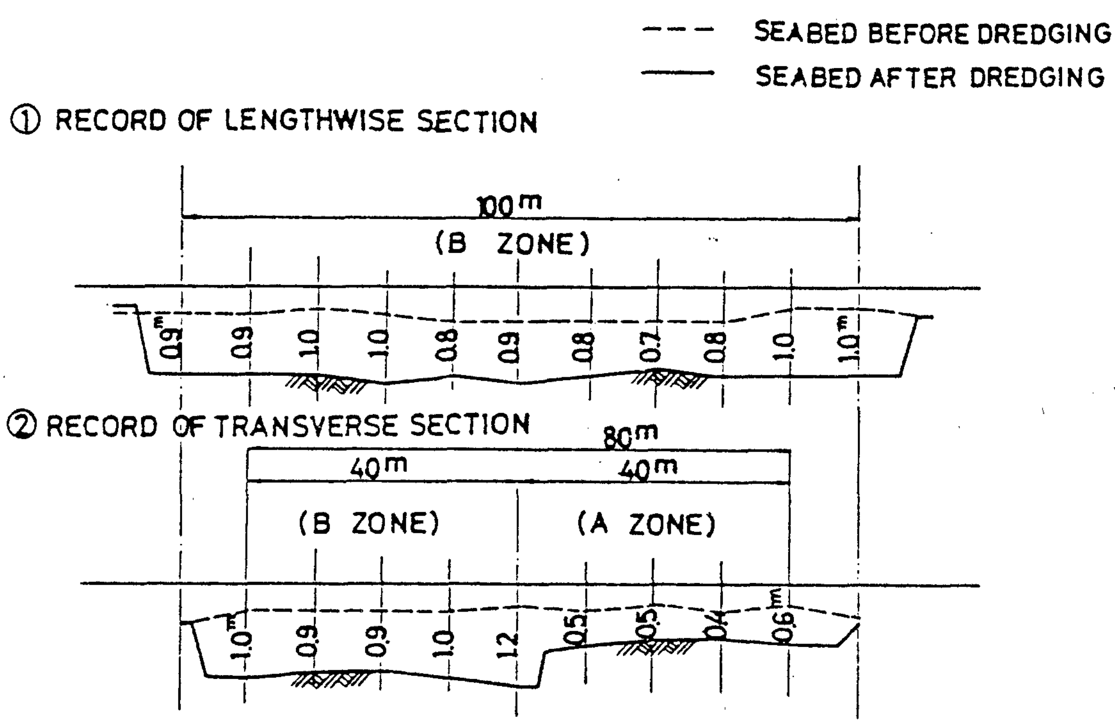


Figure 15. Seabed after dredging

CONCLUSIONS

This article has outlined the dredging test study of organic sludges in Osaka Bay and the study on the Oozer pump dredge. Our findings based on this test work are summarized as follows:

a. By fitting sonars to the upper side of the suction mouth and confirming the contours of the seabed, sludges may efficiently be dredged along the ups and downs of the seabed.

b. While dredging, the operator can judge whether or not the operation is being properly conducted by observing the contamination in the vicinity of the suction mouth.

c. If the swing velocity is held at 6 - 7 m/min or less, little contamination occurs in the vicinity of the suction mouth.

d. At a swing speed of about 6 m/min, the efficiency of the dredge is about 250 m^3/hr with a concentration ratio of about 30%.

e. By transporting the dredged sludge by a barge to the disposal site and unloading it, disposal can be efficiently effected.

f. The Oozer pump does not suck in excess water while dredging the sludge, making it possible to lessen the amount of slurry to be disposed.

Under the circumstances, we believe that the Oozer type and the Clean-up type dredges are suited for dredging and removing organic sludges. Although acceptable results were obtained on the engineering method, efficiency, etc., for dredging and removing organic sludges by this test work, the disposal method after dredging is an important subject to be solved for efficient removal and disposal of a considerable amount of sludges piled up over a wide area in the Inland Sea. Therefore, investigation and study of a consistent system of disposal, as regards dredging, transportation, and treatment of sludges, should be conducted.

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MANAGEMENT TOOLS FOR ASSESSMENT OF DREDGED MATERIAL IMPACTS

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ABSTRACT

The success of laboratory bioassays as diagnostic tools for assessing the effects of environmental perturbations has been limited. It is proposed that the adenylate energy charge coupled with analysis of selected metabolic enzymes may overcome some of these limitations. The adenylate energy charge can be calculated from concentrations of three adenine nucleotides: ATP + 0.5 ADP/ATP + ADP + AMP. Several studies demonstrate that the energy charge can be a gauge of environmental impact of importance to the survival of particular species. Insights as to the cause of impacts on the biota from complex mixtures such as dredged material may be gained from analysis of test organisms for selected metabolic enzymes.

INTRODUCTION

Maintenance dredging of harbor entrances and channels and the deepening of ports to permit docking of deep-draft cargo vessels are essential to the economic health of the United States and other nations. In spite of its importance, there are harbors in the U.S. where dredging is presently not permitted while state authorities are attempting to establish realistic water-quality criteria that must be maintained in harbor waters during the dredging/disposal process. There are other areas where the Corps of Engineers cannot undertake dredging activities because of the presumed hazardous nature of the dredged material as determined by laboratory tests. The permitting process generally requires the carrying out of bioassays of the sediment to be dredged to determine its probable impact upon the biota of the dumpsite. The kinds of bioassays to be carried out and the techniques to be employed are stipulated by the U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers. At the present time, the criterion of impact in the bioassay is the difference in mortality between test organisms exposed to the sediment to be dredged and a control sediment. One point of interest and concern to me is that laboratory bioassays are poor simulators of field conditions and to my mind they have more severe impacts upon the test species than the same sediments will have upon the organisms resident at the proposed dumpsite. Another concern is simply that using death of the test organisms gives us very little information on the development of chronic responses. For these reasons, I am prepared to recommend that (1) bioassays should be carried out in the field, and (2) that a criterion other than death should be used to determine whether or not test organisms are under severe stress from dumped sediments. Thus, my objective is to provide the environmental manager with a tool called the adenylate energy charge (EC) that will give him an insight into the significance of the biological impacts resulting from his schedule of dredged material disposal. Then I plan to describe briefly a method for narrowing the possible cause or causes of any severe stress that is observed from the EC analysis.

THE ADENYLATE ENERGY CHARGE

All the functions of organisms are controlled by rather specific enzymes that are called metabolic enzymes. The adenylate energy charge (EC) is believed to be a primary factor regulating the activities of these enzymes. The EC is thought to represent the metabolic energy potentially available from the adenylate pool to an organism at the moment of sampling (Atkinson, 1968; Atkinson & Walton, 1967). Its determination depends upon measuring from cellular extracts the concentrations of three adenine nucleotides (ATP): adenosine-5'-triphospate, -diphosphate (ADP), and -monophosphate (AMP) and calculating the EC ratio as follows: ATP + 0.5 ADP/ATP + ADP + AMP. By definition, the ratio ranges from 0 to 1.0.

A healthy organism can be expected to have an EC of 0.7 or above; however, it is believed that growth or reproduction will not occur unless it is 0.8 or above (Atkinson, 1968; Chapman et al., 1971). When it falls to 0.5, it can be expected that the organisms will not recover when the impacting condition is removed (Ivanovici, 1980b). When a ratio of 0.5 persists, death will inevitably follow (Behm & Bryant, 1975; Wijsman, 1976). The response of EC is rapid (e.g. an exposure of 24 hours is adequate) and is more elucidating than mortality data. For example, Ivanovici (1980a) working with a small marine snail (Pyrazus ebeninus) found that when the EC dropped as a result of a 24-hour exposure to an impact, it did not drop further in the following three days of the experiment (Table 1).

APPLICATION OF THE ENERGY CHARGE TEST

TerEco Corporation studies off the coast of Louisiana for LOOP, Inc., investigated possible impacts of the discharge of brine solutions (8.6 times salinity of normal seawater) on shrimp and other organisms (Pequegnat, 1981). EC as well as selected metabolic enzyme tests have been carried out at 8 stations placed at distances ranging from a few meters to several nautical miles away from the diffuser through which the brine derived from the water excavation of a terrestrial salt dome (for oil storage) is discharged into the ocean. EC data derived from the five field surveys conducted by TerEco between October 1979 and May 1981 are presented in Table 2. Two points must be considered before these data can be interpreted. First, the initial four surveys gathered benchmark data since they were carried out prior to the first discharge of brine in April 1981. Second, during Surveys 1 and 2, test species were exposed in the field for a period of 5 days, whereas in subsequent surveys exposure time was reduced to 3 days.

Three important conclusions can be derived from the EC data in Table 2: (1) the discharge of brine through the diffuser has had no important impact upon the health of the grass shrimp (Palaemonetes pugio) and commercial shrimp (Penaeus aztecus), (2) the EC response occurs within 3 days and possibly sooner as noted above, and (3) a marked reduction of EC followed a drop in concentration of dissolved oxygen (to less than 1 ml/l) in the bottom water only. It

TABLE 1. RESPONSE TIME OF THE ADENYLATE ENERGY CHARGE IN THE GASTROPOD PYRAZUS EBENINUS REDUCTION IN SALINITY AND ELEVATED TEMPERATURE (MODIFIED FROM IVANOVICI, 1980a).

Salinity (o/oo)	Temperature (°C)	Time of sample (days)	Adenylate energy charge*
0	20°	1	0.63 ± 0.07
		4	0.66 ± 0.02
	29°	1	0.51 ± 0.01
		4	0.54 ± 0.03
17	20°	1	0.66 ± 0.03
		4	0.66 ± 0.02
	29°	1	0.55 ± 0.01
		4	0.60 ± 0.04
34	20°	1	0.86 ± 0.02
		4	0.89 ± 0.02
	29°	1	0.73 ± 0.05
		4	0.70 ± 0.01

* Values are means of 3 animals ± standard error

TABLE 2. COMPARISON OF MEANS OF ADENYLATE ENERGY CHARGE RATIOS BETWEEN SURVEYS 1, 2, 3, 4, AND 5
(OCT., DEC. 1979; JUNE, NOV. 1980; AND APRIL-MAY 1981)
FOR WHOLE GRASS SHRIMP AND ABDOMINAL MUSCLE OF COMMERCIAL SHRIMP
REFERENCE CONTROL IS ANIMALS SACRIFICED AT TIME BOMs ARE LOADED
STATION 3 IS AT DIFFUSER. BRINE DISCHARGE BEGAN BETWEEN SURVEYS 2 AND 3.

Station	Survey 1	Survey 2	Survey 3	Survey 4	Survey 5
	GRASS SHRIMP (Palaemonetes) 15 Whole Animals per Assay				
1 (B-BOM)	.75 ± .12	.95 ± .10	Anoxia	.95 ± .02	.69 ± .12
2 (B-BOM)	.73 ± .12	.90 ± .09	Anoxia	.92 ± .03	.75 ± .09
3 (B-BOM)			Anoxia	.96 ± .02	.75 ± .08
4 (B-BOM)	.86 ± .08	.90 ± .15	Anoxia	.95 ± .03	.79 ± .02
5 (B-BOM)	.82 ± .12	.92 ± .12	Anoxia	.92 ± .04	.70 ± .03
6 (B-BOM)	.79 ± .11	.85 ± .04	Anoxia	.94 ± .06	.81 ± .03
7 (B-BOM)	.84 ± .13	.96 ± .12	.10 ± .001	.91 ± .04	.84 ± .02
8 (B-BOM)	.73 ± .17	.85 ± .11	.58 ± .01	.95 ± .03	.86 ± .03
3 (P-BOM)	.72 ± .07	.79 ± .10	.79 ± .11	.94 ± .04	.88 ± .03
8 (P-BOM)	.77 ± .12	.80 ± .08	.73 ± .11	.98 ± .02	.86 ± .02
Reference Control	.77 ± .12	.75 ± .07	.76 ± .18	.93 ± .02	.89 ± .04
Mean of Means	.78	.86	.60	.94	.79
	COMMERCIAL SHRIMP (Penaeus) 6 Replicates per Assay				
1 (B-BOM)	.81 ± .08	.90 ± .9	Anoxia	.85 ± .02	.82 ± .09
2 (B-BOM)	.85 ± .14	.93 ± .08	Anoxia	.81 ± .04	.89 ± .06
3 (B-BOM)			Anoxia	.92 ± .04	.87 ± .08
4 (B-BOM)	.83 ± .09	.90 ± .13	Anoxia	.91 ± .07	.83 ± .05
5 (B BOM)	.83 ± .10	.81 ± .07	Anoxia	.86 ± .08	.87 ± .06
6 (B BOM)	.87 ± .01	.93 ± .17	Anoxia	.89 ± .06	.90 ± .03
7 (B BOM)	.78 ± .11	.89 ± .05	Anoxia	.91 ± .05	.92 ± .07
8 (B-BOM)	.77 ± .07	.83 ± .05	Anoxia	.92 ± .05	.96 ± .03
Reference Control	.77 ± .13	.99 ± .07	.94 ± .05	.98 ± .01	.93 ± .04
Mean of Means	.81	.90		.89	.89

can be seen also in Table 2 that during Survey 3 the grass shrimp adapted somewhat better than the commercial shrimp to the offshore, low-oxygen bottom water that swept across the test area during the 3-day exposure period. The average EC of grass shrimp exposed to the bottom water dropped to 0.34 (Table 2, Stations 7 and 8, B-BOMs) but was the same as the control in the oxygenated surface waters (Stations 3 and 8, P-BOMs). The commercial shrimp had no survivors in the low-oxygen bottom waters at any station. There is other evidence that EC responds by reduction below control values when environmental conditions deteriorate from optimal. For example, Ivanovici (1980b) found that the EC of the snail Pyrazus ebeninus dropped significantly with change of tide and even to a greater extent under abnormal flood conditions (Table 3). Wijsman (1976) found that EC decreased in Mytilus edulis under anaerobic conditions.

Data are accumulating that show that EC responds to both natural and manmade perturbations. For instance, mollusks experimentally exposed to an environment contaminated by petroleum hydrocarbons developed depressed ECs (below 0.7), as did those exposed to the outlet stream of heated water (8°C above ambient) from a power plant (Ivanovici, 1980a). In both cases, the low ECs were associated with very sparse populations. This fact supports the contention that low ECs are coupled with low reproductive and survival potentials.

METABOLIC ENZYMES

As indicated above for petroleum hydrocarbons and excess heat, the EC drops rapidly under certain chemical or physical changes in the environment. In many instances, however, it is not clear just what substance or substances in a waste such as contaminated dredged material will cause the EC drop. In some instances, this can be determined by analyzing the field test organisms for selected metabolic enzymes (Pequegnat and Wastler, 1980). For instance, the activity of the metabolic enzyme ATPase was found to change markedly (Table 4) in the presence of substantial amounts of PCBs in dredged material in the New York Bight (Pequegnat and Wastler, 1980). Chlorinated hydrocarbons also will cause a rapid drop in EC ratios. In like manner, anotner enzyme, namely cytochrome P-420 and P-450, increases in organisms exposed particularly to petroleum and chlorinated hydrocarbons, and catalase is particularly sensitive to toxic metals. Thus, by these means it should be possible for the environmental manager to ascertain the class of toxic components of his dredged material that may be causing a drop of EC in important species. Moreover, he and the regulatory agency should be reassured that irreparable damage is not being done to the receiving environment so long as the EC remains at or above 0.7.

CONCLUSION

These findings elevate the EC to the important role of an early warning system of stressful conditions, which are predictive of the development of chronic conditions in the biota. This, then, can become an important tool for the environmental manager who can adjust the rate of waste disposal into the environment at levels that will permit the biota as a whole or key species to retain their viability and reproductive capacities.

TABLE 3. PYRAZUS EBENINUS. ADENYLATE ENERGY CHARGE OF INDIVIDUALS SAMPLED IN THE FIELD: NON-POLLUTED ENVIRONMENTS. VALUES ARE MEANS OF N ANIMALS (INDICATED IN BRACKETS). MOLLUSCS FREEZE-CLAMPED IN THE FIELD (FROM IVANOVICI, 1980b).

Sample	AEC High tide		AEC Low tide
Population from Jervis Bay			
Normal conditions:			
July 1975 (5)	0.90		0.79
Oct. 1975 (10)	0.86		0.80
July 1976 (5)	0.87		0.80
		± 0.014	
Abnormal conditions:			
Flood (12)		0.65 ± 0.034	
Population from Port Hacking (6)		0.85 ± 0.02	

TABLE 4. ATPase LEVELS IN FUNDULUS GRANDIS LIVER AFTER 7 DAYS EXPOSURE ON THE BOTTOM (IN B-BOM CAGES) IN THE NEW YORK MUD DUMPSITE*

Location	No. of fish analyzed	ATPase units** x 10^{-4}/mg protein	Standard deviation 10^{-4}
B-BOM upstream of Dumpsite	33	12.400	.0004
B-BOM in Dumpsite	35	4.000	.0002
1 Mile downstream of Dumpsite	32	9.100	.0003

* In this table, analysis of variance was used to evaluate the data

** Bergmeyer Unit for ATPase = amount of enzyme needed to decompose 1 g of NADH (Nicotinamide adenine dinucleotide reduced form) in 1 min

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AD P002 207

PURIFICATION OF WATER AND SEDIMENTS USING ORGANISMS (LIVING FILTER)-- REMOVAL OF SUSPENDED SOLIDS AND NUTRIENTS BY *PHRAGMITES COMMUNIS* T. AND *ZOSTERA MARINA* L.

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ABSTRACT

In order to clarify the purification efficiency of removal of SS (suspended solids) and nutrients in seawater by *Phragmites communis* T. and *Zostera marina* L., experiments were carried out to determine the correlations between the removal rates for three conditions: (1) the differences of flowing down systems (cascade vs maze system), (2) the volume of flowing water (3 flow conditions), and (3) the concentrations of SS in both planted and nonplanted test ponds.

The following methods are generally considered more desirable for purification of the water:

a. For removing SS and nutrients, the flowing down method using the cascade type ponds under less volume of flowing water,

b. For removing nutrients, the flowing down method controlling the volume of flowing water to remain for 8 - 10 days.

c. For removing PO4-P, a filtrating process using sand-gravel layers.

INTRODUCTION

Many studies on the purification of water and sediments using aquatic plants, *Scirpus lacustris* L., *Phragmites communis* L., and *Eichhornia* crassipes S., etc., have been conducted since the late 1940's, in Western Germany and in the U.S.A.[1-5]. Most of these investigated mainly the eutrophied lake water, urban sewage, industrial drainage, or contaminated sludges; few investigations of the polluted water and contaminated sediments in the sea have been carried out, and there are still many problems to be solved in this area.

Furthermore, although several studies on the absorption efficiency of nutrients in seawater using sea weeds have already been done in Japan[6, 7], the removal rates of nutrients in seawater by Phragmites communis and Zostera marina, which were flourishing in brackish water at the coastal zone, have scarcely been studied as yet.

In this study, in order to clarify the purification efficiency of removals of SS and nutrients in seawater by Phragmites and Zostera, experiments were carried out to determine the correlations between the removal rates for three conditions: (1) the differences of flowing down systems, (2) the volume of flowing water, and (3) the concentrations of SS in both planted and nonplanted test ponds (May-Oct., 1979 and 1980).

MATERIALS AND METHODS

Aquatic Plants

Aquatic plants used in this study, Phragmites communis and Zostera marina, had respective body lengths of about 97 to 177 cm (average 140.3 cm) and 53 to 86 cm (average 68.8 cm); the respective body wet weights were about 15 to 50 g (average 29.4 g) and 4 to 21 g (9.1 g); and the respective densities planted were 13 roots/m^2 and 20 roots/m^2. Thick vinyl packing tape was used as the para-Phragmites communis and the para-Zostera marina for the control experiments. This tape simulated the leaf action of the plants.

Seawater

Seawater used in this study was drawn from a well and fixed concentrations were added of kaolin for SS, and of KH_2PO_4, $(NH_4)_2 SO_4$, N_aNO_2, KNO_3, and $HOOCCH_2CH_2CH(NH_2)COOH$ for nutrients (Table 1).

Facilities

Facilities used in this study were composed of a cistern for stirring up the seawater (10.0 m × 7.0 m × 1.2 m, equipped with two stirring apparatuses), a tank tower for pouring into (ϕ 0.3 m, height 3.2 m, depth 1.6 m), a cascade

TABLE 1. QUALITIES OF SEAWATER DRAWN FROM A WELL

Items	Characteristics
Temperature	18.3 - 18.7°C
Cl^-	15.89 - 16.68%
PH	8.2 - 8.4
DO	52 - 65%
COD	0.0 - 0.2 ppm
NH_4-N	0.020 - 0.040 ppm
NO_2-N	0.002 - 0.006 ppm
NO_3-N	2.700 - 5.260 ppm
Inorg.-N	2.722 - 5.306 ppm
PO_4-P	0.090 - 0.300 ppm

type test pond (3.4 m × 15.0 m × 1.25 m), and a maze type test pond (10.0 m × 7.0 m × 1.2 m, width of a water way (1.0 m), and length of a waterway (60.0 m); their arrangements and a detailed section of the cascade type test pond are shown in Figs. 1 and 2. In the cascade type test pond, pits (1.5 m × 0.6 m × 1.25 m) were established both on the upper and lower sides of each small test pond (1.5 m × 2.0 m × 1.25 m), and heads of 10 to 20 cm were made, respectively. In the bottom of each small test pond, sand-gravel or sands, respectively, were laid to fixed thickness according to the purpose of experiments; vinyl chloride tubes with slits (diameter = 10 cm, length = 1.5 m) were embedded for underdraining.

Methods and Conditions

For every SS and nutrient removal experiment, the seawater used was stirred in the cistern and pumped into the tank tower for eventual pouring into the cascade or maze type test pond. The volume of flowing water was controlled with the cock valve. In the continuous surface flow and filtration experiments, the water flowed continuously during the fixed time, and was sampled and measured once just before the conclusion of each experiment. However, in the static water experiments, the water was sampled and measured 6 times (after 0, 0.5, 1, 3, 4, and 7 days) in the nonacclimated experiments and 11 times

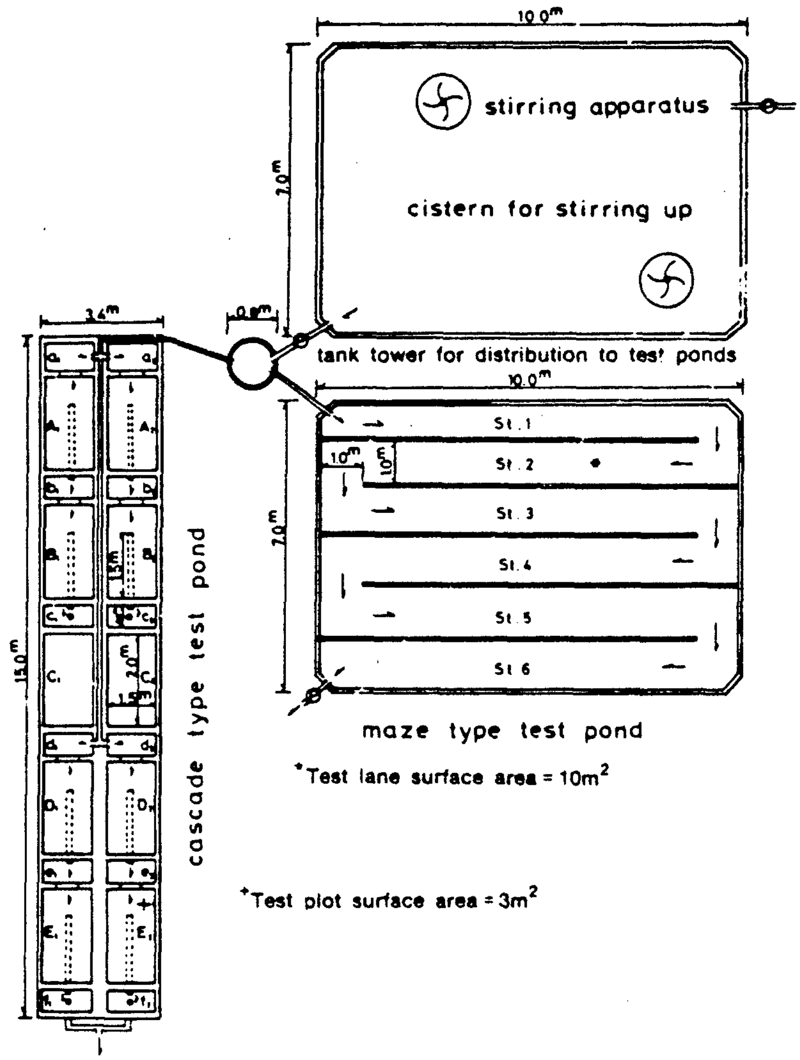

Figure 1. Arrangement of experimental facilities

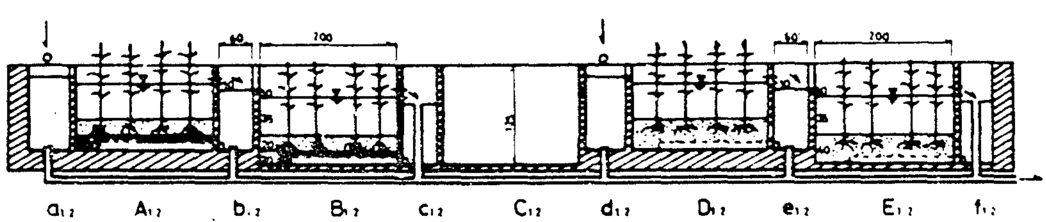

Figure 2. Section of the cascade type test pond

(every day) in experiments acclimated for 2 days. The items of water quality measured were temperature, Cl-, pH, DO, and SS in the removal experiments of SS, and temperature, Cl-, pH, DO, NH_4-N, NO_2-N, NO_3-N, Inorg -N, PO_4-P, and COD in the removal experiments of nutrients. The contents of each experiment are discussed in the following paragraphs.

Removal Experiments of SS

Continuous surface flow experiments in the cascade type test pond. The conditions of the experiments and the small test ponds used were set up as shown in Table 2. The concentrations of SS were 100, 300, and 500 ppm; the

TABLE 2. REMOVAL EXPERIMENTS OF SS - CASCADE TYPE TEST POND

Concentrations of SS (ppm)	Volume of flowing water (m^3/hr) (flow)	Time (hr)	Plants*	Test ponds**
	0.5 1.0 2.0	6.0 3.0 1.5	*Phragmites communis*	A_1, B_1
100 300 and 500	0.5 1.0 2.0	6.0 3.0 1.5	Para-*P.*† *communis* and No Plants	A2 and B_2
	1.5 3.0 6.0	6.0 3.0 1.5	*Zostera marina*	D_1, E_1
	1.5 3.0 6.0	6.0 3.0 1.5	Para-*Z.*† *marina* and No Plants	D2 and E_2

* Densities planted: 13 roots/m^2 in *Phragmites*, 20 roots/m^2 in *Zostera*.
** Water depth: 35 cm in *Phragmites* and 80 cm in *Zostera*.
† Control experiment using vinyl tape to simulate the action of the grasses.

volumes of flowing water were 0.5, 1.0, and 2.0 m^3/hr in *Phragmites* and 1.5, 3.0, and 6.0 m^3/hr in *Zostera*; and the terms of the experiments were 6.0, 3.0, and 1.5 hr, respectively. With the following conditions, 3 concentrations, 3 flow/time combinations, 4 plant conditions, a total of 36 experiments were conducted.

Continuous surface flow experiments in the maze type test pond. Only Phragmites communis was used in this study. The conditions of the experiments were set up as shown in Table 3.

TABLE 3. REMOVAL EXPERIMENTS OF SS - MAZE TYPE TEST POND

Concentrations of SS (ppm)	Volume of flowing water (m^3/hr) (flow)	Time (hr)	Plants
	5	10.0	Phragmites communis
	10	5.0	
100	15	3.5	
and	5	10.0	
500	10	5.0	No
	15	3.5	

The concentrations of SS were 100 and 500 ppm; the volumes of flowing water were 5, 10, and 15 m^3/hr, and the terms of the experiments were 10.0, 5.0, and 3.5 hr. With the following conditions, 2 concentrations, 3 flow/time combinations, 2 planting conditions, a total of 12 experiments were conducted.

Removal Experiments of Nutrients

Continuous surface flow experiments. In the cascade type test pond, the conditions of experiments and the small test ponds used were set up as shown in Table 4. The concentrations of nutrients were fixed; the volumes of flowing water were 0.125, 0.25, and 0.5 m^3/hr in Phragmites and 0.375, 0.75, and 1.5 m^3/hr in Zostera; and the terms of the experiments were 24, 12, and 6 hr, respectively. With the following conditions, 1 concentration, 3 flow/time combinations, 4 planting conditions, a total of 12 experiments were conducted.

In the maze type test pond, the conditions of experiments were set up as shown in Table 4. The concentrations of nutrients were fixed; the volumes of flowing water were 5, 10, and 15 m^3/hr, and the terms of the experiments were 10, 5, and 3.5 hr, respectively. Only Phragmites was used in this study. With the following conditions, 1 concentration, 3 flow/time conditions, 2 planting conditions, a total of 6 experiments were conducted.

TABLE 4. REMOVAL EXPERIMENTS OF NUTRIENTS - CONTINUOUS SURFACE FLOW EXPERIMENTS

Concentrations of nutrients (ppm)	Volume of flowing water (m^3/hr) (flow)	Times (hr)	Plants		Test ponds
	0.125	24.0	*Phragmites*		
	0.250	12.0	*communis*		A_1, B_1
	0.500	6.0			
				The	
	0.125	24.0			
	0.250	12.0	No	cascade	A_2, B_2
$(NH_4)_2S_4$ 2,	0.500	6.0			
				type	
	0.375	24.0	*Zostera*		
N_aNO_2 2,	0.750	12.0	*marina*	test	D_1, E_1
	1.500	6.0			
				pond	
KNO_3 2,	0.375	24.0			
and	0.750	12.0	No		D_2, E_2
	1.500	6.0			
KH_2PO_4 2,	5.000	10.0	*Phragmites*		
	10.000	5.0	*communis*		The maze
	15.000	3.5			
					type test
	5.000	10.0			
	10.000	5.0	No		pond
	15.000	3.5			

Filtration experiments. Only *Phragmites* was used in this study. The conditions of experiments and the small test ponds used were set up as shown in Table 5.

The concentrations of nutrients were fixed; the volumes of flowing water were 0.125, 0.25, 0.5, 1.0, 3.0, and 5.0 m^3/hr in sand-gravel layers (each thickness 20 cm) and 1.0, 2.0, and 3.0 m^3/hr in sand layers (thickness 40 cm); and the terms of the experiments were 24, 12, 6, 10, 3.5, and 2 hr and 10, 5 and 3.5 hr, respectively. As per Table 5, a total of 18 experiments were conducted.

TABLE 5. REMOVAL EXPERIMENTS OF NUTRIENTS - FILTRATION EXPERIMENTS

Concentrations of nutrients (ppm)	Volume of flowing water (m^3/hr) (flow)	Times (hr)	Plants	Test ponds	Filtration layers
	0.125	24.0			
	0.25	12.0	Phragmites communis	A_1, B_1	
	0.5	6.0			
$(NH_4)_2SO_4$ 2,	1	10.0			
	3	3.5		A_2, B_2	
N_aNO_2 2,	5	2.0			Sand-gravel
	0.125	24.0			
KNO_3 2,	0.25	12.0		A_2, B_2	
and	0.5	6.0	NO		
	1	10.0			
KH_2PO_4 2	3	3.5		A_1, B_1	
	5	2.0			
	1	10.0	Phragmites communis		
	2	5.0		D_2, E_2	
	3	3.5			
					sands
	1	10.0			
	2	5.0	No	D_1, E_1	
	3	3.5			

Static water experiments. The conditions of experiments and the small test ponds used were set up as shown in Table 6. The concentrations of nutrients were fixed, and the terms of the experiments were 7 days in the nonacclimated experiments (both *Phragmites* and *Zostera*) and 10 days in the acclimated experiments (only *Phragmites*). As per Table 6, a total of 6 experiments were conducted.

TABLE 6. REMOVAL EXPERIMENTS OF NUTRIENTS - STATIC WATER EXPERIMENTS

Concentrations of nutrients (ppm)	Times (days)	Plants	Test ponds
$(NH_4)_2SO_4$ 2, $NaNO_2$ 2, KNO_3 2, and KH_2PO_4 2	7	*Phragmites communis*	A_1, B_1
		No	A2
		Zostera marina	D1, E1
		No	D_2
$(NH_4)_2SO_4$ 2, $NaNO_2$ 2, KNO_3 2, KH_2PO_4 2, and $HOOCCH_2CH_2$-$CH(NH_2)COOH$ 20,	10	*Phragmites communis*	D_2, E_2
			D_1
		No	

RESULTS

Results obtained in this study are discussed below.

Removal Rates of SS

Continuous Surface Flow Experiments in the Cascade Type Test Pond

In the cascade type test pond, the SS removal rates by *Phragmites communis* and *Zostera marina* obtained in this study are shown in Figure 3.

The *Phragmites* SS removal rates at 3 and 6 m^2 in planted flowing down areas were, respectively, 49.6-62.7% and 84.1-89.5% in 0.5 m^3/hr, 25.1-44.1% and 56.1-66.6% in 1.0m^3/hr, and 9.6-33.6% and 27.8-45.5% in 2.0 m^3/hr of the volume of flowing water. There was a tendency for the rates to show higher values according to higher concentrations of SS and less volume of flowing water. This tendency was especially noticeable in the first 3-m^2 areas planted. The differences of removal rates in each concentration of SS were larger according to more volume. At 3 m^2 rather than 6 m^2, the differences

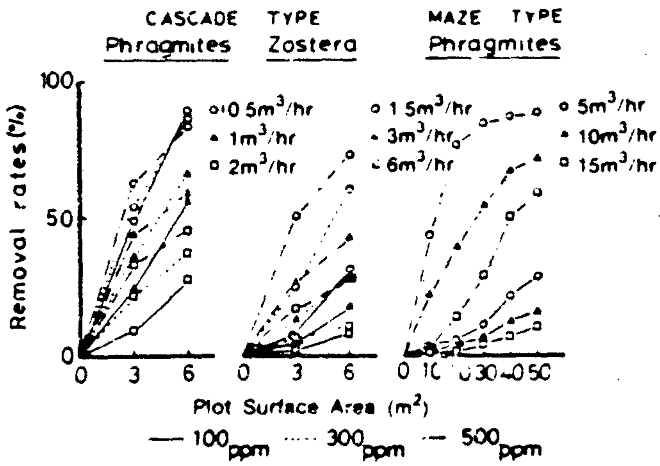

Figure 3. Removal rates of SS

between 100 and 300 ppm were 2.7-5.2% in 0.5 m^3/hr, 10.5-11.2% in 1.0 m^3hr, and 9.6-12.8% in 2.0 m^3/hr, and the differences between 100 and 500 ppm were 5.4-13.1% in 0.5 m^3/hr, 10.5-19.0% in 1.0 m^3/hr, and 17.7-24.0% in 2.0 m^3/hr, respectively.

The SS removal rates in nonplanted test ponds were lower than in the planted ponds, and their differences were 26.1-33.4% in 0.5 m^3/hr, 17.2-26.7% in 1.0 m^3/hr, and 13.7-17.9% in 2.0 m^3/hr at 6 m^2 of flowing down areas. The differences tended to be larger according to less volume, on the order of 300 > 100 > 500 ppm in the concentrations of SS. The rates in para-Phragmites were lower than in planted, and their differences showed higher values of 18.9-22.7% in 500 ppm; however, they were scarcely detected in 100 and 300 ppm.

In this study, the temperature was 21.8-25.4°C, Cl^- was 15.91-16.89^o/oo, pH was 7.5-8.6, and DO was 88-105%, respectively; pH especially tended to show lower values of 0.2-0.6 in planted test ponds.

On the other hand, the Zostera SS removal rates at 3 and 6 m^2 of planted flowing down areas were, respectively, 7.9-50.3% and 31.6-73.0% in 1.5 m^3/hr, 5.2-26.9% and 17.9-42.9% in 3.0 m^3/hr, and 2.1-17.0% and 7.9-29.5% in 6.0 m^3/hr of the volume of flowing water. There was a tendency similar to Phragmites with the rates showing higher values according to higher concentrations of SS and less volume. This tendency was especially noticeable in the first

3-m^2 areas planted in 500 ppm. However, their removal rates showed lower values compared with Phragmites according to lower concentrations of SS; the differences were 7.5-57.9% in 100 ppm, 15.9-37.1% in 300 ppm, and 11.1-17.2% in 500 ppm, respectively. Contrary to Phragmites, the differences of removal rates among each concentration of SS were generally less according to more volume and in first 3 m^2 than 6 m^2. The differences between 100 and 300 ppm were 17.1-28.9% in 1.5 m^3/hr, 8.3-11.6% in 3.0 m^3/hr, and 2.8-4.4% in 6.0 m^3/hr; between 100 and 500 ppm the differences were 41.4-42.4% in 1.5 m^3/hr, 21.7-25.0% in 3.0 m^3/hr, and 14.9-20.9% in 6.0 m^3/hr, respectively.

The SS removal rates in nonplanted test ponds showed lower values than in planted ponds, and the differences at 6 m^2 were 8.3-27% in 1.5 m^3/hr, 6.8-19.9% in 3.0 m^3/hr, and 3.4-15.8% in 6 m^3/hr. The differences tended to show higher values according to less volume and higher consistencies of SS. Also, the differences of removal rates of SS between planted and para-planted test ponds were 12.1-18.3% at 3 m^2 in 500 ppm; however, the differences were scarcely detected in other cases.

In this study, the temperature was 22.5-25.4°C, Cl^- was 16.15-16.86°/oo, pH was 7.6-8.6, and DO was 92-100%, respectively.

Continuous Surface Flow Experiments in the Maze Type Test Pond

In the maze type test pond, the SS removal rates by Phragmites communis are shown in Figure 3.

While the SS removal rates showed higher values according to less volume of flowing water, the 500 ppm rates (rather than 100 ppm) showed very high values, especially in the early areas of 10 and 20 m^2 (St. 1 and 2, Figure 1); however, they scarcely increased in the latter areas of 40 and 50 m^2 (St. 4 and 5, Figure 1).

Although lower values of 4.4-11.6% were found in 100 ppm at 30 m^2 in every volume, the rates tended to increase relatively from 40 to 50 m^2, and they were 29.1% in 5 m^3/hr, 16.5% in 10 m^3/hr, and 10.9% in 15 m^3/hr at 50 m^2, respectively. On the contrary, in 500 ppm in the early areas, rates tended to show very high values according to less volume, especially of 63.6% at 10 m^2 and 76.9% at 20 m^2 in 5 m^3/hr; however, they increased only slightly from 30-50 m^2, from 84.9-88.6%. Furthermore, they were, respectively, 72.0% in 10 m^3/hr and 59.7% in 15 m^3/hr at 50 m^2.

Although the rates in nonplanted test ponds showed lower values than in planted, their differences were less according to more volume in both 100 and 500 ppm.

In this study, the temperature was 13.9-18.7°C, Cl^- was $15.48\text{-}17.11^{o}/oo$, pH was 8.0-8.4, and DO was 100-105%, respectively.

Removal Rates of Nutrients

Continuous Surface Flow Experiments

In the cascade type test pond, the removal rates of nutrients by *Phragmites communis* and *Zostera marina* obtained in this study are shown in Figure 4.

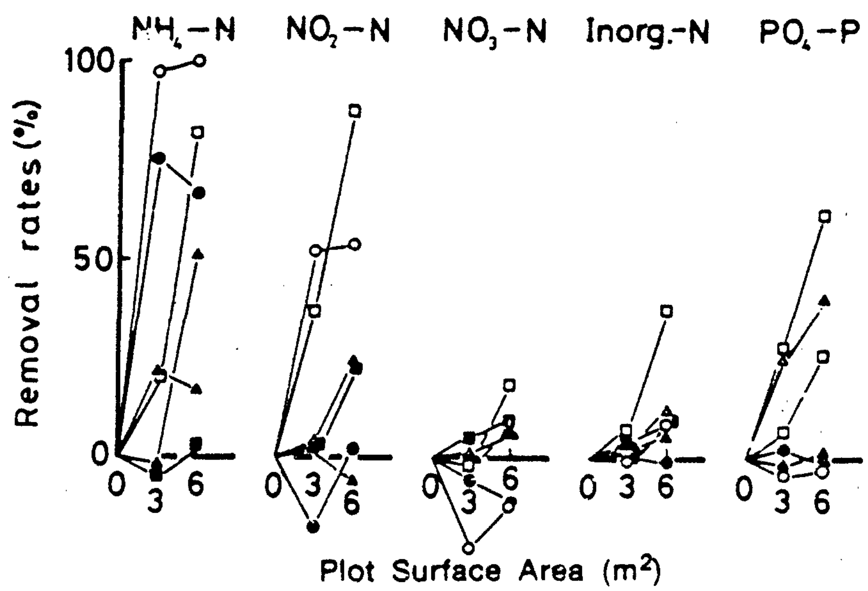

Figure 4. Removal rates of nutrients, cascade type test pond

In *Phragmites* NH4-N showed very high removal rates of about 100.0% in 0.125 m^3/hr, 51.4% in 0.25 m^3/hr, and 81.9% in 0.5 m^3/hr; NO_2-N also showed high values of 53.7% in 0.125 m^3/hr, 24.2% in 0.25 m^3/hr, and 87.6% in 0.5 m^3/hr at 6 m^2, respectively. However, no regular correlation was detected between removal rates and flow. On the contrary, NO_3-N showed very low values of removal rates in every flow rate. Inorg.-N values (summed NH_4-N, NO_2-N, and NO_3-N) were 8.5% in 0.125 m^3/hr, 12.1% in 0.25 m^3/hr, and 37.3% in 0.5 m^3/hr at 6 m^2. There was a tendency for the rates to show higher values according to more volume within the range investigated in this study. The removal of PO_4-P was scarcely detected in 0.125 m^3/hr; however, the rates showed very high values of 40.5% in 0.25 m^3/hr and 61.6% in 0.5 m^3/hr at 6 m^2. Like Inorg.-N, the rates showed higher values according to more volume.

Furthermore, with respect to the differences of removal rates between planted and nonplanted test ponds, although NH_4-N and NO_2-N showed higher values of 18% and 6.8-64.0%, respectively, such differences were scarcely detected in NO_3-N, Inorg.-N, and PO_4-P.

On the other hand, Zostera removal rates were generally lower compared with Phragmites, and although the rates of NH_4-N showed high values of 66.7% in 0.375 m^3/hr, they showed low values of 17.3% in 0.75 m^3/hr and 3.3% in 1.5 m^3/hr and 6 m^2. There was a tendency for the rates to decrease according to the volume increases. NO_2-N showed a high value of 22.7% in 1.5 m^3/hr, but the removals were scarcely detected in 0.375 m^3/hr and 0.75 m^3/hr. No regular tendency was recognized between the removal rates and the volume of flowing water. NO_3-N showed relatively low values in every volume, and the rates tended to increase according to the volume increasing. Inorg.-N had a similar tendency.

With respect to the differences of removal rates between planted and nonplanted test ponds, in every case the differences were scarcely detected in 0.375 m^3/hr; however, there were a few differences: NH_4-N showed 5.3% in 0.75 m^3/hr and 13.0% in 1.5 m^3/hr, Inorg.-N 4.0-4.4% in 0.75 m^3/hr and 1.5 m^3/hr, and PO_4-P 9.3% in 1.5 m^3/hr, respectively.

In this study, the temperature was 23.1-25.5°C, Cl^- was 17.00-17.89o/oo, pH was 7.8-8.7, and DO was 74-105%, respectively.

In the maze type test pond, the removal rates of nutrients by Phragmites communis obtained in this study are shown in Figure 5.

All removal rates of nutrients showed gradually higher values according to the increasing flowing down areas in the lower flow conditions. Although this tendency was more noticeable, it was scarcely detected for NH_4-N and NO_2-N which showed, respectively, very low values in every flow condition.

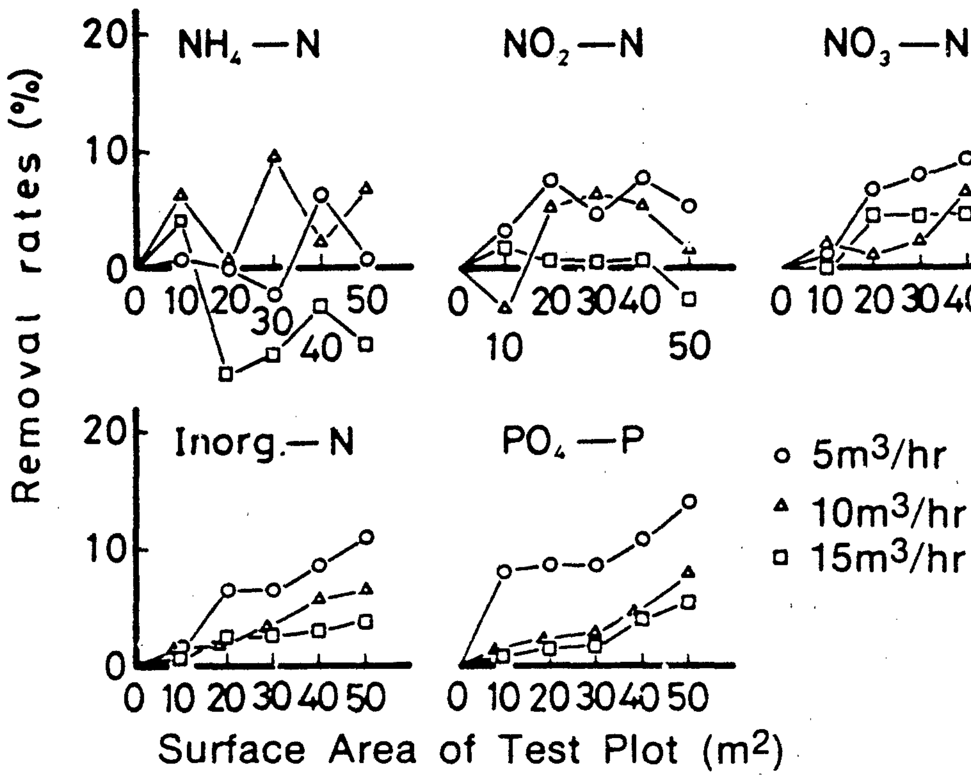

Figure 5. Removal rates of nutrients, maze type test pond

Also, NO_3-N, Inorg.-N, and PO_4-P, respectively, showed low values of 13.8, 7.7, and 6.8%; 11.0, 6.6, and 3.8%; and 14.0, 8.0, and 5.4% in 5, 10, and 15 m^3/hr at 50 m^2. The rates tended to decrease gradually as the flow increased.

With respect to the differences between planted and nonplanted test ponds, all nutrients except NH_4-N showed higher removal in planted ponds as the flow decreased. In this study, the temperature was 17.8-23.0°C, Cl^- was 15.11-17.39°/oo, pH was 8.0-8.4, and DO was 98-105%, respectively. Also, pH especially tended to decrease gradually to about 0.1-0.3 in planted test ponds as the areas of flowing down increased.

Filtration Experiments

Sand-gravel layer. By filtrating the sand-gravel layers planted with *Phragmites communis*, the nutrient removal rates shown in Figure 6 were obtained.

The nutrient removal rates of NH_4-N, NO_2-N, and PO_4-P tended to decrease gradually as the flow increased, but the opposite was true for NO_3-N and Inorg.-N. The removal rates of NH_4-N showed very high values of 86.0% in 0.125 m^3/hr, 50.4% in 0.25 m^3/hr, and 45.0% in 0.5 m^3/hr at 6 m^2; and NO_2-N also showed high values of 44.3% in 0.125 m^3/hr, 43.5% in 0.25 m^3/hr, and 20.8% in 0.5 m^3/hr. However, the removals of both nutrients were scarcely detected over their volumes. While the removal rates of PO_4-P showed very high values of 90.8-91.2% in 0.125, 0.25, and 0.5 m^3/hr, they also showed high values of 61.4% in 1.0 m^3/hr, 20.1% in 3.0 m^3/hr, and 14.6% in 5.0 m^3/hr. These results suggested that the filtration layers were very effective methods for purification. The rates of NO_3-N and Inorg.-N were only 2.5-7.5% and 4.4-15.8%, respectively.

The differences in removal rates between planted and nonplanted test ponds were scarcely detected in NH_4-N, NO_2-N, and NO_3-N, and there were lower differences for a smaller volume of flowing water. On the other hand, in PO_4-P some differences were detected in a higher volume of flowing water.

In this study, the temperature was 18.5-24.3°C, Cl^- was 16.29-17.63^o/oo, pH was 7.0-8.6, and DO was 25-104%, respectively. Also, pH decreased to about 0.5-1.3 in planted and 0.1-1.2 in nonplanted test ponds, respectively, by filtrating, and the tendency was more remarkable in less volume of flowing water. At the same time, it was also recognized that DO decreased to about 26-77% in 0.125-0.5 m^3/hr in both planted and nonplanted test ponds by filtrating.

Sand layer. By filtrating the sand layers planted with *Phragmites communis*, the nutrient removal rates shown in Figure 6 were obtained.

The removals of NH_4-N, NO_2-N, and NO_3-N were scarcely detected in every volume by filtrating; however, the rates of PO_4-P showed higher values of 60.% in 1.0 m^3/hr, 43.2% in 2 m^3/hr, and 39.7% in 3 m^3/hr at 6 m^2, similar to sand-gravel layers in less volume of flowing water. Although the differences of removal rates between planted and nonplanted test ponds were scarcely detected for NH_4-N, NO_2-N, and NO_3-N, the rates of PO_4-P showed higher values in planted test ponds.

In this study, the temperature was 18.5-22.0°C, Cl^- was 16.29-17.27^o/oo, pH was 7.4-8.4, and DO was 98-104%, respectively. The pH decreased to the extent of about 0.6-1.0 by filtrating.

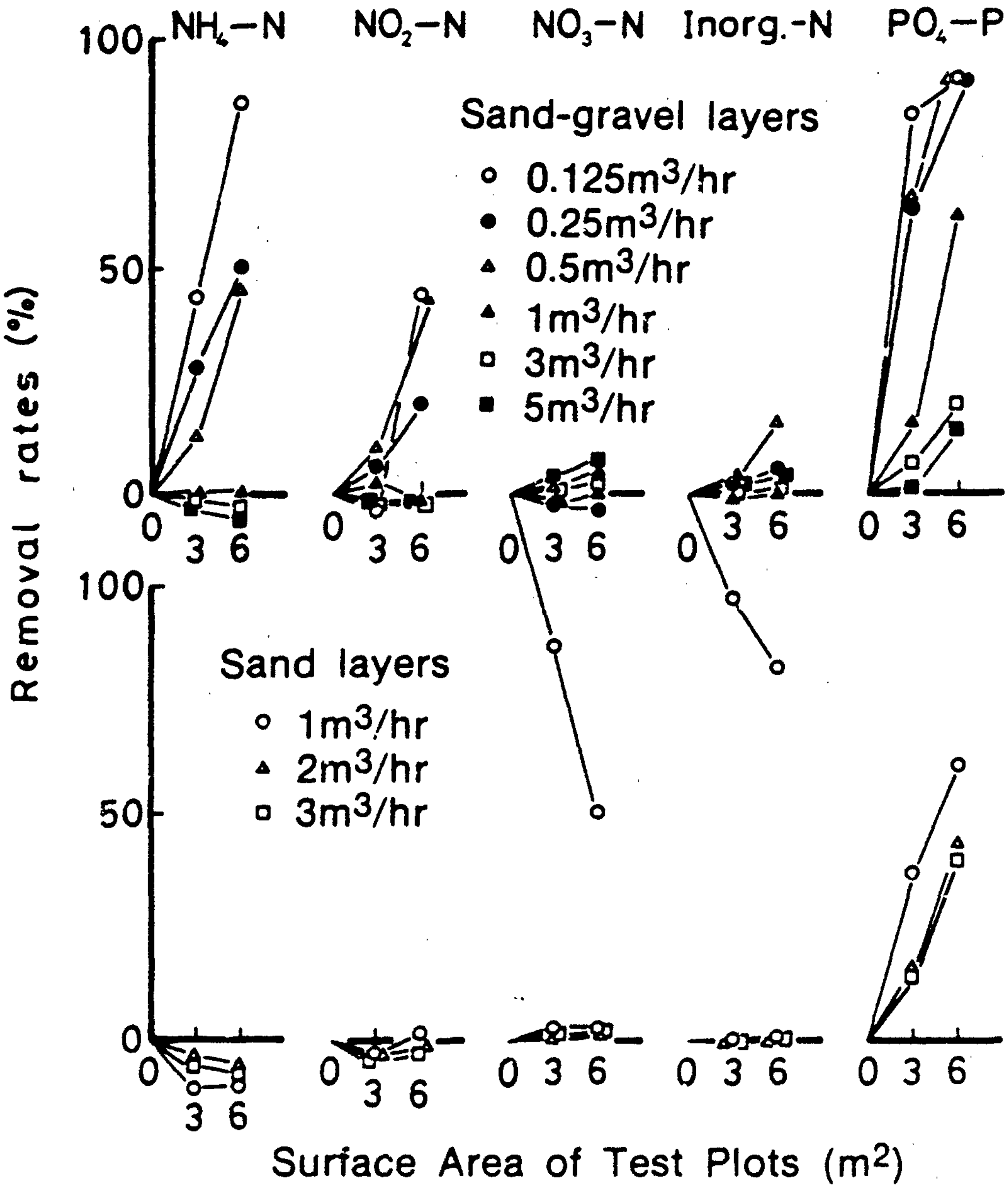

Figure 6. Removal rates of nutrients, filtrating experiments

Static Water Experiments

The nutrient removal rates in static seawater, by Phragmites communis and Zostera marina, obtained in this study are shown in Figure 7.

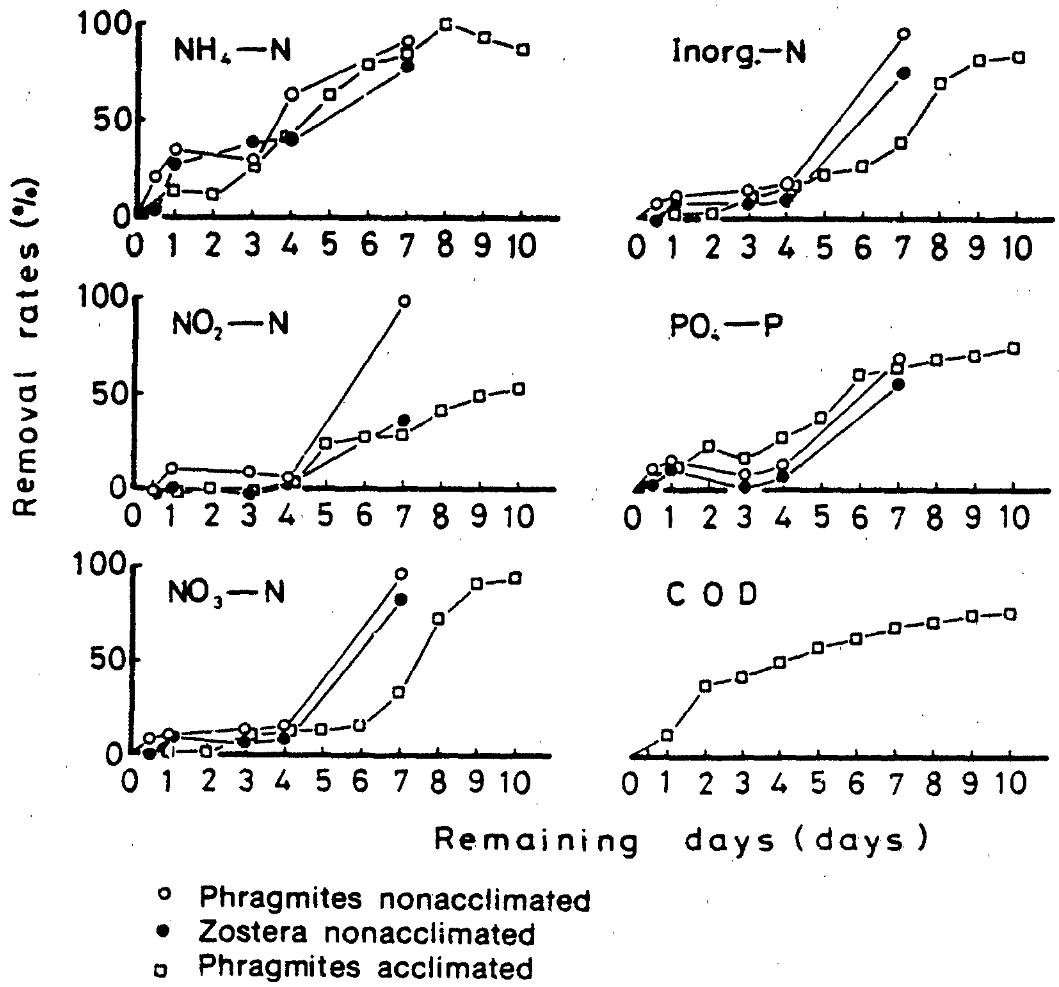

Figure 7. Removal rates of nutrients, static water experiments

In the nonacclimated static water experiments, in both Phragmites and Zostera, the rates of Inorg.-N and PO_4-P increased for a time in the 1st day, then decreased to the 3rd day, and again increased sharply from the 4th to 7th day. While Phragmites compared with Zostera showed relatively higher values, the rates of Inorg.-N and PO_4-P showed very high values of 95.7 and

69.3% in Phragmites and 75.4 and 56.3% in Zostera during 7 days, respectively.

On the other hand, in the static water experiments using Phragmites acclimated for 2 days, the rates of Inorg.-N increased gradually from the 2nd day and sharply from the 6th to 8th day, and again gradually inclined to the 10th day. PO_4-P increased in some degree to the 2nd day, decreased to the 3rd day, increased sharply from the 3rd to 6th day, and gradually inclined from the 6th day. COD increased sharply to the 2nd day and gradually inclined from the 2nd to 10th day. The rates of Inorg.-N, PO_4-P, and COD showed high values of 84.2, 74.3, and 76.5% during 10 days, respectively.

Thus, in acclimated experiments compared with nonacclimated, the gradually inclining or declining terms were shorter in the early days and the curves of removal rates increasing were gentler. Furthermore, the differences between planted and nonplanted test ponds, in Phragmites and Zostera nonacclimated, showed higher values of 53.5 and 74.7% in Inorg.-N, and 40.1 and 36.2% in PO_4-P on the 7th day, respectively. However, in Phragmites acclimated, the differences were scarcely detected, about 9.4% in Inorg.-N, 5.9% in PO_4-P, and 10.8% in COD on the 10th day.

In this study, the temperature was 16.2-22.9°C, Cl^- was 15.74-18.19^o/oo in nonacclimated and 7.92-10.49^o/oo in acclimated, pH was 7.7-9.3, and DO was 48-105%, respectively. In Phragmites test ponds, pH decreased to about 0.4 in the early days, and DO showed lower values of about 48.0-74.5% around the 2nd-3rd day and the 9th-10th day.

CONCLUSIONS AND DISCUSSION

In this study, in order to clarify the purification efficiency of removal of SS and nutrients in seawater by Phragmites communis and Zostera marina, experiments were carried out to determine the correlations between the removal rates for three conditions: (1) the differences of flowing down systems, (2) the volume of flowing water, and (3) the concentrations of SS in both planted and nonplanted test ponds, under fixed densities of 13 roots/m^2 in Phragmites and 20 roots/m^2 in Zostera.

Higher removal rates were detected in narrow areas in the cascade type test ponds, and Zostera rates showed lower values in lower concentrations of SS. However, in every case, the rates showed higher values in less volume of flowing water, in higher concentrations of SS, and in larger areas of flowing down.

In the maze type test pond planted with 13 roots/m^2 of Phragmites, the following correlation formula was developed among the removal rates of SS (R_{SS}:%), the volume of flowing water (Q:m^3/hr), the areas of flowing down (A:m^2), and the concentrations of SS (N:ppm):

$$R_{SS} = -5.4982 + 0.0459\left(\frac{A.N}{Q}\right) - 4.7884 \times 10^{-6}\left(\frac{A.N}{Q}\right)^2 - 1.4494 \times 10^{-10}\left(\frac{A.N}{Q}\right)^3$$

(standard deviation of residual 4.8637)

On the other hand, as for the removal rates of nutrients, in the surface flow experiments, higher values of a few times were detected in the cascade type as compared to the maze type test pond. The considerably higher values were especially detected in 0.5 m^3/hr in the cascade type and in 5 m^3/hr in the maze type test pond. The rates of PO_4-P also showed generally higher values than Inorg.-N; this tendency was more noticeable in the cascade test pond.

In the maze type test pond planted with Phragmites, the following correlation formula was among the removal rates of Inorg.-N (R_N:%) and PO_4-P (Rp:%), the volume of flowing water (Q:m^3/hr), and the areas of flowing down (A:m^2):

$$R_N = 0.1552 - 0.1940\left(\frac{A}{Q}\right) + 0.5747\left(\frac{A}{Q}\right)^2 - 0.0391\left(\frac{A}{Q}\right)^3$$

(standard deviation of residual 0.5461)

$$Rp = -4.7279 + 1.0617\left(\frac{A}{Q}\right) + 0.2550\left(\frac{A}{Q}\right)^2 - 0.0183\left(\frac{A}{Q}\right)^3$$

(standard deviation of residual 0.8420)

In the filtrating experiments, in both sand-gravel and sand layers, the rates of PO_4-P removal showed very high values of about 91% in less volume of flowing water, 0.125-0.5 m^3/hr; however, the values decreased gradually as the volume increased. In sand-gravel layers, the removals of NH_4-N and NO_2-N were detected in 0.125-0.5 m^3/hr, but in sand layers, they were scarcely detected in every case of NH_4-N, NO_2-N, NO_3-N, and Inorg.-N.

In the static water experiments, the removal rates of nutrients increased gradually with the lapse of time: every case showed very high values after the 7th-8th day, and it was found that the rates of Inorg.-N, PO_4-P, and COD showed very high values of 84.2, 74.3, and 76.5%, respectively, on the 10th day. The differences of removal rates between planted and nonplanted test ponds were scarcely detected. In planted test ponds pH declined to the neutral side.

In the static seawater tests planted with Phragmites the following correlation formula was developed between the removal rates of Inorg.-N (R_N:%), PO_4-P (Rp:%), COD (R_{COD}:%), and remaining days (D:days).

$$R_N = 21.8587 - 18.7148D + 5.5525D^2 - 0.3040D^3$$

(standard deviation of residual 12.4444)

$$Rp = 30.8557 - 21.1121D + 6.4850D^2 - 0.3976D^3$$

(standard deviation of residual 5.9626)

$$R_{COD} = -6.7443 + 23.7050D - 2.6741D^2 + 0.1146D^3$$

(standard deviation of residual 2.6447)

From these results, the following methods were generally considered more desirable for purification of the water: (1) flowing down method using the cascade type ponds under less volume of flowing water for removing SS and nutrients; (2) flowing down method controlling the volume of flowing water to remain for 8-10 days, especially for removing nutrients; and (3) adopting a filtrating process using sand-gravel layers for removing PO_4-P.

In conclusion, in order to continue this study, there are still many problems to be solved: the tolerance of aquatic plants to seawater, the differences of removal rates by different plants and in various plant densities; the seasons carried out, the mechanism of removing SS and nutrients, and the hydrological movements of flowing water in ponds. These problems need to be investigated in the future.

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THE EFFECTS OF NUTRIENT RELEASE FROM SEDIMENTS ON THE FORMATION OF WATER BLOOMS

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ABSTRACT

Simulation of the formation of water blooms dominated by *Microcystis* (blue-green algae) was carried out by using the mathematical model on the vertical migration, phosphorus uptake, and growth of the algal colonies in a water column under the coexistence of nonmigrating algae. Phosphorus supplies both through the inflow of water and sediment release were considered in the model. Numerical solutions of the model were in agreement qualitatively with the observations reported on *Microcystis* behavior in eutrophic lakes. Phosphorus release from sediments did not enhance the growth of *Microcystis* nor that of the nonmigrating algae in cases of abundant inflow of phosphorus. In the absence of phosphorus inflow, however, phosphorus release from sediments enhanced only the growth of *Microcystis* without significant stimulation of the growth of the nonmigrating algae. Daily vertical mixing from 1200 to 1700 in the upper layer of the water column had little effect on the dominancy of *Microcystis* over the nonmigrating algae.

INTRODUCTION

Water blooms flourishing frequently in summer seasons in eutrophic lakes and ponds are a nuisance to the community because they release unpleasant odors, impair the scenic beauty, and degrade the water quality. Microscopic examinations have revealed that specific planktonic blue-green algae, e.g. *Anabaena flos-aquae*, *Microcystis aeruginosa*, are dominant among microorganisms of the water bloom (1, 2).

Water blooms caused by planktonic blue-green algae accumulate sometimes during the summer season at the surface of still waters of lakes and/or ponds and form a thick layer. This phenomenon does not always imply an anomaly in the algal growth, but most probably is caused by an upward migration of the algal cells (colonies) from deeper layers of water, wherein the cells acquire buoyancy by the regeneration of gas vacuoles.

It is well known that intracellular gas vacuoles of these blue-green algae inflate and/or collapse depending on the cellular photosynthetic activities. Increase and/or decrease in buoyancy caused by the inflation and/or collapse of gas vacuoles triggers the vertical travel of these algae in still water columns. Periodic emergence and/or disappearance of the water bloom, either diurnal, monthly, or even seasonal, as reported by field observers could be ascribed to this particular travel of those algae (3-6). Several laboratory works and field observations on this subject have been presented in qualitative terms by other workers. For instance, Okino and Reynolds observed independently that colonies of *M. aeruginosa* ascend during the period from midnight to the early morning, forming a surface mat (or scum) of the algae, and migrate downward in the afternoon (2, 5). It is also known that algal colonies, once they migrate upward, stay at the water surface without showing the diurnal migration. Factors responsible for the mat formation are considered to be numerous and complicated; they can be extricated and identified only through simulation of the water blooms.

Despite numerous papers on eutrophication that have been presented from various circles during the past 50 years (especially the last 10), simulative works in which characteristics of algal growth are taken appropriately into consideration are surprisingly scarce except for a few; for instance, a simulation of seasonal succession of algae in a eutrophic environment (7-9). If simulation of the water blooms were successful in the sense of extrapolating laboratory and/or field observations to a certain extent, the simulation would provide a clue of how to control and/or minimize the water blooms.

In addition to the mat formation, the self-controlled vertical migration may also play important roles in the dominancy of the bloom-forming algae. The vertical migration brings different environmental conditions to algal cells, i.e., different light intensity and nutrient concentration compared to the nonmigrating algae. It may be possible for vertically migrating algae to uptake sufficient nutrients and to store them inside the cells during their stay in nutrient-rich deeper zones, and to grow rapidly under high intensity of solar radiation when they ascend to surface layers (1).

Whatever species of nutrients responsible for the water bloom, either phosphorus, nitrogen, carbon, or other unknown materials, this work presupposes that only phosphorus limits the growth of the blue-green algae. The various rate equations on vertical migration, phosphorus uptake, and growth, and the water bloom formation processes in a water column under the coexistence of the nonmigrating algae (denoted herefter as reference algae) were studied herein. The role of sediment phosphorus release on the formation of the water bloom was especially discussed.

MATHEMATICAL MODEL

Construction

An assemblage of *Microcystis* colonies in natural lakes is represented in this model by 56 different sets of colonies defined by different values of state variables at t = 0 (see later on). State variables that define i-th ($i = 1 \sim 56$) set of colonies are X_i, Z_i, V_{r_i}, P_i, C_i, R_i, and f_{s_i}.* The growth of i-th set of colonies (denoted hereafter as i-th colonies) corresponds to the increase only in the value of X_i, and R_i is assumed to be constant throughout the growth. As control variables, diurnal variation of light intensity (sunrise = 0500, sunset = 1900, maximum light intensity at noon = 80 klux), phosphorus loading through inflow of water and/or release from sediments, and vertical mixing in the water column are considered.

Another assemblage of algae, the reference algae, is represented by 8 sets of state variables defined respectively in 8 layers in the water column from surface to bottom. Two state variables, Y_k and f_{s_k} ($k = 1 \sim 8$), correspond to the algae in each layer. S_k ($k = 1 \sim 8$) denotes phosphorus concentration in the k-th layer of the water column.

A schematic diagram to clarify a mutual relationship among the state and control variables concerned only with i-th colonies of *Microcystis* (subscript i omitted) is constructed in Fig. 1 (outflow of colonies from the water column is omitted), based on papers already published and field observation (3, 5, 10, 11).

The rate of change either in chlorophyll-a content, turgor pressure, cell mass concentration, gas vacuoles, algal location underwater, or intracelluler phosphorus concentration (dC/dt, dP/dt, dX/dt, dV_f/dt, $-dZ/dt$, or df_p/dt shown respectively in the figure) constitutes the key to the mechanism of water bloom behavior. Except for I, Z, S, etc., which are all extracellular and physical in character, most of the variables in Fig. 1 deal with intracellular and physiological activities of each colony of *Microcystis*. Arrows in the figure indicate that a specific variable is dependent on another variable, from which the arrow originates. For instance, Q_{o_2} is shown as an explicit function of I and C, whereas Q_{o_2} is assumed to affect explicitly the rate, dP/dt.

Similar to *Microcystis*, the rate of growth for the reference algae is assumed to be an explicit function of I and f_s. The transport of the biomass of the reference algae through boundaries of each layer, i.e. sedimentation, and eddy diffusion is taken into consideration instead of the vertical migration of *Microcystis* colonies. Outflows of algal cells from the water column are assumed both for *Microcystis* and the reference algae.

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* See Notation at end of text.

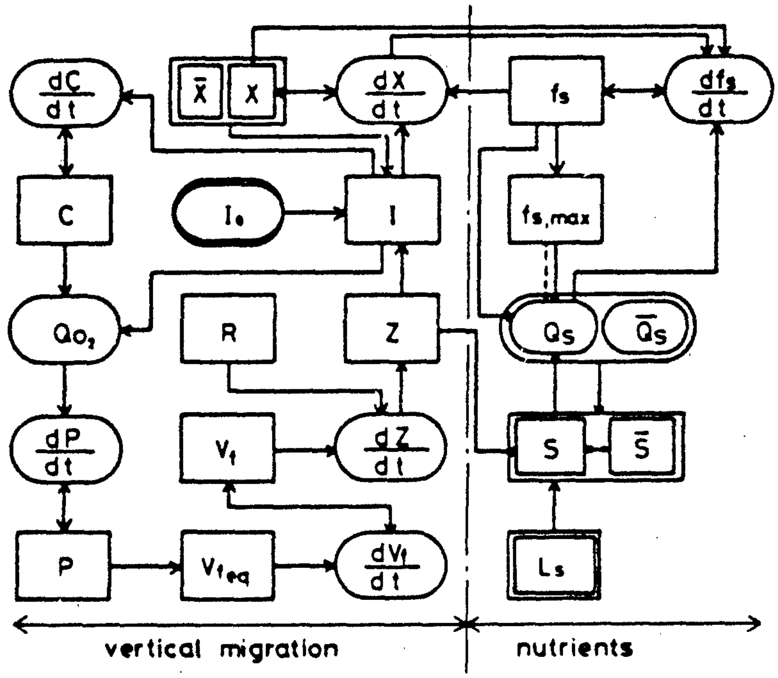

Figure 1. Schematic diagram of state and control variables to be used in simulation of the water bloom (*Microcystis*)

Unit processes and their rate equations are presented in References 11-16 to account for the vertical migration of *Microcystis* in the water column and rate of phosphorus uptake. The formulation on the phosphorus uptake by *Microcystis* is assumed to be applied to that of reference algae. A model of a system of differential equations to solve for and/or simulate the algal behaviors (*Microcystis* and the reference algae) is based on the rate equations in Table 1.

Solution of the Model

Parameter values used in this simulation are the same as those presented previously. It must be noted that all the values related to the physiological state of *Microcystis* came from laboratory experiments and/or field observations on *Microcystis aeruginosa*, except for some parameters on the rate equations of turgor pressure (which came from a blue-green alga, *Anabaena flos-aquae*).

Using the results of field observations of a *Microcystis* water bloom in Lake Kasumigaura, 7 radii of colonies, 15, 25, 35, 45, 55, 65, and 75 μm were assumed. Colonies of each radius started simultaneously from 8 different depths taken at the same interval from the surface to the bottom of the water column (depth = -8.0 m, 1.0-m intervals from -0.5 to -7.5 m). Thus,

TABLE 1. SYSTEM EQUATIONS AND ADJUNCT EQUATIONS USED FOR THE SIMULATION MODEL

System of differential equations (360 dimensional : i = 1, 56; k = 1,8)

$$\frac{dX_i}{dt} = \mu_i X_i - \left(\frac{Q}{-Z_{min}}\right) X_i \qquad (1\text{-}i)$$

$$\frac{dW_i}{dt} = Q_{s,i} \; X_i - \left(\frac{Q}{-Z_{min}}\right) W_i \qquad (2\text{-}i)$$

$$\frac{dZ_i}{dt} = - \frac{2g(\rho_c - \rho_w - a'V_{f_i})R_i^2}{9\mu_w} \times 3,600 \qquad (3\text{-}i)$$

$$\frac{dV_{f_i}}{dt} = - \frac{(V_{f_i} - V_{f_{eq,i}})}{dt} \qquad \text{for } V_{f_i} \geq V_{f_{eq,i}} \qquad (4\text{-}i)$$

or

$$= \lambda \qquad \text{for } V_{f_i} < V_{f_{eq,i}}$$

$$\frac{dP_i}{dt} = \alpha(P_{max} - P_i)Q_{O_{2,i}} - \beta(P_i - P_{min}) \qquad (5\text{-}i)$$

$$\frac{dC_i}{dt} = \alpha'(C_{max} - C_i) - \gamma I C_i \qquad (6\text{-}i)$$

$$\frac{dY_k}{dt} = D_{p,k} \frac{(Y_{k+1} - Y_k)}{(-Z_{min}/8)^2} + D_{p,k-1} \frac{(Y_{k-1} - Y_k)}{(-Z_{min}/8)^2}$$

$$- \frac{QY_k}{-Z_{min}} + \frac{8v_s Y_{k-1}}{-Z_{min}} - \frac{8v_s Y_k}{-Z_{min}} + \mu_k Y_k \qquad (7\text{-}k)$$

TABLE 1. (Continued)

$$I_i = I_0 \exp(-\sum_{j=1}^{56} \varepsilon_{i,j} X_j C_j - \sum_{j=1}^{8} \varepsilon'_{i,j} Y_j + n'Z_i) \qquad (12\text{-}i)$$

$$\varepsilon_{i,j} = 0 \qquad \text{for } Z_i \geq Z_j$$

$$= m' \qquad \text{for } Z_i < Z_j$$

$$\varepsilon'_{i,j} = 0 \qquad \text{for } Z_i \geq jZ_{min}/8$$

$$= m'' \qquad \text{for } Z_i < jZ_{min}/8$$

$$I_k = I_0 \exp(-\sum_{j=1}^{56} \varepsilon''_{k,j} X_j C_j - \sum_{j=1}^{k-1} m''Y_j + n'\frac{(k-1)}{8} Z_{min}) \qquad (13\text{-}i)$$

$$\varepsilon''_{k,j} = m' \qquad \text{for } Z_j > (k-1)Z_{min}/8$$

$$= 0 \qquad \text{for } Z_j \leq (k-1)Z_{min}/8$$

$$Q_s = \frac{S}{K_s + S}(Q_{se} + Q_{ss}\frac{f_{s,max} - f_s}{K_q + f_{s,max} - f_s}) \qquad (14\text{-}i,k)$$

$$Q_{ss} = Q_{ss,max}\frac{f_{s,max} - f_{sc}}{K_{qs} + f_{s,max} - f_{sc}}$$

$$f_{s,max} = f(f_s, t)$$

$$\mu = \frac{I}{p + qI + rI^2}\frac{f_s - f_{s,min}}{K_q + f_s - f_{s,min}} \qquad (15\text{-}i,k)$$

TABLE 1. (Continued)

$$\frac{dW_k}{dt} = D_{p,k}\frac{(W_{k+1} - W_k)}{(-Z_{min}/8)^2} + D_{p,k-1}\frac{(W_{k-1} - W_k)}{(-Z_{min}/8)^2}$$

$$- \frac{QW_k}{-Z_{min}} + \frac{8v_s W_{k-1}}{-Z_{min}} - \frac{8v_s W_k}{-Z_{min}} + Q_{s,k}Y_k \qquad (8\text{-}k)$$

$$\frac{dS_k}{dt} = D_{p,k}\frac{(S_{k+1} - S_k)}{(-Z_{min}/8)^2} + D_{p,k-1}\frac{(S_{k-1} - S_k)}{(-Z_{min}/8)^2}$$

$$+ \frac{L_s}{-Z_{min}} - \frac{QS_k}{-Z_{min}} - \sum_{i \in k} \frac{8Q_{s,i}X_i}{-Z_{min}} - Q_{s,k}Y_k \qquad (9\text{-}k)$$

Adjunct equations (i = 1, 56; k = 1, 8)

$$Q_{o_{2,i}} = mC_i I_i \qquad \text{for } I_i < (a\theta + b)/m \qquad (10\text{-}i)$$

or

$$= (a\theta + b)C_i \qquad \text{for } I_i \geqq (a\theta + b)/m$$

$$V_{f_{eq,i}} = V_{f_{max}} \left(1 - \int_0^{P_i} f_n(\xi,\sigma,P)dP\right) \qquad (11\text{-}i)$$

56 different sets of colonies are presupposed to simulate behaviors of an assemblage of *Microcystis* colonies in eutrophic water bodies.

Obviously, the system equations cannot be solved analytically. A numerical procedure by the Runge-Kutta-Gill method was employed to solve for the equations (HITAC M-180, Computer Centre, National Institute for Environmental Studies). About 40 simulation runs were conducted taking various combinations of conditions shown in Table 2 to assess the effects of phosphorus release from sediments on the growth of *Microcystis*. Time length for these runs was 25 days.

TABLE 2. VALUES OF PARAMETERS TAKEN IN SIMULATION RUNS OF A WATER BLOOM (SENSITIVITY ANALYSIS)

Simulation to find the effect of	Values used in simulation*
Y_k (t = 0)	1.0, 2.5, 5.0, 10.0
S_L	0.0, 0.3
P_{sed}	0.0, 5.0, 10.0, 20.0
$Q_{s,k}$	1.0, 2.0 (times of K_s value for *Microcystis*)
μ_k	1.0, 2.0 (times of μ value for *Microcystis*)
v_s	0.0, 0.1, 0.5
mixing	none, 12:00 - 17:00

* Values underlined were used throughout simulation runs except for otherwise noted. For the control run, all of the underlined values were used.

RESULTS AND DISCUSSION

Vertical migration and growth of *Microcystis*

Patterns of vertical migration of 12 colonies (taken arbitrarily from 56 colonies) in the control run (see Table 2) are shown in Figure 2. Smaller colonies showed little oscillating behavior during growth and ascended to the surface layers with time. Larger ones, on the other hand, migrated vertically with a cycle of 3 days, ascending to the water surface every three days, and descending to the deeper layers depending on the size of colonies, i.e. the

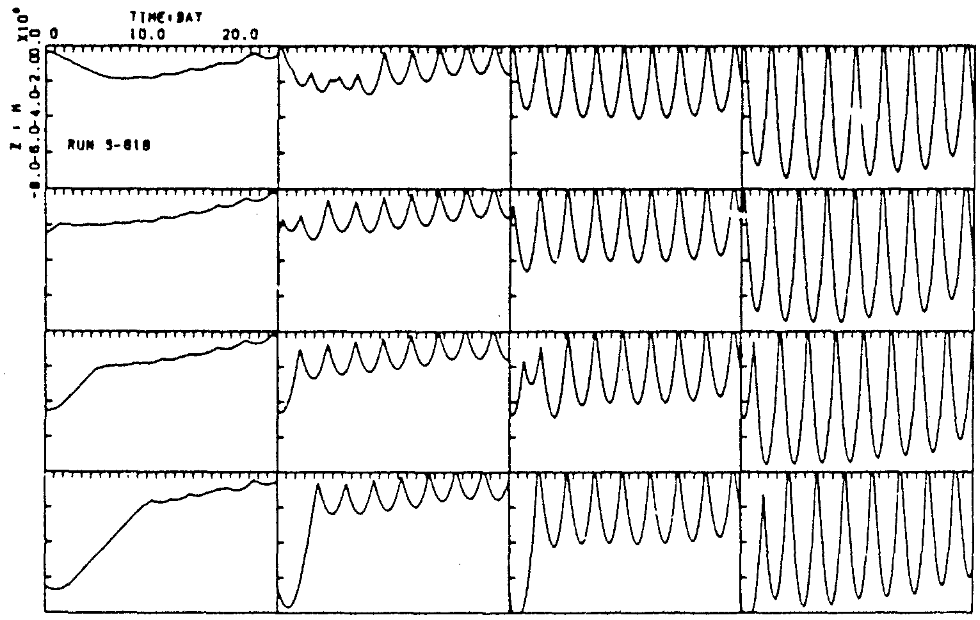

Figure 2. Oscillation of Z_i as affected by the change in initial conditions and colony radius; from top to bottom: $Z_i(t = 0) = -0.5, -2.5, -4.5, -6.5$ m, from left to right: $R_i = 15, 35, 55, 75$ μm

deeper migration was observed for the larger ones. In other runs (except the cases of vertical mixing), similar patterns of migration were observed.

In accordance with these migrations, each colony showed stepwise growth (not shown here), i.e. the specific growth rate during their stay near the water surface was more than 10 times that observed when colonies descended to deeper layers. However, water column average concentration of the assemblage of 56 colonies increased linearly in logarithmic scale as shown in Figure 3.

Diurnal variations in the vertical profile of *Microcystis* colonies in still waters are shown in Figure 4. When total concentration of algae, i.e. *Microcystis* plus the reference algae, was low (Figure 4a), maximum concentration in the water column was observed at the middle layer (ca. -2.0 m). Although a part of the *Microcystis* colonies appeared in the water surface, the amount was small. As shown in Figure 4b, typical diurnal migration of *Microcystis* was observed when total concentration was high, i.e. colonies accumulated at the water surface in the morning, and descended in the afternoon. In extreme cases, almost all colonies stayed near the water surface without showing diurnal migration (not shown here). In all cases mentioned above, each colony showed vertical migration with a cycle of 3 days. However, the vertical range of migration narrowed with the increase of total algal concentration even in the same colony radius.

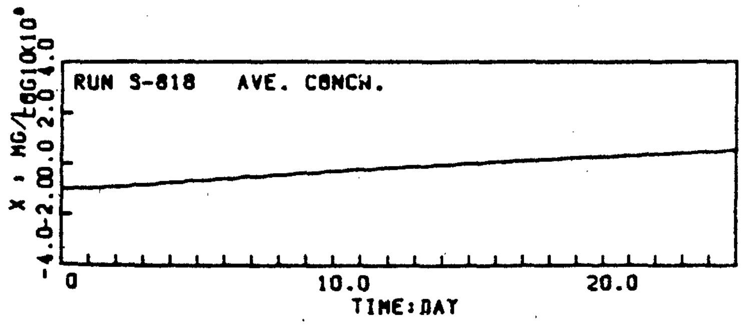

Figure 3. Growth curve of the assemblage of *Microcystis* (water column average concentration of colonies, $X = \log(\Sigma_i X_i/(-Z_{min}))$, vs. t)

Wind-driven vertical mixing in the surface layers of the water column frequently occurs in Lake Kasumigaura where dense water blooms of *Microcystis* appear every summer. The vertical profile of *Microcystis* under a mixing condition (daily mixing between 1200 and 1700 was assumed using Lake Kasumigaura as an example) is shown in Figure 5. Vertical profile patterns similar to those observed in Lake Kasumigaura were observed in the simulation runs, i.e. homogeneous vertical profile during mixing, upward migration of algal colonies after that, and surface accumulation until the initiation of mixing was simulated.

Several studies have reported on the vertical migration of *Microcystis* (2, 5, 6). However, environmental conditions such as water temperature, solar radiation, mixing in the water column, and nutrient concentrations are not reported in detail; it is quite natural that vertical migration of single colonies has not been reported due to the difficulty of measurement. A cycle of 3 days was shown in this study for single colonies in spite of a daily cycle for an assemblage of colonies shown both in this study and in field observations. Thus, model verification in a strict meaning is impossible for this model. However, the infeasibility of quantitative verification does not totally invalidate the usefulness of this model. In a qualitative meaning, the model behavior corresponded very well with the field observation, i.e. all three patterns of vertical migration shown by this model have been observed in natural lakes, and the specific rate of growth (ca. $0.1 \sim 0.2\ day^{-1}$) calculated by this model for the assemblage of *Microcystis* colonies is quite reasonable compared to field observations of approximately $0.1\ day^{-1}$ based on the data reported by Reynolds (5). The model presented here, therefore, could open the way to understand basic characteristics of the water bloom, although the applicability of the model to predict water bloom formation by *Microcystis* in a specific water body is not confirmed.

Effects of phosphorus release from sediments

The effects of phosphorus release from sediments on the specific rate of growth, μ, are shown in Figures 6 and 7. If phosphorus inflow from outside

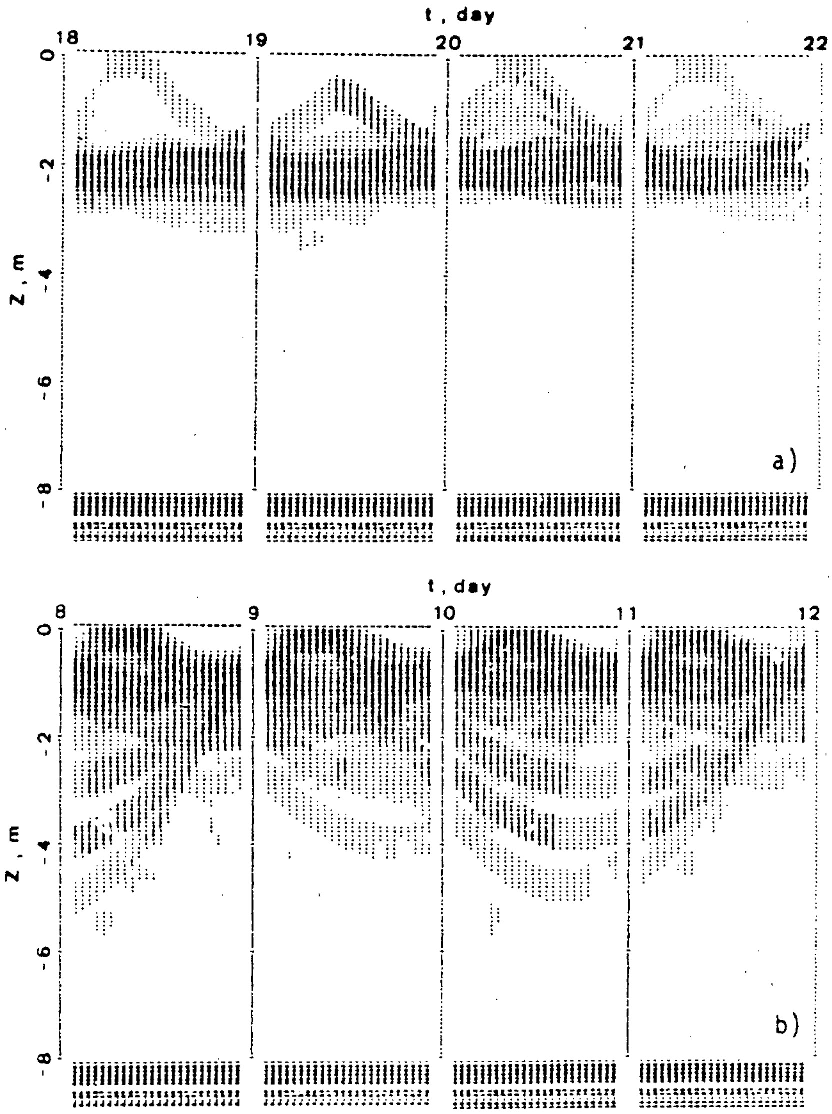

Figure 4. Vertical profiles of the concentration of *Microcystis* vs. t (without mixing). Relative concentration based on maximum concentration in water column (Z_{min} = -8.0 m) for each time is shown by darkness in the figure. Higher concentration corresponds to darker print and a band between broken lines shows the time span of one day
a) (upper) lower total algal concentration
b) (lower) higher total algal concentration

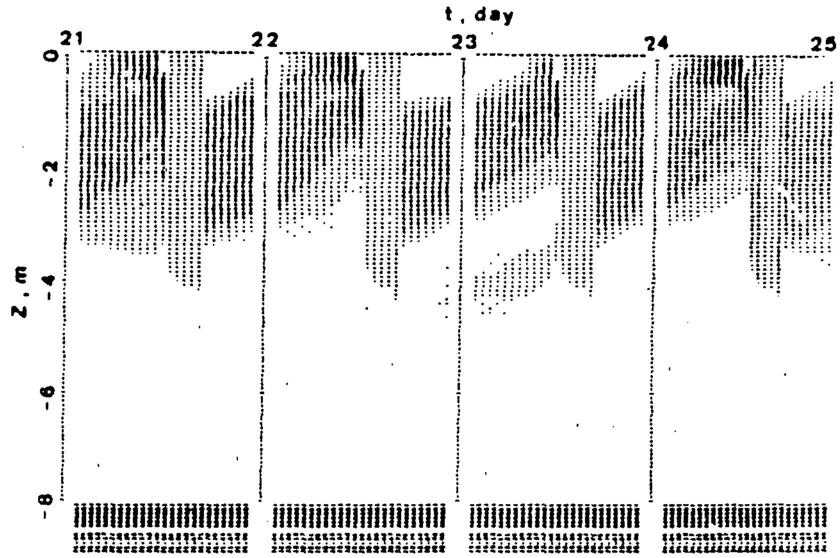

Figure 5. Vertical profile of the concentration of *Microcystis* vs. t (with mixing between the surface and -4.0 m and daily from 1200 to 1700). See the legend of Figure 4 except that relative concentrations here are based on maximum concentration in the water column at the end of a simulation run

was abundant (Figure 6), release of sediment phosphorus P_{sed} did not enhance the growth of *Microcystis* nor that of the reference algae. Although rate constants for growth and phosphorus uptake of the reference algae were assumed to be equal to those for *Microcystis*, μ values of *Microcystis* were larger than those of the reference algae. The difference in μ values between these two algae was more significant when Y_k (t = 0) was high, i.e. high concentration of total algae and rapid extinction of solar radiation in the water column. Similar results were also obtained even if the rate of sedimentation v_s was assumed to be zero.

If phosphorus inflow from outside became negligible, P_{sed} enhanced μ values of *Microcystis*, whereas those of the reference algae increased slightly (Figure 7). μ of *Microcystis* were still larger than those of the reference algae also in these cases. It must be noted that μ values were not zero even if P_{sed} were equal to zero. This is because intracellular phosphorus at t = 0 (assumed as 1.0% for all simulation runs) supported algal growth.

The fact that μ values of the reference algae did not increase significantly with the increase of P_{sed} implies that phosphorus released from sediments is not as useful for the growth of the reference algae as for that of

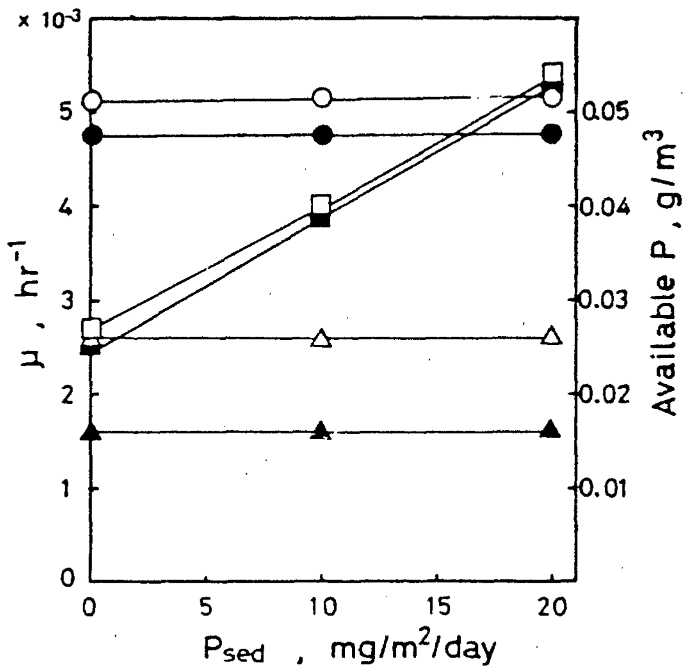

Figure 6. μ and average available phosphorus concentration as affected by release rates of phosphorus from sediments P_{sed} with abundant phosphorus inflow from outside (2.4×10^{-2} $gP/m^2/day$). (○, ●) *Microcystis aeruginosa*; (△, ▲) reference algae; (□, ■) available phosphorus concentration. Open symbols Y_k (t = 0) = 2.5 g/m^3; closed Y_k (t = 0) = 10.0 g/m^3

Microcystis. Thus, the reference algae can utilize mainly phosphorus supplied through the inflow of water. However, it is plausible for vertically migrating algae such as *Microcystis* to utilize both inflowed and released phosphorus. It is noteworthy that *Microcystis* grows well in the presence of large amounts of algal cells compared to the reference algae, because the difference in μ values of *Microcystis* between two initial values of Y_k (2.5 and 10.0 g/m^3) is smaller than those of reference algae.

Each colony responded differently to the changes in the sources of phosphorus supply. As shown in Figure 8, the smallest radius of colonies (15 μm) showed the largest μ value, but μ decreased with the increase of colony size if phosphorus was supplied abundantly. However, if phosphorus supply through the inflow of water stopped, μ values of smaller colonies decreased; hence, the maximum μ value was observed in medium-sized colonies. Q_s values changed similarly; i.e. maximum Q_s values also appeared in the

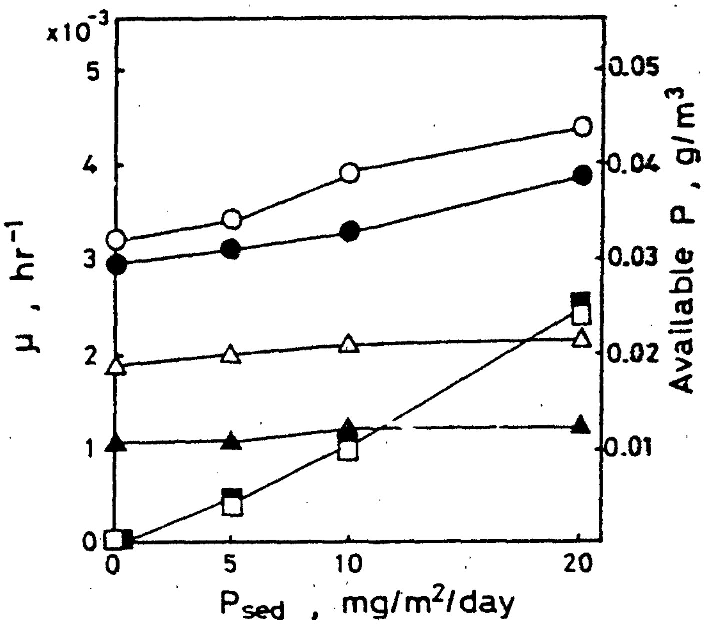

Figure 7. μ and average available phosphorus concentration as affected by release rates of phosphorus from sediments P_{sed} without phosphorus inflow from outside. Refer to the legend of Figure 6 for symbols.

smallest colonies under phosphorus-rich conditions and shifted to larger colonies in cases where sediment was the sole phosphorus source (not shown in the figure). Colonies from 45 to 55 μm and from 55 to 75 μm showed maximum value of Q_s when P_{sed} was 10 mg P/m^2/day and 5 mg P/m^2/day, respectively. It is plausible that larger colonies have an advantage when competing for phosphorus uptake with smaller colonies or nonmigrating algae if phosphorus supply through the inflow of water is decreased and the release of phosphorus from sediments becomes the major source of phosphorus. In other words, the characteristic of vertical migration may play an important role in sediment phosphorus uptake and the dominancy of *Microcystis*.

μ values were not affected significantly by the daily vertical mixing of the water column from 1200 to 1700. Simulation results shown in Figure 9 correspond to those in Figure 7 except vertical mixing considered in runs shown in Figure 9. Although a slight increase in μ values of the reference algae when compared with nonmixing conditions was observed as expected, the effects of vertical mixing were negligible. Sediment phosphorus release also only affected the growth of *Microcystis* if phosphorus inflow with water became negligible.

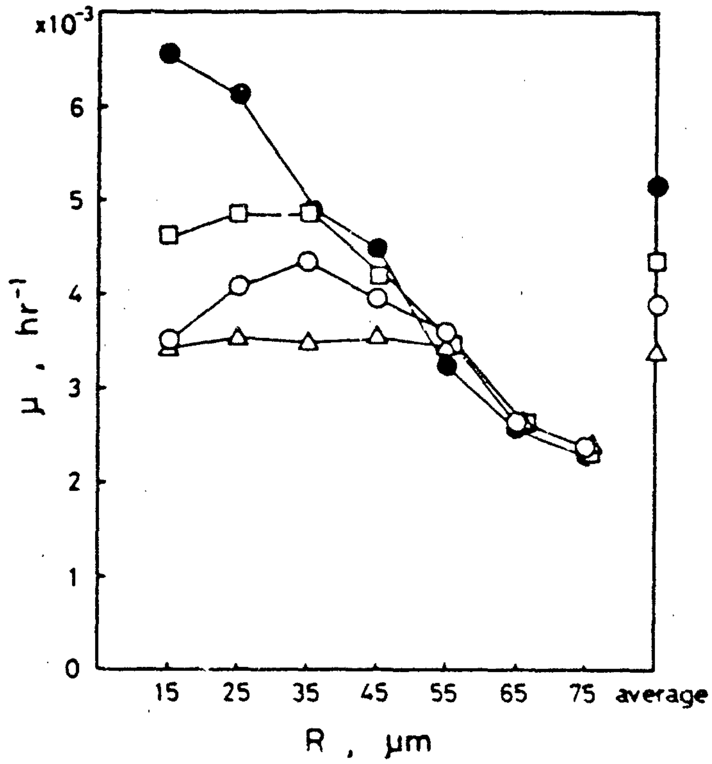

Figure 8. Average specific growth rates for each colony of *Microcystis* as affected by the sources of phosphorus supply: P inflow and P_{sed} = 10 mg P/m^2/day

W/O P inflow and P_{sed} = 20 mg P/m^2/day

W/O P inflow and P_{sed} = 10 mg P/m^2/day

W/O P inflow and P_{sed} = 5 mg P/m^2/day

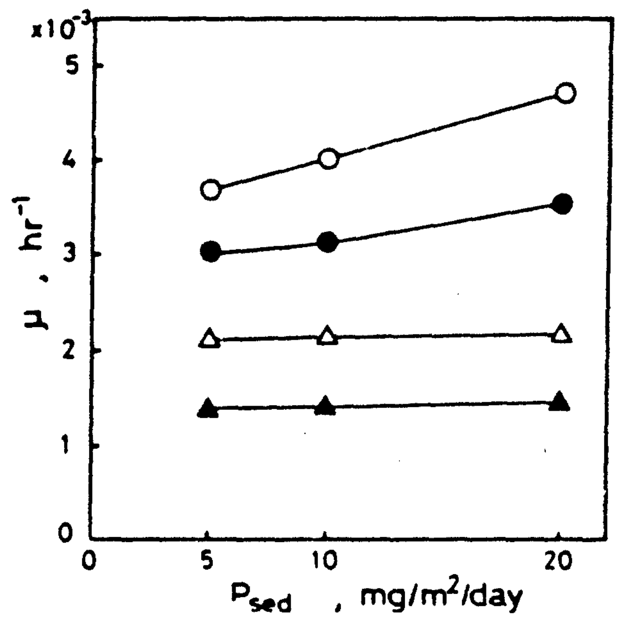

Figure 9. μ as affected by P_{sed} when the water column is mixed vertically from 1200 to 1700 (0 ~ -4 m) and phosphorus is not supplied from outside. Refer to the legend of Figure 6 for symbols

CONCLUSION

Numerical solutions obtained from the model presented herein were in agreement qualitatively with the observations reported on *Microcystis* behavior in eutrophic lakes.

According to the model, phosphorus release from sediments enhanced the growth of *Microcystis* without significant stimulation of nonmigrating algae if sediment phosphorus was the major source of phosphorus supply into water bodies. Daily vertical mixing from 1200 to 1700 had little effect on the dominancy of *Microcystis* over nonmigrating algae.

NOTATION

a, a', b	= empirical constants	[-]
C	= chlorophyll-a content in algal cells	[%]
C_{max}	= maximum value of C	[%]
D_p	= eddy diffusion constant	[m^2/h]
f_n	= normal distribution of gas vacuoles with respect to turgor pressure	[-]
f_s	= intracellular phosphorus concentration	[g/g]
f_{sc}	= critical value of f_s between starved and nonstarved conditions	[g/g]
$f_{s,max}$	= maximum value of f_s	[g/g]
g	= acceleration due to gravity	[m/s^2]
I	= light intensity underwater	[klx]
I_0	= light intensity outdoors	[klx]
K_s, K_q, K_{qs}	= empirical constants	[-]
L_s	= phosphorus loadings from outside and sediments	[$g/(m^2 \cdot h)$]
m, m', m''	= empirical constants	[-]
n'	= empirical constant	[-]
P	= turgor pressure of cells	[kN/m^2]
P_{max}	= maximum value of P	[kN/m^2]

P_{min}	= minimum value of P	[kN/m^2]
P_{sed}	= release rate of phosphorus from sediment	[$g/(m^2 \cdot h)$]
P	= empirical constant	[-]
Q	= hydraulic loading	[$m^3/(m^2 \cdot h)$]
Q_{O_2}	= photosynthetic activity of cells	[$cm^3/(g \cdot h)$]
Q_s	= specific rate of phosphorus uptake	[$g/(g \cdot h)$]
Q_{se}	= specific rate of phosphorus uptake under phosphorus-rich conditions	[$g/(g \cdot h)$]
Q_{ss}	= specific rate of phosphorus uptake under phosphorus-starved conditions	[$g/(g \cdot h)$]
q	= empirical constant	[-]
R	= radius of algal colonies	[μm]
S	= available phosphorus concentration	[g/m^3]
S_L	= available phosphorus concentration of inflowing water	[g/m^3]
r	= empirical constant	[-]
t	= time	[h]
v_s	= sedimentation rate constant	[m/h]
V_f	= volume fraction of gas vacuoles in colonies	[%]
$V_{f_{eq}}$	= V_f in equilibrium with turgor pressure	[%]
$V_{f_{max}}$	= maximum value of V_f	[%]
W	= algal phosphorus concentration	[g/m^3]
X	= mass concentration of colonies	[g/m^2]
Y	= mass concentration of reference algae	[g/m^3]
Z	= algal location underwater, using the level of water surface as zero	[m]
Z_{min}	= minimum value of Z, depth	[m]

$\alpha, \alpha', \beta, \gamma$	= empirical constants	[-]
$\varepsilon, \varepsilon', \varepsilon''$	= extinction coefficients	[-]
θ	= water temperature	[°C]
λ	= empirical constant	[-]
μ	= specific growth rate	[h^{-1}]
μ_w	= viscosity of water	[kg/(m · s)]
ξ	= mean value of P for f_n	[kN/m^2]
ρ_c	= density of algal colonies with nonvacuolated cells	[kg/m^3]
ρ_w	= density of water	[kg/m^3]
σ	= standard deviation for f_n	[kN/m^2]

Subscripts

i,j	= set of colonies
k	= layer in the water column

Superscripts

-	= other sets of colonies j (j = 1 ~ 56, j ≠ i) than a set of colonies i under consideration

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AD P002409

SUMMER PEAK OF NUTRIENT CONCENTRATIONS IN LAKE WATER

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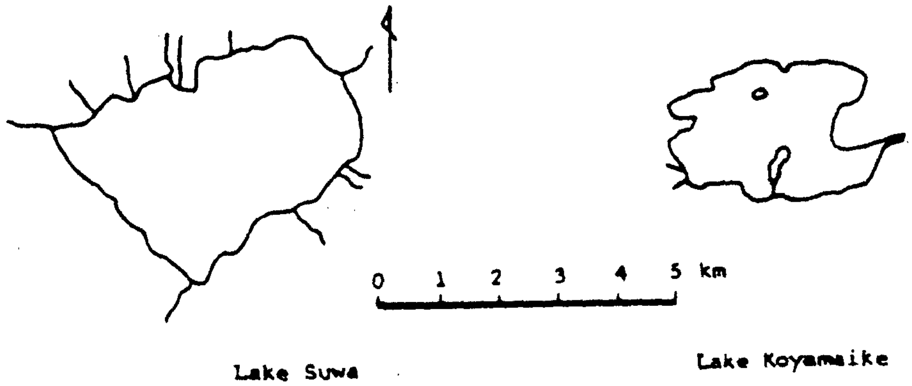
Abstract

The nutrient concentrations of lake water are strongly influenced by both inflowing nutrients and those released from sediment in the lake. The former may be related to the basic nutrient concentration of the lake in winter and the latter to the peak concentration in summer. This paper considers the problem of how the summer peak may be generated, using actual data from two lakes in Japan. By using a mathematical simulation, it can be shown that the summer peak may be generated largely from nutrient materials released from sediment. Using this approach, release rates have been calculated for two lakes. The approach makes a prediction of water improvement due to sediment removal.

Background

The lakes used in this paper are Lakes Suwa and Koyamaike.



Lake Suwa is situated in the mountain district near the Nippon Alps and has a lake area of 13.7×10^6 m^2 and a mean depth of 4 m. Three big cities, Suwa, Okaya, and Chino, are located around it with a population of about 170,000 people. There are a number of manufacturing industries in the area.

The Suwa district is also the most famous hot spring site in Japan, and the sightseeing population amounts to about 600,000 people in a year. These special conditions increase the seriousness of eutrophication.

Lake Koyamaike is situated in the western district facing the Nippon Sea, and, in contrast, has the lowest population density in Japan. Although no factories and no big cities are located around it, the lake is polluted. This is probably due to the effects of agricultural and rural drainage. The lake has an area of 6.94×10^6 m^2 and a mean depth of 3 m.

Summer Peak of Nutrient Concentrations

The 1973 seasonal variation of total phosphorus (T-P) concentrations in Lake Suwa, offshore of Kamikawa, is plotted in Figure 1.

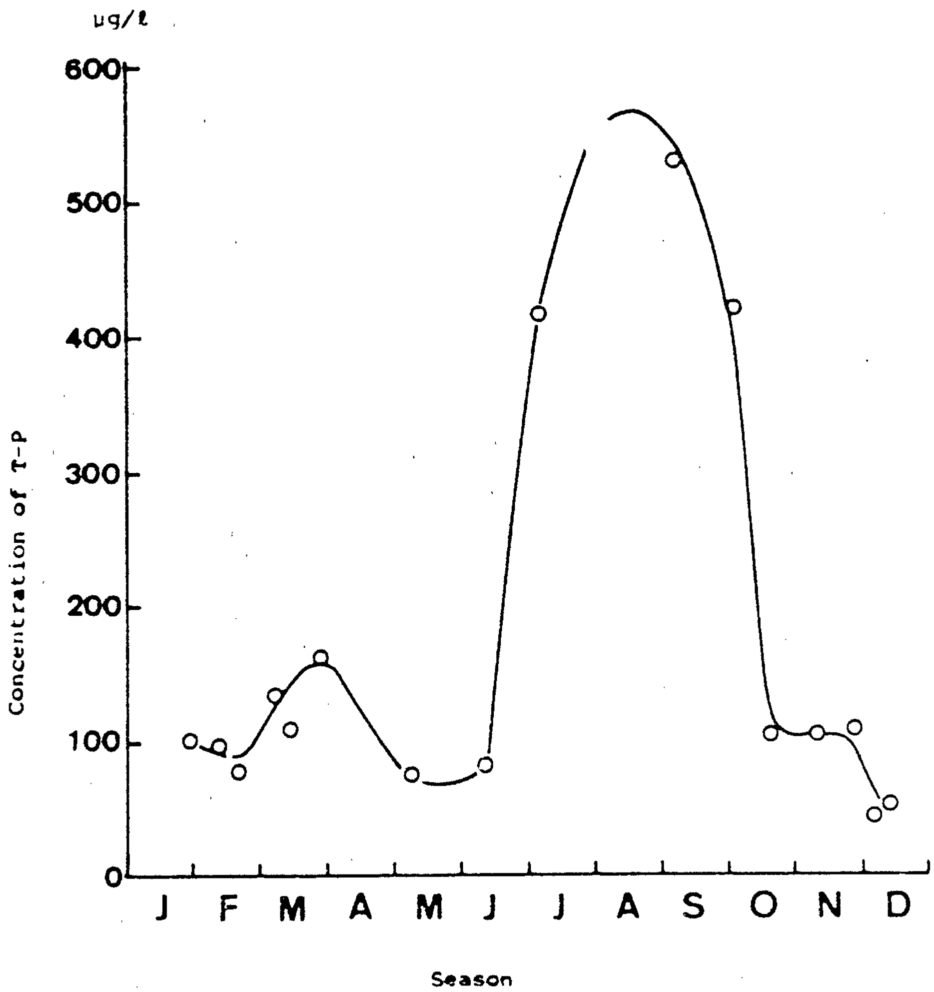


Figure 1. Seasonal variation of T-P concentrations in Lake Suwa (1973)

The measurements were made at 10 points on the lake. The location off Kamikawa was the highest concentration.

It is apparent that an exceptionally high phosphorus concentration was generated in summer. During the remainder of the year, the concentrations of T-P are below 100 μ3/ℓ, although a small peak of about 150 μg/ℓ is seen in spring. From the end of June, they increase rapidly and reach a maximum value of about 550 μg/ℓ in summer.

The seasonal change in T-P concentrations in Lake Koyamaike is shown in Figure 2. In this a summer peak is also seen. The concentrations of T-P during the nonsummer period are about 50 μg/ℓ, but in summer they increase to a peak of about 400 μg/ℓ.

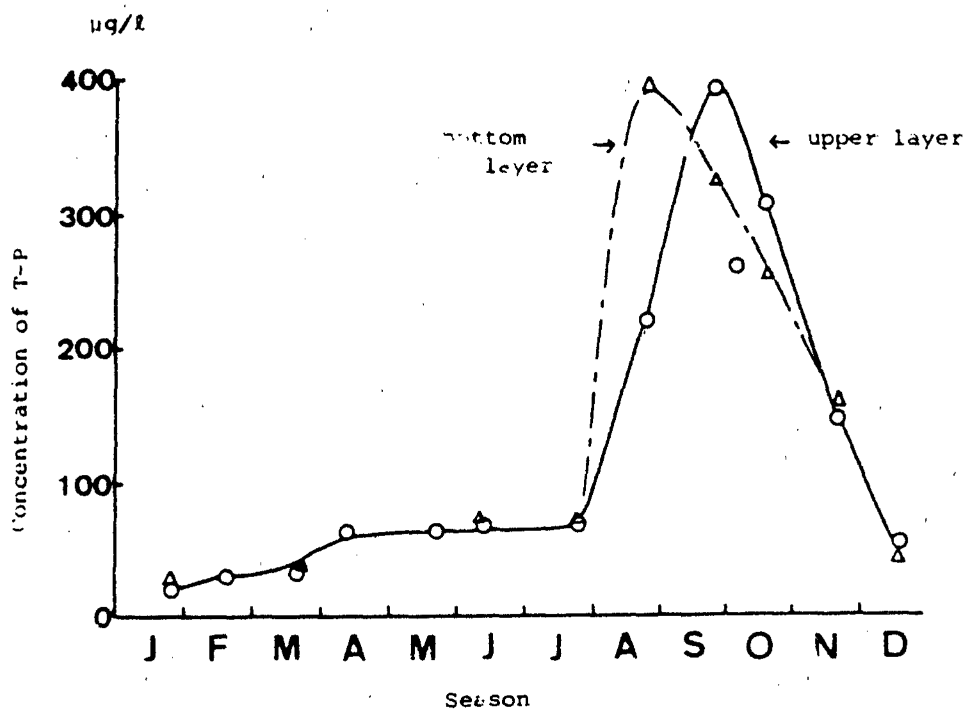
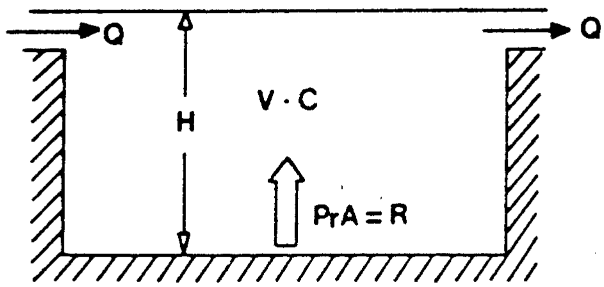


Figure 2. Seasonal variation of T-P concentrations in Lake Koyamaike (1978)

From these data it is clear that a summer T-P peak is generated in both lakes, resulting in highly eutrophic conditions. The cause of this problem is investigated herein using a model approach.

Model Approach on Summer Peak

Regarding summer peaks, we approach a lake model as follows. If we assume that the quantities of inflowing pollutants to a model lake are constant, we have to take into account only the effects of the released materials from bottom sediments. The variation of nutrient concentrations in lake water may be releated to them and can be represented as follows.



$$V \frac{\partial c}{\partial t} = p_r A - cQ \tag{1}$$

Here:

V	= water volume of lake	m^3
Q	= quantities of inflowing water	m^3/d
A	= lake area	m^2
R	= released quantities	mg/d
c	= mean concentration of nutrients in lake water	mg/m^3 ($\mu g/\ell$)
p_r	= release rate of T-P	$mg/m^2/d$

Eq. (1) is rewritten as follows

$$\frac{\partial c}{\partial t} + \frac{Q}{V} c = p_r \frac{A}{V} = \frac{p_r}{H} \tag{2}$$

Here H denotes the water depth of the lake.

The solution of Eq. (2) becomes

$$c e^{\frac{Q}{V} t} = \int \frac{p_r}{H} e^{\frac{Q}{V} t} dt + C \tag{3}$$

Since p_r is a function of time, it is necessary to solve it for the integration of the right side of Eq. (3).

The seasonal change in water temperatures is shown in Figure 3.

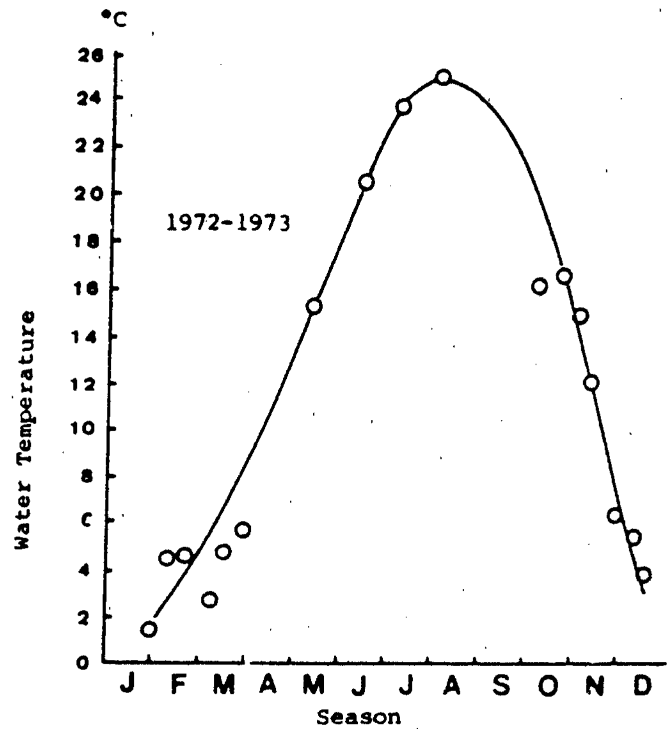


Figure 3. Seasonal change of water temperature in Lake Suwa

As the figure shows, the seasonal curve of water temperature is very regular and can be simulated as a parabolic curve (Figure 4).

Here we assume the following equation for the variation in water temperature.

$$T = T_{max} - \frac{t^2}{2p_t} \tag{4}$$

where:

T = water temperature at lake bottom

t = time

p_t = figure index of parabolic curve

$$= \frac{\tau^2}{2(T_{max} - T_{min})}$$

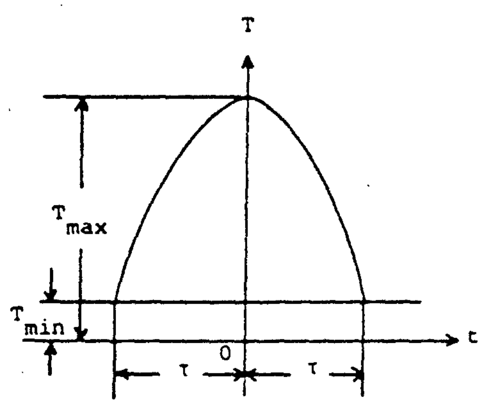


Figure 4. Parabolic curve

The relationships between release rates and water temperature have been based on our test results, shown in Figure 5.

From these, the following equation can be proposed

$$p_r(t) = p_r(20°C)\alpha^{T-20}$$

$$\alpha = 1.11 \tag{5}$$

Hence we obtain

$$p_r(t) = p_r(20°C)\alpha^{T_{max} - 20 - \frac{t^2}{2p_t}}$$

Next we must consider the effects of DO on release rates.

The measured DO concentrations at lake bottom are shown in Figure 6.

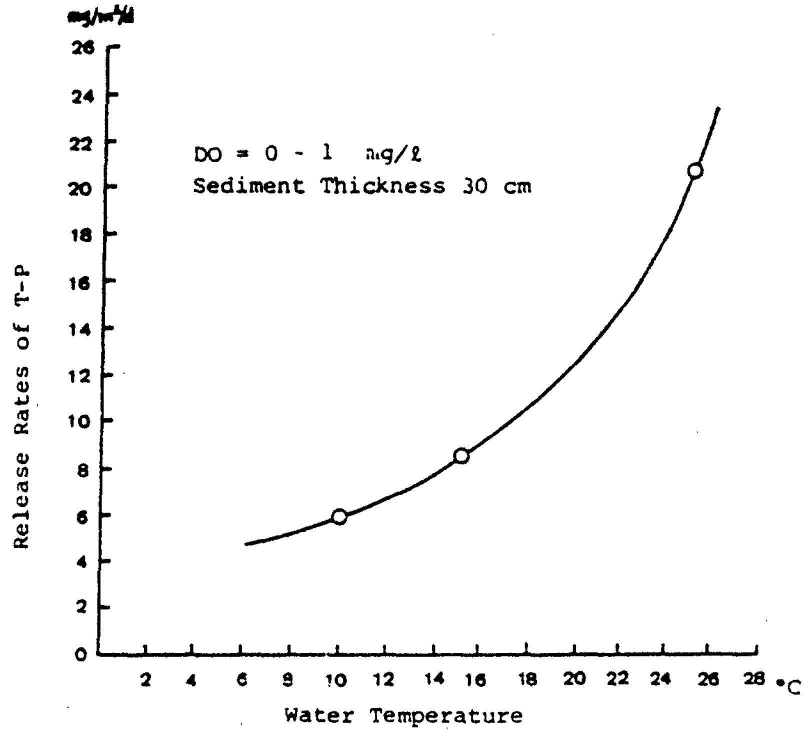


Figure 5. Relationships between release rates of T-P and water temperature, Lake Suwa

Figure 6 shows that the DO concentrations at lake bottom change greatly, according to the season. They are high in winter, but decrease rapidly during the transfer from spring to summer. They reach a minimum value of 1 mg/ℓ in July. After that, they increase to regain the winter value. Because it is very difficult to simulate this by a curve, we have used an empirical approach.

Then Eq. (3) becomes as follows:

$$ce^{\frac{Q}{V}t} = p_r(20°C)\alpha^{T_{max}-20} \cdot \frac{1}{H} \int \alpha^{-\frac{t^2}{2p_t}} e^{\frac{Q}{V}t}\, dt + C \qquad (7)$$

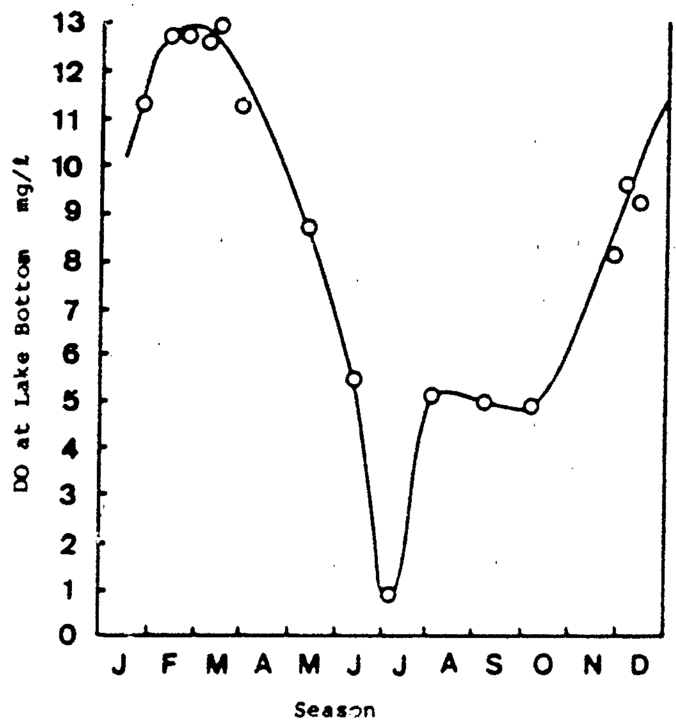


Figure 6. Seasonal change of DO at lake bottom, Lake Suwa

Here we put,

$$F(t) = \int \alpha^{-\frac{t^2}{2p_t}} e^{\frac{Q}{V} t} \, dt$$

This function is represented in series as follows.

$$F(t) = t + \frac{1}{2}\frac{Q}{V} t^2 + \left(\frac{1}{2}\frac{Q^2}{V^2} - \frac{0.05218}{p_t}\right)\frac{t^3}{3}$$

$$+ \left(\frac{1}{6}\frac{Q^3}{V^3} - \frac{0.05218}{p_t}\right)\frac{t^3}{4} + \left(\frac{1}{24}\frac{Q^4}{V^4} - \frac{0.02609}{p_t^2}\frac{Q^2}{V^2} + \frac{0.00136}{p_t}\right)\frac{t^5}{5}$$

$$+ \left(\frac{1}{120}\frac{Q^5}{V^5} - \frac{0.0087}{p_t}\frac{Q^3}{V^3} + \frac{0.00136}{p_t^2}\frac{Q}{V}\right)\frac{t^6}{6} + \ldots$$

$(\alpha = 1.11)$

Finally we obtain the mean concentration of nutrients in lake water caused by release of sediment materials, as follows:

$$C = \frac{p_r(20°C)}{H} \alpha^{T_{max}-20} F(t)e^{-\frac{Q}{V}t} + Ce^{-\frac{Q}{V}t} \qquad (8)$$

Since the boundary condition is $t = 0$; $C = C_0$, and $F(0) = 0$, we get $C = C_0$. Hence Eq. (8) becomes,

$$C = \frac{p_r(20°C)}{H} \alpha^{T_{max}-20} F(t)e^{-\frac{Q}{V}t} + C_0e^{-\frac{Q}{V}t} \qquad (9)$$

The release rates (p_r) involve the effects of DO, and $F(t)e^{-\frac{Q}{V}t}$ is a function of water temperature and Q/V. Therefore, we can say that the summer peak is caused by three factors: DO, water temperature, and Q/V.

Numerical Calculations

Lake Suwa

On the basis of measured values of the summer peak at the center of the lake, the release rates (p_r) may be obtained by calculation. Here we assume that the basic concentration of T-P in winter is 80 μg/ℓ (Figure 7). This is also presumed to be similar to the concentration of inflowing pollutants. The variation of water temperature used for the calculation is shown in Figure 8. Table 1 indicates the calculated values of p_r, which are graphed in Figure 9.

$C_{max} = 480 - 80 = 400$ μg/ℓ

$C_0 = 460 - 80 = 380$ μg/ℓ

$T_{max} = 23°C$

$T_{min} = 4°C$ (t = 135 days)

$$P_t = \frac{t^2}{2(T_{max} - T_{min})} = \frac{135^2}{2(23 - 4)} = 480 \text{ day}^2/°C$$

$Q = 15 \text{ m}^3/S = 1,296,000 \text{ m}^3/d$

$V = 63.65 \times 10^6 \text{ m}^3$ $\quad$ $Q/V = 0.02 \text{ day}^{-1}$

$\alpha^{T_{max}-20} = 1.11^{23-2-} = 1.368$ $\quad$ $H = 2.6$ m

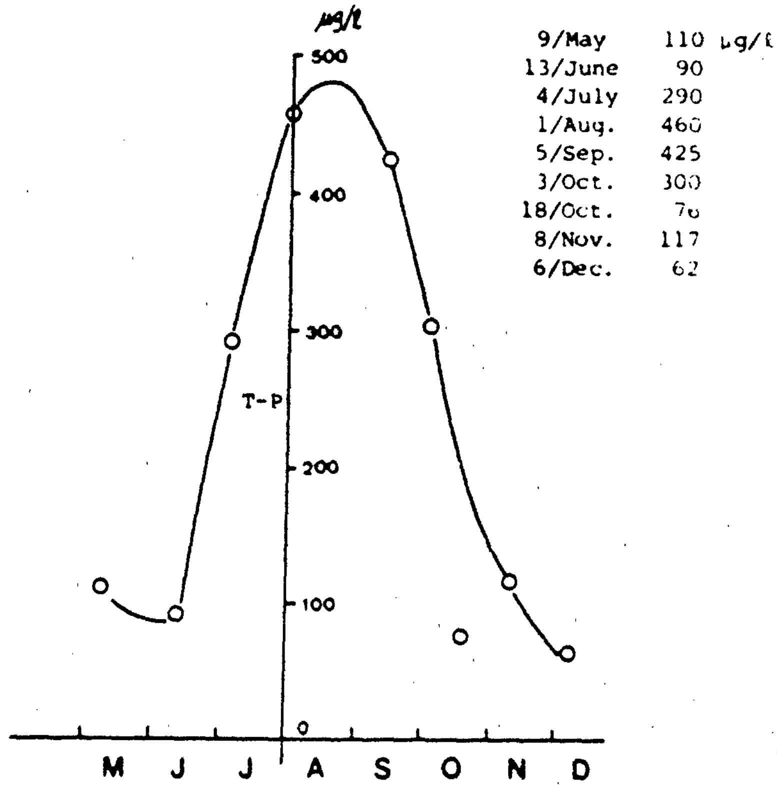


Figure 7. Peak concentrations of T-P in Suwa (1973)

Table-1 Back-calculation of p_r

t day	F(t)	$e^{-\frac{Q}{V}t}$	$C_0 e^{-\frac{Q}{V}t}$ μg/ℓ	ΔC μg/ℓ	C μg/ℓ	p_r mg/m²/d
-60	-820.3	3.32	1261.6	$-1432.9p_r$	0	1.14
-30	-57.88	1.82	691.6	$-55.4p_r$	180	9.21
0	0	1	380	0	380	(17.4)
15	16.43	0.741	281.6	$6.4p_r$	400	18.5
30	31.88	0.549	208.6	$9.2p_r$	350	15.37
60	196.48	0.301	114.4	$31.1p_r$	220	3.40
90	1788.2	0.165	62.7	$155.2p_r$	70	0.05
120	8901	0.091	34.58	$426.2p_r$	0	-0.08
150	30102	0.050	19.0	$791.9p_r$		

$$\Delta C = p_r \frac{a}{H}^{T_{max} - 20} F(t) e^{-\frac{Q}{V}t} \qquad C = \Delta C + C_0 e^{-\frac{Q}{V}t}$$

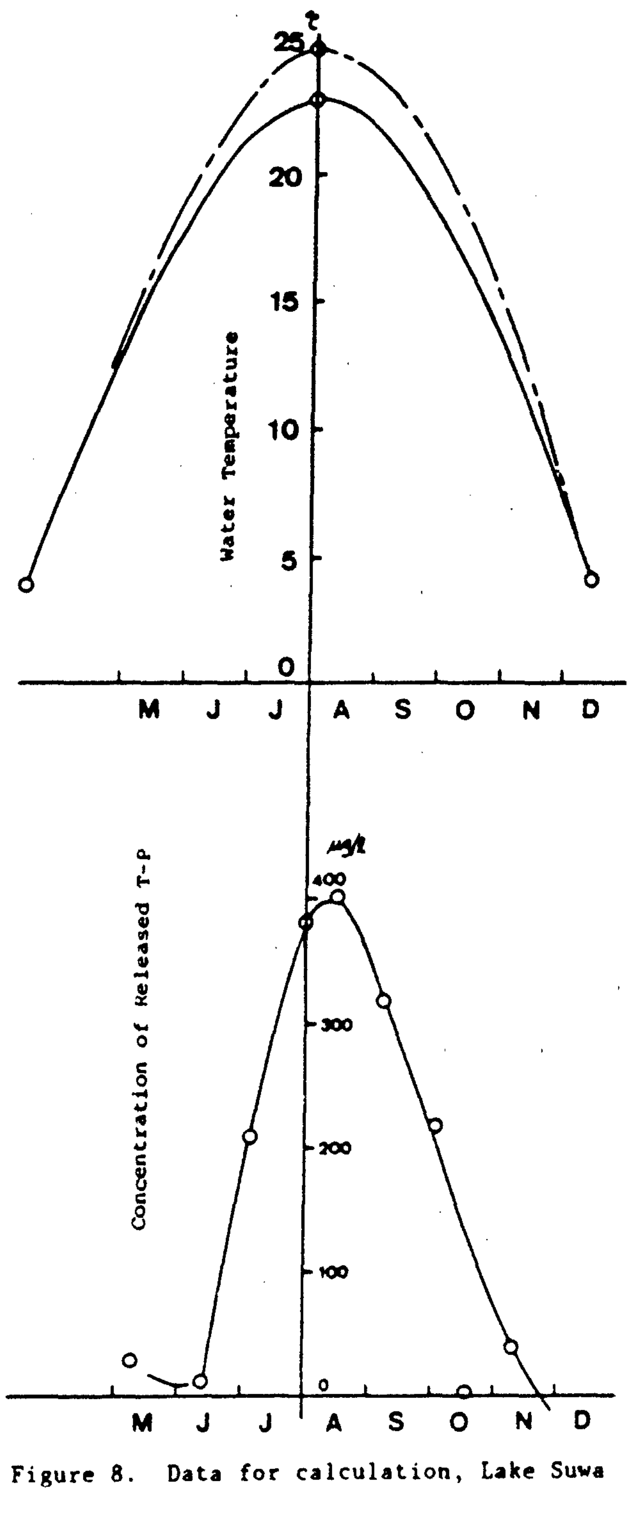


Figure 8. Data for calculation, Lake Suwa

Since the function F(t) is 0 at t = 0; the release rates (p_r) at this point cannot be obtained by calculation. So it has to be estimated from the continuity of the curve. The laboratory test results for sediment samples were $p_r = 15.8$ mg/m^2/d in an anaerobic condition (Figure 9). On this basis the calculated values appear to be comparable to those of the test results.

Lake Koyamaike

The seasonal variation of water temperature and the summer peak of T-P in Lake Koyamaike are shown in Figure 10. It is apparent that the maximum point is much delayed from that of water temperature in Lake Suwa. Here we assume that the basic concentration of T-P in winter is 50 μg/ℓ.

$$C_{max} = 400 - 50 = 350 \quad \mu g/\ell \ (t = 54 \text{ days})$$

$$C_0 = 80 - 50 = 30 \quad \mu g/\ell$$

$$T_{max} = 31 \quad °C$$

$$T_{min} = 5 \quad °C \ (t = 150 \text{ days})$$

$$p_t = \frac{t^2}{2(T_{max} - T_{min})} = \frac{150^2}{2(31 - 5)} = 433 \quad \text{day}^2/°C$$

$$Q = 4.6 \text{ m}^3/\text{sec} = 397{,}440 \quad \text{m}^3/\text{d}$$

$$V = 18.5 \times 10^6 \quad \text{m}^3$$

$$\frac{Q}{V} = \frac{397{,}440}{18{,}500{,}000} = 0.02 \quad \text{day}^{-1}$$

The back-calculation of p_r is summarized in Table 2, and the calculated values of p_r are graphed in Figure 11. The release rates of total nitrogen are also computed by the same method; the results are indicated in Table 3 and Figure 12.

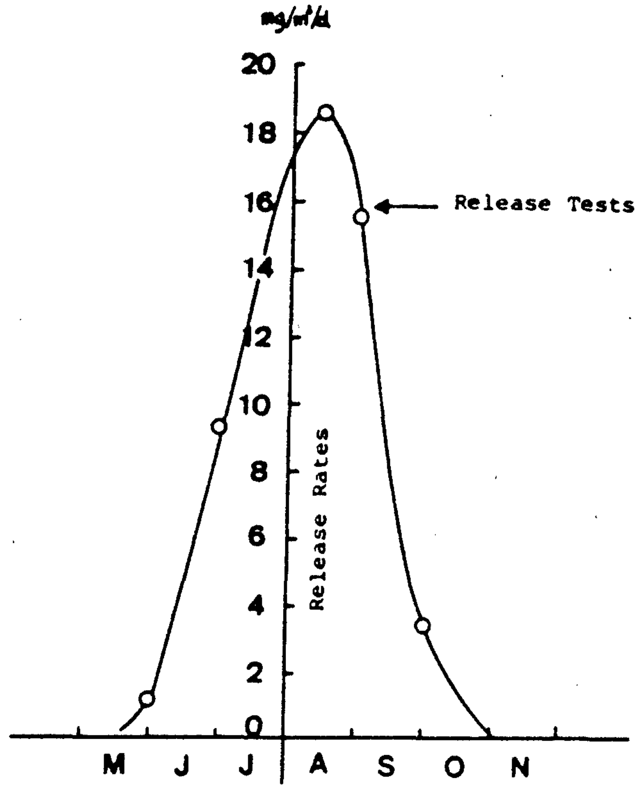


Figure 9. Calculated release rates, Lake Suwa

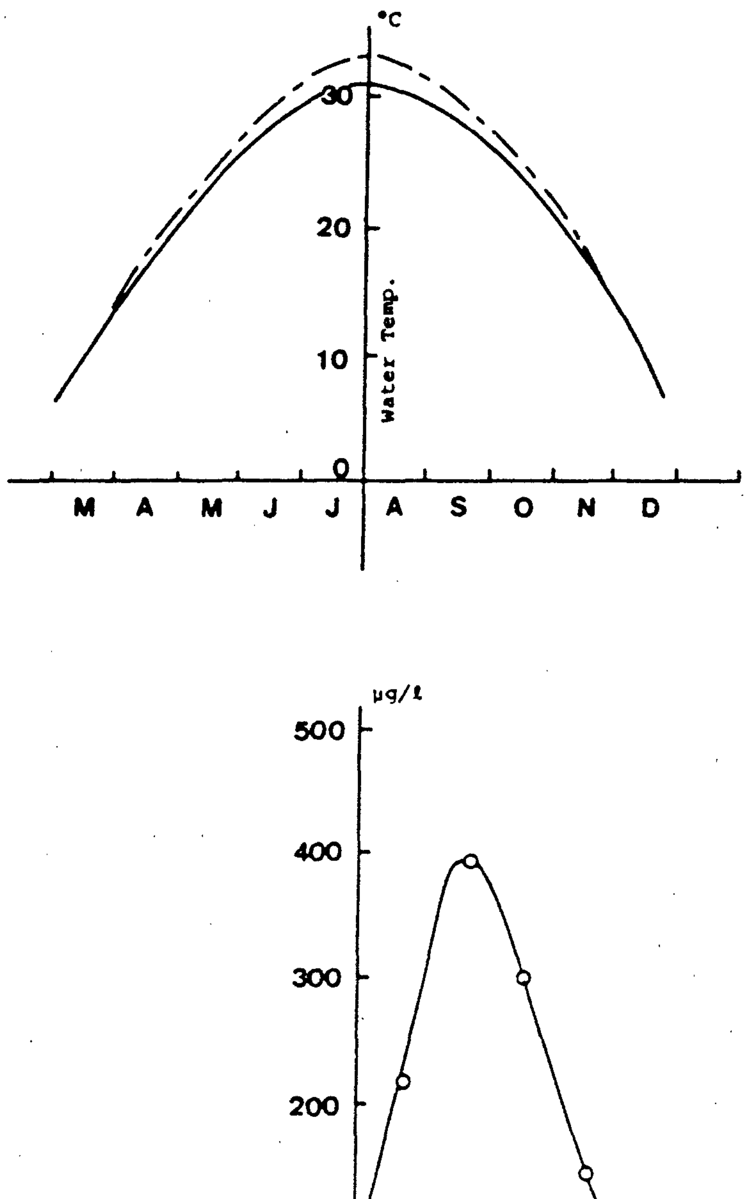


Figure 10. Data for calculation, Lake Koyamaike (1978)

Table-2 Back-calculation of p_r

t day	F(t)	$e^{-\frac{Q}{V}t}$	$C_0 e^{-\frac{Q}{V}t}$ μg/ℓ	ΔC μg/ℓ	C μg/ℓ	p_r mg/m²/d
-60	-905.4	3.32	99.6	$-3509.3p_r$	10	0.03
-30	-61.15	1.82	54.6	$-1299p_r$	10	0.3
0	0	1	30	0	30	(5.5)
30	30.88	0.549	16.5	$19.79p_r$	250	11.8
54	123.17	0.340	10.2	$48.89p_r$	350	6.95
60	205.36	0.301	9.0	$72.16p_r$	330	4.45
90	1956.7	0.165	5.0	$376.9p_r$	200	0.5
120	9824.4	0.091	2.7	$1043.7p_r$	75	0.07
150	33315	0.050	1.5	$19446p_r$	0	0

$$\Delta C = \frac{p_r(20\ ^\circ C)}{H} \alpha^{T_{max} - 20} F(t) e^{-\frac{Q}{V}t} \qquad C = \Delta C + C_0 e^{-\frac{Q}{V}t}$$

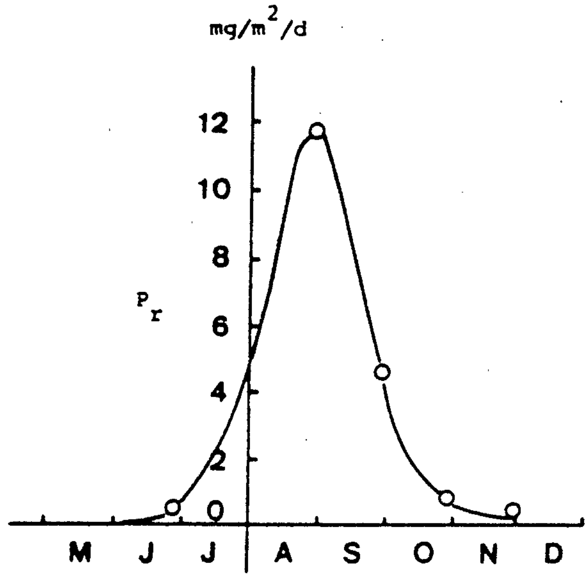


Figure 11. Calculated release rates of T-P, Lake Koyamaike (1978)

Table-3 Back-calculation of n_r

t day	F(t)	$e^{-\frac{Q}{V}t}$	$C_0 e^{-\frac{Q}{V}t}$ μg/ℓ	ΔC μg/ℓ	C μg/ℓ	n_r $mg/m^2/d$
-60	-905.4	3.32	1328	$-3509.3n_r$	20	0.4
-30	-61.15	1.82	728	$-1299n_r$	160	4.4
0	0	1	400	0	400	(37.0)
30	30.88	0.549	219.6	$19.79n_r$	1570	68.2
54	123.17	0.339	135.6	$48.89n_r$	1900	36.1
60	205.36	0.301	120.4	$72.16n_r$	1910	24.8
90	1956.7	0.165	66.0	$376.9n_r$	134	0.2
120	9824.4	0.091	36.4	$1043.7n_r$	72	0.03
150	33315	0.050	20.0	$19446n_r$	0	0

$$\Delta C = \frac{n_r(20\ °C)}{H}\,\alpha^{T_{max}-20}\,F(t)e^{-\frac{Q}{V}t} \qquad \Delta C = C + C_0 e^{-\frac{Q}{V}t}$$

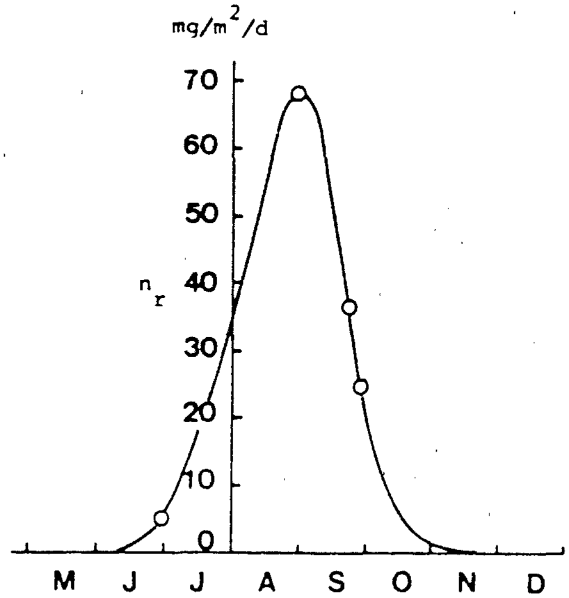
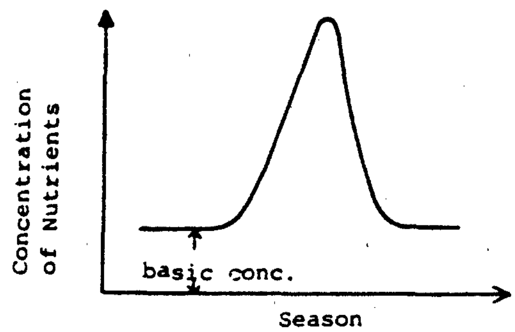


Figure 12. Calculated release rates of T-N

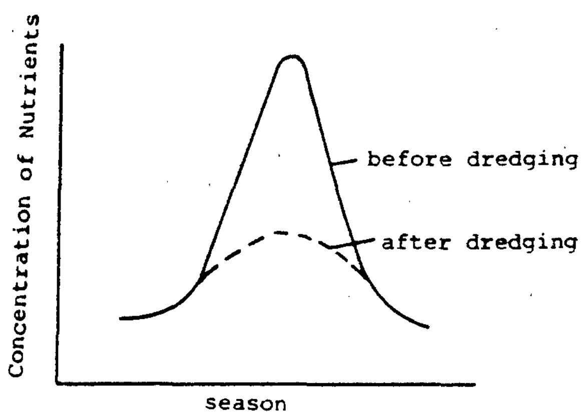
Considerations of Lake Restoration

As mentioned before, the nutrient concentrations of lake water are composed of the following two components: (1) basic concentration in winter, and (2) peak concentration in summer.



In these cases, the mean annual concentration of nutrients has no meaning. The low concentrations are related to inflowing nutrients and, by using a mathematical simulation, the summer peak can be related to nutrient materials released from sediment. It is unlikely that nutrient release from sediments occurs in winter.

Based on these suppositions, it seems possible to restore the lakes by removing the summer peak. The best way may be to remove sediment, that is, to cut off internal loading. However, a gradual buildup of nutrient levels in newly exposed sediments may require repeated sediment removal at some future date if nutrient input loadings remain at high levels.



As to the release rates after dredging, we can obtain them by release tests in the laboratory, or by calculating their theoretical values (Yoshida, 1980). Since the presumed values of release rates after sediment removal are known, we can predict a restored water quality.

Conclusions

A mathematical simulation of the summer peak of nutrient concentrations, generated by materials released from the sediment, has been given. From these studies, it seems that internal loading from released materials may have a great influence on lake pollution.

There are many lake restoration projects in Japan based on sediment removal, and, under the conditions of our studies, these seem to be an effective and immediate way to reduce the summer peak. The long-term effectiveness of such treatment, however, has not been considered in this presentation.

Reference

T. Yoshida, Mathematical Model of Phosphorus Release from Lake Sediment, XXIst Congress of International Association of Theoretical and Applied Limnology, August 1980.

AD P002 410

1981 STATUS REPORT ON THE ENVIRONMENTAL AND WATER QUALITY OPERATIONAL STUDIES PROGRAM

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ABSTRACT

In October 1977, the Environmental and Water Quality Operational Studies (EWQOS) was initiated under the sponsorship of the Office, Chief of Engineers (OCE). The EWQOS was planned as a 6-year program of applied research to answer select, high-priority environmental quality problems associated with the Civil Works activity of the Corps of Engineers (CE). Rapid development of technology and changing priorities of research have expanded both the scope and the planned duration of the program to 8 years and a scheduled completion in fiscal year 1985. The program is managed for OCE by the Waterways Experiment Station (WES), Vicksburg, Mississippi. This paper will present the program in its present form and provide the status of the research to date.

INTRODUCTION

The EWQOS Program roots can be traced to a survey of the CE field offices during 1976. The purpose of the survey was to identify and assess the magnitude of environmental quality (EQ) problems facing the Corps and to determine the major areas of common problems that could be addressed by a comprehensive research program to the benefit of the Corps as a whole.

Meetings were held at each of the CE Continental United States (CONUS) Division offices with representatives of planning, engineering, and construction/operations elements from the Districts and Divisions participating. Representatives from OCE also attended. These meetings were used not only as a forum to present environmental problems, but the Division offices also were asked to provide detailed information on specific problems, their frequency and effects, and the CE projects associated with them.

At the conclusion of the survey, the problems were compiled and analyzed at the WES and published in Technical Report E-77-1, "Reservoir and Waterways - Identification and Assessment of Environmental Quality Problems." Contained in the report was the research proposal that was later identified as the EWQOS Program. Formal approval for EWQOS was obtained in the spring of 1977 and an intensive effort was initiated to finalize research plans and select data collection and technique development and demonstration sites. One of the early recommendations was that the program contain an extensive effort of long-term comprehensive field studies both at Corps reservoirs and select waterway project sites. The long-term field sites were felt essential to the program both as a comprehensive source of data and as demonstration sites for the operational/management techniques developed within the program.

To ensure the research remained responsive to the Corps' needs, a Field Review Group (FRG) was formed to monitor progress, assist in technology transfer, and make recommendations on the scope and direction of the program. The FRG is composed of representatives of the 10 CE CONUS Divisions and meets twice yearly to review progress and provide input to the following year's research plans. The Technical Monitors (TM), of which EWQOS has three, represent the Planning, Engineering, and Construction/Operations Divisions of OCE. They are responsible for program review and approval as it relates to OCE policy. The intent of this elaborate review system is to ensure the responsiveness of the program to the changing needs of the Corps.

EWQOS ORGANIZATION

Since it was not feasible to address all the environmental problems identified in the original survey, considerable time was devoted to organizing those that could be addressed into an efficiently operating, comprehensive program. The problems fell logically into six general categories which represent a grouping of work that meets a major program objective. These groupings, or projects as they have been named, were divided into work units and the work units further subdivided into tasks. The table attached gives the current breakdown to the task level and the status as of the end of FY 81. The reservoir and waterways long-term field study efforts, identified earlier as essential to the program, have been segregated into individual projects. They are designed to meet multiple objectives over the duration of the EWQOS Program. Their principal goal is to provide information that can be used in other projects to meet specific objectives. Other field studies were planned and are being conducted under specific tasks, but are generally of short duration and require only small amounts of the program resources.

The objective of EWQOS is to provide the CE with the new technology required to meet the national environmental and water quality objectives while fulfilling the assigned mission of water resources development and management. Inherent with this objective is that the technology developed will be provided in the form of usable end-products to the appropriate functional element within the Civil Works area of the CE. In essence, the technology transfer aspect of the EWQOS Program is essential to the successful completion of the program.

The current research areas, their status, and the anticipated benefits are presented in the project framework used to organize EWQOS.

PROJECT I
PREDICTIVE TECHNIQUES TO DETERMINE ENVIRONMENTAL EFFECTS

Research efforts within Project I involve work on understanding the physical, chemical, and biological processes that are taking place in the reservoir and waterway environments, and, having improved our understanding, develop predictive models that will better describe the impacts of project alternatives on the environment. Methods for determining annual loadings to reservoirs and the development of simplified techniques for predicting environmental effects of reservoirs are also being researched through the compilation and analysis of a massive data set.

Progress to Date

Accomplishments related to the physical processes of reservoir hydrodynamics include research designed to describe reservoir inflow and internal mixing processes, physical modeling of reservoirs, effects of scale distortion in physical models, evaluation of two-dimensional hydrodynamic models, studies on the hydrodynamics of pumpback hydropower operation, and sediment transport in reservoirs. Results of studies on inflow and internal mixing have been incorporated into existing models improving their capability to accurately simulate reservoirs. Work related to inflow mixing and physical modeling has been completed. Methods to evaluate pumpback mixing processes on reservoir hydrodynamics are being developed.

Evaluation of two-dimensional models has resulted in selection of one model for improvement. This model will serve as a base for including reservoir chemical and biological processes and other water quality algorithms. Revised procedures for simulating key biological processes in reservoirs, including benthos, phytoplankton, zooplankton, and fisheries, have been developed and incorporated in appropriate one-dimensional models. Guidance on the use of these techniques including data requirements, sampling procedures, and interpretation of model output have been prepared for CE field offices. The improvements to models for simulating both aerobic and anaerobic processes in reservoirs are under way utilizing both laboratory and field studies. Guidance has been developed on the use of remote sensing for determining the nature and extent of reservoir ice cover, and methods have been developed for modeling the thermal exchange between reservoir sediment and overlying water.

CE-QUAL-R1, a one-dimensional reservoir water quality and ecological model, with many of the new algorithms installed, is presently undergoing verification, and a user's manual is available. Existing riverine water quality models have been evaluated with respect to applicability to CE needs.

Guidance has been prepared on available techniques for predicting loadings to reservoirs with emphasis on study requirements, objectives, and comparative evaluation of current techniques. A data base of reservoir water quality and associated project data has been compiled for over 300 projects. Initial evaluation of the properties of these data has yielded information on existing data variances that will be applicable to improving sampling and monitoring programs.

Benefits

Predictive techniques are required during all project phases to determine potential environmental effects on reservoir or riverine environments. During the preliminary planning phase, predictive techniques can be employed to determine whether projects will meet established environmental quality objectives, and to assist in defining the range of alternatives for further consideration. The resultant savings would be time and money needed to study unacceptable alternatives and will increase the range of alternatives that may be explored. During engineering, predictive techniques are useful in determining the environmental effects of various designs and will provide the necessary information to aid in design decisions. For operational projects, predictive techniques are essential in evaluating new operational procedures to meet environmental quality objectives and will result in monetary savings by eliminating or reducing postproject modifications that are not cost-effective in meeting environmental quality objectives. Generally, predictive techniques produced from Project I will save time required for environmental studies and result in more defensible studies--thus reducing the time required for project completion. Project I will not produce a single procedure, but rather a number of procedures that, depending on the situation, will reduce the time and data required for making an environmental evaluation. For example, in certain operational situations or in the early planning stage of a project, a substantial savings can be realized by employing one of the simplified techniques rather than a more elaborate and costly analytical technique.

PROJECT II
RESERVOIR OPERATIONAL AND MANAGEMENT TECHNIQUES TO MEET ENVIRONMENTAL OBJECTIVES

Many of the environmental problems facing the Corps may be influenced to a greater or lesser degree by the operational and management techniques used at the project. Nuisance algal blooms, reservoir release problems, contaminants, reservoir regulation, effects of fluctuating reservoir pool levels, and the importance of preimpoundment site preparation are being investigated within Project II.

Progress to Date

Accomplishments in Project II include an evaluation of control methods for nuisance algae (including state programs) and a national workshop to select the most promising techniques requiring additional development. Guidance on the significance of internal nutrient cycling by aquatic plants to reservoir eutrophication was published. Field studies to develop release criteria for both flood control and hydropower projects were performed and the effort coordinated with the U. S. Fish and Wildlife Service. A problem-oriented bibliography and literature review for reservoir releases were published and distributed to field offices along with guidance on their use. Field studies of the use of vegetation to control impacts of fluctuating reservoir pool elevations are continuing. Initial guidance on selection of flood-tolerant plant species (EP 1110-1-3) to ameliorate problems associated with fluctuating reservoir pool elevations has been published, and updates have been prepared based on results of the field studies. A national workshop on fluctuating reservoir pool elevations and their associated problems was held emphasizing case studies and solutions. A survey of the nature and extent of contaminant problems at CE reservoir projects has been completed and includes information on the fate and effect of major contaminants in CE reservoirs plus initial management strategies to solve these problems. Work on single reservoir regulation procedures is continuing and a specific application has been made. A user manual for a basin-wide regulation model is available and work is continuing on expanding this technique to include different operational scenarios as well as multiple water quality parameters. Laboratory studies have been used to successfully simulate water quality impacts of reservoir sediments and can be used to assess the effectiveness of alternative site preparation plans. A report on site preparation factors that affect fishing quality in reservoirs was published.

Benefits

A majority of the benefits derived from the results of Project II will be applicable, in general, to operational projects and will result in a reduction of lost project benefits caused by environmental quality problems. The results of Project II will document the costs and benefits of any technology, thus forming the basis for rational decisionmaking and establishing trade-offs between water use and environmental quality objectives. Benefits from work on nuisance algal control will include reduced aesthetic problems (increased recreational value) and associated water quality problems results from eutrophication. Initial results have been used by St. Paul, Savannah, and Albuquerque Districts. Results from the reservoir release studies will provide a sound basis (or criteria) for establishing reservoir releases and allow the documentation of their benefits, and reallocation of water for other purposes (i.e., impact on water conservation). Application has been made to Lake Hartwell (South Atlantic Division). Results from work concerning major reservoir contaminants will provide guidance on the fate and effects of these constituents in reservoirs, thereby reducing delays associated with questions concerning these contaminants on new projects and providing methods to reduce losses due to contaminant effects on water supply, recreation, and fisheries. Benefits from improved reservoir regulation techniques will provide better management for water quality objectives avoiding poor (and costly) management procedures or project modifications. Techniques have been applied at Cowanesque Reservoir (Baltimore District) to solve a fishery problem downstream from the project. This technique maximizes the capability of selective withdrawal systems avoiding increased design or construction costs. Results from work on fluctuating reservoir pool elevations will provide guidance to reduce the impact on aesthetics, recreation, and water quality. Since this problem is known to affect more than 100 operational projects, potential benefits will be significant. Field studies ongoing at Lake Wallula (Walla Walla District), Lake Oahe (Omaha District), Lake Texoma (Tulsa District), and DeGray Lake (Vicksburg District) will produce results directly applicable to reservoirs in these respective regions. Application of results to Walter F. George and George W. Andrews reservoirs (Savannah District) is anticipated to result in a substantial cost savings over other methods of erosion control and, due to prevention of loss, project benefits. Work related to reservoir site preparation will provide guidance to Division and District offices to minimize subsequent water quality problems, standardize clearing practices for a variety of project purposes, and reduce the requirement for unnecessary site preparation. Work on reservoir site preparation has been performed or is ongoing at B. Everett Jordan (Wilmington District), Bloomington (Baltimore District), Richard B. Russell (Savannah District), and Beech Fork and East Lynn (Huntington District).

PROJECT III
ENGINEERING TECHNIQUES FOR MEETING RESERVOIR WATER QUALITY OBJECTIVES

The engineering design of the outlet works stilling basins and associated structures has great potential for improving release water. Other engineering techniques within the reservoirs are also showing great progress for water quality improvements. Work in Project III was designed to examine these engineering techniques.

Progress to Date

Accomplishments in this project include the field evaluation of reaeration for nonhydropower projects, work to determine the reaeration potential of structural modifications, and improvement in the capability to describe selective withdrawal under varying designs, plus updated design guidance and input to a revised outlet works manual (EM 1110-2-1602). Work related to improvement of in-reservoir water quality involved evaluation of mixing/destratification techniques and aeration techniques. Initial guidance on reservoir destratification has been published. An engineering technical letter on calibration of the D'Aoust saturometer was produced and reports on modeling reaeration in hydraulic structures, use of tracers to measure reaeration, design guidance on reaeration through gated-conduit outlet works, and associated field studies were published. Field studies on reservoir aeration and possible nitrogen supersaturation were completed along with a literature review on the environmental effects of reservoir destratification/aeration.

Benefits

Engineering solutions to reservoir environmental quality problems by the modification of projects or improvement in design represent a significant improvement to technology. Thorough knowledge of the costs, both capital and operating, will allow evaluation of this engineering technology. Coupled with the benefits, which can be quantified through other results of the program, this will permit a careful evaluation of project designs and modifications thus improving the design efficiency and effectiveness while providing a solution to reservoir water quality problems. Studies to assess the selective withdrawal capability of outlet structures have been applied to Sutton Dam (Huntington District), Lake Sidney Lanier (Mobile District), Dickey-Lincoln Dam (New England Division), Clark Hill (Savannah District), and Lost Creek (Portland District). Results have also been applied to Harry S. Truman (Kansas City District), Richard B. Russell (Savannah District), Tablerock (Norfolk District), and Littlerock, Carlyle, and Shelbyville (St. Louis District). Improvements to the D'Aoust saturometer have been used to evaluate nitrogen supersaturation problems at significant cost savings over previously used procedures. Results from reaeration studies have been employed to evaluate low-head hydropower impacts on the Illinois waterway (Rock Island District) and lock and dam structures in the Red River (New Orleans District) and Coosa River (Mobile District) projects.

PROJECT IV
ENVIRONMENTAL ASSESSMENT TECHNIQUES FOR PROJECT PLANNING AND OPERATIONAL REQUIREMENTS

Work within Project IV includes improvement of environmental assessment techniques, evaluation of environmental data management systems, and use of biological indices or indicators for assessment.

Progress to Date

Prior accomplishments in Project IV include review documents for critical variables in the four accounts under Principles and Standards, environmental assessment methodologies (including publication of EC 1105-2-102), legal aspects of quantitative approaches to environmental assessment, environmental data management systems, and biological indicators and indices for riverine systems. Guidance summarizing available biological indices and their use is available. An Evaluation and Analysis Sensitivity Program (ESAP) was developed for application to EQ planning, and a user manual is available.

Project IV will be concluded with the completion of EQ planning and evaluation techniques during FY 82.

Benefits

Establishment of regulations related to EQ planning resulted in many questions as to how these regulations may be implemented with the myriad of available techniques. Project IV will produce recommended techniques applicable to these regulations that have been field tested and will produce time and cost savings in environmental planning; will produce more defensible environmental assessments; and will prevent project delays and costly litigation. The results of work on environmental assessment are being used in the Whitewater River Basin study and Central Arizona Water Control study (Los Angeles District) plus the Northeast Cape Fear River study (Wilmington District). Results of efforts related to environmental data management and biological indices will result in savings by streamlining environmental data manage-ment, eliminating the collection of redundant data, and reducing the amount of data required for a defensible environmental assessment.

PROJECT V
ENVIRONMENTAL IMPACT OF WATERWAY ACTIVITIES

Work in Project V consists of literature review and short-term field studies of environmental impacts of selected channelization, bank stabilization, and navigation activities on waterways. This project is specifically designed to complement and extend the applicability of results obtained from the Waterway Field Studies.

Progress to Date

Prior accomplishments in this project include completion of a short-term field study of Section 32 demonstration projects (Omaha District) and publication of the results of the pilot study on the Mississippi River. The latter is a series of reports detailing design, sampling, and analysis of data for environmental studies of large waterways applicable to other, similar projects.

Benefits

Knowledge on the environmental effect of waterway activities, especially as it pertains to flood control and navigation project purposes, is required to prepare meaningful and defensible environmental assessments, to develop resource management plans that maximize project environmental benefits (plus allow quantification of them), and as input to produce improved design and/or operational guidance for Division and District offices. An excellent example of the application of these results is the direct application to environmental analysis of the Tennessee-Tombigbee project (Mobile District).

PROJECT VI
WATERWAY PROJECT DESIGN AND OPERATION FOR MEETING ENVIRONMENTAL QUALITY OBJECTIVES

Work within Project VI has concentrated on review of available design and operations technology to meet environmental quality objectives as well as the development of improved procedures based on the results of Project V and the Waterway Field Studies.

Progress to Date

Prior accomplishments include completion of an evaluation of current design and operations technology for waterway projects from available literature, CE Division and District offices, and other Federal agencies. Work on the operational aspects of waterways projects has been completed and guidance on improved methods for planning and construction of Section 205 Flood Control Projects (channelization) has been provided. Initial guidance on the environmental impacts associated with the design of dikes, levees, and streambank protection projects has also been developed and provided to field offices for review.

Benefits

Improved design and operations technology represents one of the most desirable end-products of research on the environmental effects of waterway activities. Given information on the environmental effects, improved techniques can be developed, and costs can be documented and compared to benefits to produce guidance for Division and District offices on new design and construction concepts to meet environmental quality objectives. Since authorized project purposes are known, new technology developed within Project VI ensures attainment of the primary objective of the EWQOS Program. The products of Project VI will minimize delays in waterway projects, facilitate their efficient design, and maximize environmental benefits.

PROJECT VII
LONG-TERM FIELD STUDIES

Reservoir Field Studies

Long-Term Reservoir Field Studies include comprehensive, long-term work at selected sites to meet multiple program objectives. The fundamental objectives of these studies are to provide an understanding of cause and effect between project design and operation and reservoir environmental quality, and to obtain required data for technology development, demonstration, and verification.

Progress to Date

Prior accomplishments include the development of selection criteria, screening of candidate reservoir projects, and final selection of sites. The four study sites selected were DeGray (Vicksburg District), Red Rock (Rock Island District), Eau Galle (St. Paul District), and West Point (Mobile District). Following site selection, available data on all projects were compiled and analyzed. Field studies have been initiated at all field study sites under varying operational and seasonal conditions. Detailed studies were concluded at DeGray and Red Rock sites to provide input to other work within the program. A comprehensive data management program has been established and analysis of data from all field study sites is proceeding. Detailed studies in support of Projects I and II are ongoing at the Eau Galle site, and specific studies of reservoir processes have been performed at the West Point site. Guidance documents related to sampling and reservoir processes have been provided to field offices.

Benefits

The primary benefit of the Reservoir Field Studies will be increased understanding and information relating project design and operation to environmental quality objectives. This information is significant because it can provide many answers to specific environmental problems related to reservoirs and can be used in the planning, design, and operation of reservoir projects. The results will minimize delays in reservoir projects due to environmental questions and will provide the basis to correct many environmental quality problems. Because of the selection criteria employed, this information will be generally applicable. Data from the Reservoir Field Studies will be used to verify techniques developed, demonstrate new or improved technology, and provide further insight into specific environmental processes. Verified techniques and demonstrated technology have a distinct advantage of producing end-products that are readily usable by Division and District offices, have been fully evaluated, and thus facilitate technology transfer. This will result in substantial monetary savings by avoiding costly trial-and-error application of end-products. Similarly, if technology to solve environmental quality problems at reservoirs is based on a thorough understanding of a particular environmental process, then it will produce a more usable end-product. Since the Reservoir Field Studies are performed at operating projects, the results are more credible and do not require additional, extensive verification. New or improved guidance for sampling, testing, and analysis of environmental data from reservoir projects will result in cost savings for monitoring or study efforts, and will produce data that have meaning and usefulness to Division and District offices. These results have been applied by numerous Districts in design of water quality sampling programs with resultant cost savings.

Waterway Field Studies

The Waterway Field Studies consist of long-term, comprehensive studies of waterway projects involving channel alignment, bank stabilization, or navigation channelization. The objectives of these field studies are very similar to the Reservoir Field Studies: to provide information on the environmental effects of various waterway activities plus development of resource management plans and new or improved design and operation guidance to maximize environmental benefits or attain environmental quality objectives.

Progress to Date

Comprehensive field studies on a selected reach of the Lower Mississippi River (Vicksburg District) and the Tennessee-Tombigbee project (Mobile District) have been completed. Data analysis is proceeding in conjunction with Project V to prepare synthesis reports and environmental guidance documents based on study results. Specific emphasis is being given to guidance on study design, sampling methods, and data analysis for waterways.

Benefits

There is a significant lack of data regarding the environmental effects of CE activities on navigable river systems. Results of the Waterway Field Studies will provide valuable and urgently needed information to answer many of the environmental questions raised by these CE activities. This will result in minimizing project delays, more defensible environmental assessments, and reduction of costly litigation associated with more controversial projects. Because of the lack of information regarding waterway activites, it is difficult to claim environmental benefits associated with these activities, determine possible mitigation actions, or justify modifications to current design practice. Results from the Waterway Field Studies will allow the development of resource management plans to maximize environmental benefits and provide a basis for their quantification, and will be used to develop new or improved design procedures. These may result in larger project benefits for certain activities and minimize the costs required for modification or possible mitigation. Some of the CE waterway activities fall under the purview of regulatory functions. Knowledge of the environmental effects of these projects will greatly reduce the costs and difficulty associated with the regulatory aspects for these projects. Improved sampling, testing, and analysis guidance for environmental data associated with waterway projects will improve the efficiency of monitoring and survey activities, reduce the cost due to unnecessary data collection, and make collected data more defensible. Specifically, sampling and experimental design procedures have been used by the Rock island and St. Paul District for environmental studies of the upper Mississippi River. Results have also been applied by the Mobile and Huntington Districts on studies of waterway projects. Results from the Lower Mississippi Field Study have been directly applicable to additional environmental studies being performed by the Lower Mississippi Valley Division at a significant cost savings.

PROPOSED RESEARCH

Under current plans, EWQOS is scheduled for completion in FY 1985; consequently, long-range objectives are oriented toward the successful completion of the programs. The objectives include the integration of task results to meet project objectives, full utilization of field study results, production and distribution of end-products, and conduction of training (i.e., workshops) required to fulfill technology transfer goals. A continual technology transfer effort throughout the conduct of EWQOS will ensure that results are directed to the proper user, are in the appropriate form for maximum utility, and allow feedback to the program as input to out-year research.

Complete synthesis of research results to produce logical and meaningful end-products will be the highest priority activity during the last year of the program. EWQOS will provide three Environmental Engineering Manuals within this series representing the culmination of a significant portion of the research. Input to other Engineering Manuals is anticipated and will be performed to the extent that need and desirability dictates. Other guidance documents such as input to ER's, EC's, and ETL's, design manuals, handbooks, and user manuals will complement input provided via Engineering Manuals and provide the necessary information to meet EWQOS technology transfer objectives.

Completion of the EWQOS Program will represent a major milestone in environmental research and development associated with Civil Works activities of the CE. Utilization of products produced from EWQOS are expected to produce substantial cost savings in solving environmental quality problems related to water resource management and development. Many of these benefits can be attributed to reduction or elimination of conflicts between environmental goals and other project purposes, and improved procedures and criteria for analyzing and solving environmental problems based on increased knowledge of environmental consequences of Civil Works activities.

EWQOS STATUS SUMMARY, SEP 81

Project Title/Work Unit/Task	Mode of Conduct	Completion	Cost to Date	Status
I. Predictive Techniques for Determining Environmental Effects				
IA. Reservoir Hydrodynamics				
1 Develop and verify techniques for describing inflow mixing processes	EL, WES	Sep 81	$ 148,000	Complete
2. Develop and verify techniques for describing internal reservoir mixing processes	EL, WES,	Sep 82	288,000	Active, mixing algorithms verified, field studies completed
3. Improve and verify physical hydrodynamic modeling techniques for reservoirs	HL, WES, Contract, W Va Univ	Sep 81	220,000	Complete, internal working document
4. Improve and verify multidimensional hydrodynamic mathematical models	HL, WES, HEC, Contract, J E Endinger Asso., Inc	Sep 84	380,000	Active, two-dimensional model improvements ongoing, initial verifications completed, TR E-81-2
5 Develop and verify techniques for describing pumpback mixing processes	HL, WES, Contract, Ga. Tech Univ.	Sep 82	146,000	Active, one-dimensional model simulations completed and refined, TR E-81-3
6. Modification of HEC-6	HEC	Sep 78	25,000	Complete
7. The behavior of fine sediments in reservoirs	HL, WES	Sep 81	186,000	Complete, will be published as part of 1C
IB. Improved Description of Ecological and Water Quality Processes				
1. Improve and verify understanding and descriptions for reservoir ecological processes	EL, WES, FWS (NRRP); USEPA; Las Vegas	Sep 83	718,000	Active, improved algorithms for benthos; zooplankton, and phytoplankton have been verified and installed on water quality model; TR E-80-3, TR E-80-4, TR E-81-13, MP E-81-2
2. Develop and verify description for aerobic/anaerobic chemical processes	EL, WES	Sep 84	778,000	Active, field and laboratory studies under way to quality unknown process rates under anaerobic conditions; TR E-81-6
4. Formation and breakup of reservoir ice cover and effects on thermal energy budget computations	CRREL	Sep 82	282,000	Active, simplistic algorithm developed and installed on model,
IC. Mathematical Water Quality and Ecological Predictive Techniques				
1. Improve and verify existing one-dimensional reservoir quality and ecological prediction techniques	EL, WES	Sep 84	880,000	Active, model/users manual available
2. Develop and evaluate multidimensional reservoir water quality and ecological predictive techniques	EL, WES	Sep 84	300,000	Active, two-dimensional model tested against field study data sets
3. Improve and verify riverine water quality and ecological predictive techniques	EL, WES, USGS	Sep 86	300,000	Active, existing one-dimensional model report available, two-dimensional model selected for addition of water quality algorithms
4 Field test of the WORRS river water quality module	HEC	Sep 80	86,000	Complete
ID. Determination of Loadings to Reservoirs				
1. Evaluation of existing techniques for predicting annual loadings to reservoirs	EL, WES	Sep 79	78,000	Complete; TR E-81-1
IE. Simplified Techniques for Predicting Reservoir Water Quality and Eutrophication Potential	EL, WES, Contract, W Walker	Sep 84	246,000	Active, data base complete, techniques for nutrient loadings/trophic response tested, TR E-81-9
II. Reservoir Operational and Management Techniques				
IIA. Management of Nuisance Algal Blooms in Reservoirs				
1 Define and evaluate major causes of nuisance algal blooms in CE reservoirs	EL, WES	Sep 79	100,000	Complete, TR E-80-1
2. Develop and evaluate reservoir management methods for controlling algal blooms	EL, WES, USEPA	Sep 86	135,000	Active, field studies under way, TR E-81-7
3 Evaluation of plant-mediated phosphorus release from sediments and effects on algal growth	EL, WES	Sep 80	166,000	Complete; TR E-79-3
IIB. Guidelines for Determining Releases to Meet Environmental Quality Objectives				
1-4 Guidelines for determining reservoir releases to meet environmental quality objectives	EL, WES, FWS (NRRP), Contract, Dr J Duse, Consultant	Sep 84	1,160,000	Active, analysis of field studies proceeding, annotated bibliography completed, literature review published, TR E-81-8, TR E-81-12
IIC. Operational and Management Strategies Reservoir Contaminants				
1 Survey of the nature and magnitude of reservoir contaminant problems	EL, WES	Sep 79	20,000	Complete
2. Fate and effects of major chemical contaminants in reservoirs	EL, WES, Contract, LSU	Sep 81	105,000	Complete
IID. Reservoir Regulation Techniques for Water Quality Management				
1 Reservoir regulation constraints for water quality management	EL, WES	Sep 78	66,000	Complete
2. Reservoir regulation techniques for water quality management	HL, WES	Sep 82	207,000	Active, report in preparation

(Continued)

NOTE: Abbreviations used in this table are defined as follows:

CRREL - Cold Regions Research and Engineering Laboratory
EL - Environmental Laboratory
FWS (NRRP)- Fish and Wildlife Service (National Reservoir Research Program)
HEC - Hydraulics Engineering Center
HL - Hydraulics Laboratory
LSU - Louisiana State University
MP - Miscellaneous Paper
MSU - Mississippi State University
OSU - Oklahoma State University
TR - Technical Report
USAE - U S Army Engineer
USDA - U S Department of Agriculture
USEPA - U S Environmental Protection Agency
USGS - U S Geological Survey
WES - Waterways Experiment Station

EWQOS STATUS SUMMARY, SEP 81 (Concluded)

Project Title/Work Unit/Task	Mode of Conduct	Completion	Cost to Date	Status
IID. Reservoir Regulation Techniques for Water Quality Management (Continued)				
3. Reservoir system regulation for water quality control	HEC	Sep 84	$ 200,000	Active, initial version of HEC-5Q available in-house testing of phase II model initiated
IIE. Environmental Effects of Fluctuating Reservoir Water Levels				
1. Vegetation for reducing effects of fluctuating pool levels	EL, WES, USDA*	Sep 84	838,000	Active, field studies ongoing, literature review/initial guidance available; TR E-79-2
2. Reservoir fisheries	EL, WES, FWS	Sep 83	30,00C	Active, literature survey and data assembly initiated
IIF. Reservoir Site Preparation				
1. Develop procedures for reservoir site preparation and filling	EL, WES, FWS, USEPA	Sep 84	280,000	Active, laboratory studies ongoing, report available on fish production in new reservoirs; TR E-81-11
III. Engineering Techniques for Meeting Reservoir Water Quality Objectives				
IIIA. Techniques to Meet Environmental Quality Objectives ... Reservoir Releases				
1. Evaluate field reaeration data at existing structures	HL, WES	Sep 82	336,000	Active, reaeration studies for nonhydropower projects complete, work on nitrogen supersaturation continuing, two TR's available; TR E-81-5 and TR E-81-13
2. Develop techniques to determine the reaeration potential of structural modifications	HL, WES, Contract E. C. Tsivoglou, Inc.	Sep 81	341,000	Complete; TR E-80-5 and TR E-80-10
3. Evaluate alternatives for aeration/oxygenation of hydropower releases	HL, WES	Sep 84	46,000	Active, field studies and literature survey initiated
4. Describe the selective withdrawal characteristics of various outlet configurations	HL, WES, Contract MSU	Sep 84	484,000	Active, revised selective withdrawal model available
IIIB. In-Reservoir Techniques for Improvement of Environmental Quality				
1. Evaluate the effectiveness of reservoir mixing/destratification techniques	HL, WES, Contract OSU	Sep 82	294,000	Active, field tests/physical modeling studies ongoing, localized mixing laboratory studies completed; TR E-79-1
2. Environmental effects associated with reservoir mixing/destratification, aeration/oxygenation techniques	EL, WES, Contract Tetra Tech, Inc.	Sep 81	75,000	Complete
4. Evaluate the effectiveness of reservoir aeration/oxygenation techniques	HL, WES	Sep 81	280,000	Complete; MP E-81-3
IV. Environmental Assessment Techniques for Planning and Operational Requirements				
IVA. Alternative Techniques for Environmental Analysis	EL, WES, Contract Univ. of Colo.	Sep 81	748,000	Complete; TR E-80-2 and TR E-81-4
IVB. Data Management and Indices for Environmental Assessment				
1. Review and evaluate data management techniques applicable to environmental assessment	EL, WES	Sep 80	48,000	Complete; MP E-80-2
2. Evaluate selected biological indices that have potential application to impact assessment	EL, WES	Sep 81	180,000	Complete; Internal working document
V. Environmental Impacts of Waterway Activities				
VA. Environmental Impact of Selected Channel Alignment and Bank Revetment Alternatives on Waterways	EL, WES, FWS	Sep 84	845,000	Active, results of field studies and habitat analysis ongoing
VB. Impacts of Navigation Activities on Waterways	EL, WES	Sep 86	–	Delayed
VI. Waterways Project Design and Operation for Meeting Environmental Objectives				
VIA. Operational Procedures for Waterways Projects to Attain Environmental Quality Objectives				
1. Identify, document, and evaluate the effects of waterway operational procedures on environmental quality	EL, WES	Sep 80	85,000	Complete; Internal working document
VIB. Design and Construction Techniques for Waterway Projects to Attain Environmental Quality Objectives				
1. Identify, evaluate, document factors in design and construction of waterway projects affecting environmental objectives	EL, WES	Sep 80	169,000	Complete
2. Develop and evaluate improved design procedures for waterways to enhance environmental quality	EL, WES	Sep 84	50	Active, revised design/construction guidance development ongoing for several project categories
VII. Long-Term Comprehensive Field Studies				
VIIA. Reservoir Field Studies: Field Studies for Environmental and Water Quality Aspects of Reservoirs 1. DeGray Reservoir 2. Red Rock Reservoir 3. Eau Galle Reservoir 4. West Point Reservoir	EL, WES, USGS, USAE District, Rock Island; Ark. Water Resources Research Center	Sep 85	3,803,000	Field studies ongoing
VIIB. Waterway Field Studies: Long-Term Field Studies Associated with the Environmental Quality of Waterway Projects 1. Tennessee-Tombigbee 2. Mississippi River	EL, WES, DOE, Contract, FWS, Co-op Unit at LSU, Co-op Unit at MSU	Sep 85	2,570,000	Field studies concluded, analysis ongoing MP E-80-1, Reports 1-8

* Contract, Wave Beach Grass Nurseries, Univ. of S. Dakota, Southeastern OSU.

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MARINE TECHNOLOGY FOR ENVIRONMENTAL PROBLEMS
-Some Examples of Improved Systems on Workvessels-

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ABSTRACT

(PART I) For dredging and processing of loose sediments containing toxic materials, a system (in sequence) of the following component processes: Dredging-Transportation of dredged slurry, Dehydration and Processing of separated water, Unloading of cake solids, Disposal (Reclamation) has proved most practical. Operational cost for 50% soil concentration in the dredged slurry is 10% lower than for 25% soil concentration and centrifugal dehydration gives 4% lower costs than press dehydration. Depreciation of initial investment, interest, and maintenance are three major items consuming 22-28% of total cost of all the equipment. The processing barge for dehydration and water processing is most costly, occupying some 60% of the total cost.

(PART II) The mechanism of sea surface turbidity caused by overflowing water from a hopper dredge was determined by model experiments to be due to air-lift phenomenon of air bubbles entrained in the muddy water, and the Anti-Turbidity Overflow System (ATOS) was developed to eliminate air bubbles from the overflowing water. The effect of ATOS was confirmed by actual dredging tests. In fine sand or silt, ATOS reduced turbidity of the sea surface to as low as 10 ppm, or lower in suspended solid (SS) concentration, as compared to a level of over 400 ppm without ATOS.

INTRODUCTION

Various technological means of protecting the marine environment have been studied and are under development by governmental institutes, universities, nonprofit societies or associations, and private industries. Two such technologies are introduced herein: Part I is "Dredging and Processing of Toxic Sediments" and Part II discusses the "Anti-Turbidity Overflow System for a Hopper Dredge."

PART I. DREDGING AND PROCESSING OF TOXIC SEDIMENTS*

I.1 PREFACE

In Japan, because of industrial development, toxic materials deposited into rivers or seas have settled on the seabed in harbors or bays at a level high enough to cause a pollution problem. More recently, however, the pollution problem has become serious, and a practical method of dredging and processing the toxic sediments (which should be treated in a different way from normal materials such as sand or silt) has not yet been devised, although a few methods are under development.

At the request of the 4th Port and Harbor Construction Bureau, Ministry of Transport (MOT), the Japan Workvessel Association (JWA) formed technical committee, consisting of engineers and experts from the Port and Harbor Construction Bureau, MOT, a university, and member firms of JWA, and conducted studies of component processes (including model experiments) and systems evaluations to select the most practical overall dredging and processing system for toxic sediments.

I.2 DESCRIPTION OF COMPONENT PROCESSES AND TOTAL SYSTEMS

I.2.1 Component Processes

The total system of dredging and processing of toxic sediments is divided into the following component processes:

- Dredging
- Dehydration (Separation of solid sediment and water)
- Processing of separated water
- Transportation of processed material
- Unloading of processed material
- Disposal of processed material (Reclamation)

I.2.2 Total Systems

Assuming that all component processes except disposal of processed material are done at sea, the following combinations (systems) of component processes were taken up for comparison and evaluation (Figure I.1). Processes in each square are assumed to take place on single, indpendent, floating units in the sequence indicated by the "system flow."

The last process, disposal, is closely related to land reclamation and not discussed in this study.

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* Part I of this paper is derived from the original report (in Japanese) entitled "Study on the Development of Dredging and Processing of Loose Sediment Containing Toxic Material."

System No.	System Flow
I	Dredging — Transportation — Unloading — (Disposal)
II	Dredging — Dehydration and Water Processing — Transportation — Unloading — (Disposal)
III	Dredging Dehydration Water Processing — Transportation — Unloading — (Disposal)
IV	Dredging — Dehydration Water Processing Transportation — Unloading — (Disposal)
V	Dredging — Transportation — Dehydration Water Processing — Unloading — (Disposal)

Figure I.1 Total system flow of dredging and processing of toxic sediments

The purpose of the study was to select the most practical system, of the four studied, for dredging and processing of toxic sediment. The study was conducted in two phases:

- Preliminary studies of component processes, and
- System design studies and evaluations based on the preliminary study.

I.3 PRELIMINARY STUDIES OF COMPONENT PROCESSES

Methods for each process were studied and actual tests were conducted to confirm their practicality.

I.3.1 Dredging

Study Outline

Six different dredging heads of three types (Ejector, Suction Pump, and Vacuum Tank) were proposed for initial study and the Committee selected two heads, Submergible Centrifugal Pump (lower positioned), and Pneuma Pump for the actual dredging test.

For transfer of dredged material from the dredging head to the following processing stage, the Pressure Transfer System was selected over three other systems (Ejector, Vacuum Transfer, and Air Lift).

Test Results

Both the Submergible Centrifugal Pump and the Pneuma Pump dredged loose sediment at approximately the same level of soil concentration and reached as high as 50%, on average, except in the lowest cases. In total, the average soil concentration was 40.0% with Submergible Pump and 43.6% with Pneuma Pump.

I.3.2 Dehydration

Study Outline

Four methods were studied:

- Thermal dehydration
- Chemical dehydration
- Electrical dehydration
- Mechanical dehydration

The Committee judged that mechanical dehydration was the most practical for dehydration of rather loose material, of the four methods studied. Although six types of equipment were proposed for mechanical dehydration (Roll Press, Filter Press, Vacuum Filter, Centrifugal Decanter, Cyclone, Pallet Blanket), two (Roll Press and Cyclone) were judged obviously impractical for the purpose in terms of processing effectiveness or ease of running on a ship and only the remaining four were tested.

Test Results

Water concentration (by weight) in the cake processed by each dehydrator was as follows:

- Filter Press	40-43%
- Vacuum Filter	55%
- Centrifugal Decanter	43-53%
- Pallet Blanket	53-60%

I.3.3 Processing of Separated Water

Outline

Water separated by dehydration processing contains a large amount of suspended solids (SS) together with toxic materials such as heavy metals like mercury and cadmium or their compounds. Discharge of water to the open sea is allowed only after it is processed to such an extent that the concentration of toxic materials is less than a permissible level.

The Committee considered four processing methods (Coagulator, Tube Separator, Floatator, Sand Filter), and selected the following combinations to be tested:

- Coagulator + Sand Filter
- Tube Separator + Sand Filter

In the test, the loose dredged material was dehydrated and the separated water was processed through each of two combinations. PH, COD (chemical oxygen demand), and the concentration of SS and heavy metals in the processed water were measured.

Test Results

SS concentration in the water processed through either one of both combinations was less than 10 ppm and the ratio of residual heavy metals to SS concentration was on the order of 10^{-4} both with mercury and cadmium.

This means that heavy metal concentration can be reduced below the permissible level (mandatory restrictions) by keeping SS concentration under 10 ppm.

I.4 SYSTEM DESIGN EVALUATION

Following the preliminary studies, alternative total system designs were evaluated by cost comparisons covering both construction of the equipment and operation thereof.

I.4.1 Preliminary System Evaluation

Of the four systems to be evaluated against the basic reference system (Figure I.1), Systems III and IV were excluded on the basis of preliminary evaluations.

System III requires that all equipment for dredging, dehydration, and water processing be installed on one floating unit of relatively large size which will result in difficult operation. The processing flow of System III is the same as that of System II and its cost can be estimated based on System II.

Similarly, in System IV, all equipment for dehydration, water processing, and transportation should be aboard one barge fitted with a large capacity retaining tank for toxic sediment and water, together with a holding tank for dehydrated cake due to the nature of the system operation cycle. It is obvious that System IV will be most costly in consideration of size, construction cost, and operation cost.

Detailed evaluations were therefore limited to Systems I (the reference), II, and V.

I.4.2 Design Conditions

Dredging

- Material to be dredged

Loose sediment containing toxic material (Hg, etc.)

Water ratio to wet (solidified) sediment (by weight)	150%
Water concentration in wet sediment (by weight)	60%
Specific gravity of dried sediment	2.55
Apparent specific gravity of wet sediment	1.35

- Dredging site

Dredging depth	10 m
Thickness of sediment layer to be dredged	1 m

- Average soil concentration in the dredged slurry (volumetric percentage of wet sediment) — 50% & 25%(*1)

- Equipment

  To be of type not to cause secondary pollution, i.e., spill of dredged slurry or disturbance of sediment near dredging head

- Operation

Hours/Day	10
Shift of crew	None

*Note 1: 25% concentration was assumed for last phase of dredging when excessive layer of sediment free of toxic material may not be dredged.

Dehydration

- Residual water concentration in dehydrated cake - Less than 50%(*2)

- Operation

Hours/Day	24
Shift of Crew	2/day

- Capacity — To match dredging capacity based upon respective operation time

*Note 2: Decided in consideration of toughness of land reclamation.

Processing of Separated Water

- Residual SS — Less than 10 ppm (*3)

*Note 3: 10 ppm was proposed based on preliminary study which proved that, by keeping SS less than this level, the concentration of heavy metals can be maintained below the mandatory restriction.

- Operation

Hours/Day	24
Shift of Crew	2/day

- Capacity — To match dehydrated capacity

- Monitoring of processed water — SS concentration is to be automatically recorded with alarm system to stop overboard discharge pump

Transportation

- System — Pusher/Barges

- Distance — 5 km (one way)

- Speed — 7 Kt

Unloading

System	Equipment Unloading Site	Material To Be Unloaded	Unloading Equipment
I	Transport Barge	Slurry	Pump (aboard barge)
II	Transport Barge	Dehydrated Cake	Clam Shell Unloading Barge
V	Processing Barge	Dehydrated Cake	Conveyor (aboard processing barge)

In System V the dehydrated cake is unloaded directly by conveyor system and no holding tank of the cake is required.

Other Conditions

All equipment is installed on one floating unit such as a dredge, processing barge, or transportation barge. Electric power for the pump aboard the transportation barges will be supplied from the processing barge or from the shore.

Disposal of unloaded material is considered land reclamation and is ignored here.

I.4.3 Equipment

Based upon the design conditions described above, the following equipment was proposed for the system design:

Dredge

Type	Pump dredge with ladder
Dredging depth	Max. 17 m
Dredging head	Pneuma Pump
Dredging capacity	200 cu.m/h 270 t/h (wet sediment)
Pump capacity	400 cu.m/h 475 t/h (for 50% soil concentration) 800 cu.m/h 885 t/h (for 25% soil concentration)

The most essential point for selection of the dredging head is to secure the highest soil concentration to minimize the cost of subsequent processes. For this purpose, the Pneuma Pump was selected, and the maximum dredging capacity available at the time of study was approximately 200 cu.m which was selected for this design.

Dehydrator

The following two types of equipment were selected:

- Filter Press

Water concentration in dehydrated cake	40%
Required dehydration capacity-slurry	166.5 cu.m/h (198 t/h)(*1) 333.5 cu.m/h (369 t/h)(*2)
Yield of cake	46.5 cu.m/h (75 t/h)

- Centrifugal Decanter

Water concentration in dehydrated cake	50%
Required dehydration capacity-same as Filter Press	
Yield of cake	61.5 cu.m/h (90 t/h)

*Notes 1 & 2: For soil concentration in the dredged slurry of 50% (*1) and 25% (*2), respectively.

Water Processor

Type	Either coagulator + sand filter, or tube separator + sand filter
Required processing capacity	120 (105) cu.m/h (*1) 287 (272) cu.m/h (*2)

*Notes 1 & 2: For soil concentration in the dredged slurry of 50% (*1) and 25% (*2), respectively. Figures in parentheses are for water concentration in the dehydrated cake of 50%.

SS concentration in the processed water	Less than 10 ppm
Monitoring system	Automatic recording with alarm system

The Dehydrator and Water Processor were assumed to be installed on the same floating unit (processing barge) in consideration of continuity of processing. In addition, a conveyor system was fitted on the processing barge for unloading of dehydrated cake onto a transportation barge or onto land.

Transportation Barge

Type No. and capacity	Barge with open hopper and no bottom door. See Tables I.1 and I.2

Unloader

Type	Barge with clam shell unloading grab
Capacity of clam shell	3 cu.m

This unloading barge is required in System II. In System V, the dehydrated cake is unloaded by the conveyor system aboard the processing barge.

Electric Generator (System I only)

Type	Independent diesel engine driven generator
Capacity	100 KW (for soil concentration 50%) 200 KW (for soil concentration 25%)

Electric generator is to be installed ashore at the unloading site to supply electric power to the pump aboard the transportation barges.

Summary Table of Equipment

Equipment designed for this system study is listed in Table I.1. In total, 23 units of equipment were designed initially, of which 21 were utilized to assemble the systems.

I.4.4 System Configuration and Cost Estimation

System Configuration

System configurations or combinations of processing equipment are shown in Table I.2. System II[1] is for reference to study the cost when dehydration of 10 hours per day is applied. In this case, dredged slurry is dehydrated continuously after dredging. This system requires a dehydrator with capacity of two times that of System II but the slurry holding tank may be substituted by a separated water tank smaller in size.

TABLE I.1 EQUIPMENT FOR SYSTEM DESIGN

Equipment		Principal Particulars				
I.D.	Equipment	Type	Capacity	Hull Dim. (LxBxD)	Crew	Remarks
			Pump	m		
A	Dredge	Pump dredge w. ladder	400 m^3/h	35.0 × 11.0 × 3.0	12	Soil concentration (S.C.) 50%
B			800 m^3/h			S.C. 25%
E	Pusher	Twin prop. engines & propellers	1,000 Hp	22.0 × 7.2 × 3.4		For 750-m^3 barge
F			1,200 Hp	22.0 × 8.0 × 3.4	5	For 1,350-m^3 barge
G			1,500 Hp	22.0 × 8.0 × 3.7		For 2,700-m^3 barge
			Hopper			
H	Transportation barge	Open hopper without bottom door	750 m^3	43.0 × 10.4 × 4.5		No pump, w/1,000-Hp pusher
I			1,350 m^3	56.0 × 12.0 × 4.5		w/1-pump, w/1,200-Hp pusher
J					0	w/2-pump, w/1,200-Hp pusher
K			2,700 m^3	66.0 × 15.0 × 5.5		w/1-pump, w/1,500-Hp pusher
L						w/2-pump, w/1,500-Hp pusher
			Slurry			
M	Processing barge (dehydration & water processing)	Filter press dehydration	198 t/h	63.0 × 20.0 × 7.0		w/2,400-m^3 slurry tank, S.C. 50%
N			369 t/h	88.0 × 20.0 × 7.0		w/4,800-m^3 slurry tank, S.C. 25%
O			198 t/h	50.4 × 20.0 × 7.0		No tank, S.C. 50%
P			369 t/h	64.0 × 20.0 × 7.0	15	No tank, S.C. 25%
Q		Centrifugal dehydration	198 t/h	70.0 × 18.0 × 4.5		w/1,600-m^3 water tank, S.C. 50%
R			369 t/h	75.0 × 23.0 × 5.0		w/3,300-m^3 water tank, S.C. 25%
S			198 t/h	55.0 × 17.0 × 5.5		No tank, S.C. 50%
T			369 t/h	55.0 × 17.0 × 5.5		No tank, S.C. 25%
U	Unloading barge	Clam shell	3 m^3	28.0 × 12.0 × 2.6	10	Outreach 8 m Unloading cap. 180 m^3/h
V	Generator unit	Diesel	100 KW	3.2 × 1.2 × 1.9		165 Hp - 1,800 rpm
W			200 KW	3.9 × 1.7 × 2.5	0	340 HP - 1,800 rpm

TABLE I.2 SYSTEM CONFIGURATION

Config. No.	System	Dehydration	Soil Concen. (%)	System Configuration (Alpha letters refer to equipment in Table I.1) Dr - Dredging Tr - Transportation	D.P. - Dehydration & Processing of Water UL - Unloading			Cost Ratio
1	I	None	50	Dr $400-m^3/h$ pump dredge (A)	Tr 1 1,200-Hp pusher (F) 3 $1,350-m^3$ barge (J)		UL 100-KW generator (V)	0.41
2	I		25	Dr $800-m^3/h$ pump d. (B)	Tr 1 1,500-Hp p. (G) 3 $2,700-m^3$ b. (L)		UL 200-KW generator (W)	0.46
3	II	Filter press dehyd. 24 h/d	50	Dr $400-m^3/h$ pump d. (A)	D.P. $2,400-m^3$ tk (M)	Tr 1 1,000-Hp p. (E) 3 $750-m^3$ b. (H)	UL $3-m^3$ clamshell (U)	1.20
4	II	water p. 24 h/d	25	Dr $800-m^3/h$ pump d. (B)	D.P. $4,800-m^3$ tk (N)	Tr 1 1,000-Hp p. (E) 3 $750-m^3$ b. (H)	UL $3-m^3$ clamshell (U)	1.32
5	II[1]	Centrifugal dehyd. 10 h/d	50	Dr $400-m^3/h$ pump d. (A)	D.P. $1,600-m^3$ tk (Q)	Tr 1 1,000-Hp p. (E) 3 $750-m^3$ b. (H)	UL $3-m^3$ clamshell (U)	1.53
6	II[1]	water p. 24 h/d	25	Dr $800-m^3/h$ pump d. (B)	D.P. $3,300-m^3$ tk (R)	Tr 1 1,000-Hp p. (E) 3 $750-m^3$ b (H)	UL $3-m^3$ clamshell (U)	1.61
7	V	Filter press dehyd. 24 h/d	50	Dr $400-m^3/h$ pump d. (A)	Tr 1 1,200-Hp p. (F) 3 $1,350-m^3$ b. (I)	D.P., UL processing barge (O)		1.03
8	V	water p. 24 h/d	25	Dr $800-m^3/h$ pump d. (B)	Tr 1 1,500-Hp p. (G) 3 $2,700-m^3$ b. (K)	D.P., UL processing barge (P)		1.13
9	V	Centrifugal dehyd. 24 h/d	50	Dr $400-m^3/h$ pump d. (A)	Tr 1 1,200-HP p. (F) 3 $1,350-m^3$ b. (S)	D.P., UL processing barge (S)		1.0
10	V	water p. 24 h/d	25	Dr $800-m^3/h$ pump d. (B)	Tr 1 1,500-Hp p. (G) 3 $2,700-m^3$ b. (K)	D.P., UL processing barge (T)		1.07

Cost Estimation

- Cost items

  Depreciation of initial cost
  Interest
  Manning
  Maintenance
  Fuel
  Chemicals for water processing
  Overhead and others (insurance, port dues, contingencies, etc.)

- Lifetime of equipment (assumed)

Dredge	7 years
Transportation barge	12 years
Processing barge	7 years
Unloading barge	7 years
Electric generator unit	7 years

- Estimation method

First, based on cost items and lifetime, annual cost was calculated on each unit of equipment (23 in total), and then the various system costs were determined from the proper combination of unit costs.

Estimated system cost is shown in the extreme right column of Tables I.2 and I.3 by ratio to the cost of model No. 9 of System V which was the lowest except System I.

I.4.5 Cost Comparison and System Evaluation

Cost Comparison

- Total cost by system configuration

As shown in Table I.2, configuration No. 9 of System V (Dredging-Transportation-Centrifugal dehydration and water processing-Unloading-Disposal) for dredged slurry of 50% soil concentration is the system of the lowest cost. On the other hand, the system of the highest cost is No. 6 of System II (Dredging-Centrifugal dehydration and water processing-Transportation-Unloading-Disposal).

- Averaged cost by system

System	Total cost ratio
II	1.2
II[1]	1.5
V	1.0

This indicates that System V is the most economical.

- Cost by soil concentration in the dredged slurry

Soil concentration(%)	Total cost ratio
50	1.0
25	1.1

In other words, if average soil concentration goes down to 25% from 50%, the annual cost will increase by 10%.

- Cost by dehydration method

Method	Total cost ratio
Press Filter	1.04
Centrifugal Decanter	1.0

- Cost ratio by equipment (Table I.3)

Table I.3 shows percentage of annual cost for each unit of equipment compared to the total cost. Of the equipment, the processing barge is the most costly, requiring 60 to 70% of the total annual cost.

- Itemized cost ratio

In the case of System V with soil concentration of 50% in the dredged slurry, the cost percentage of each item to the total cost is as follows:

Item	Press dehydrated	Centrifugal dehydrated
Depreciation	25	22
Interest	23	21
Manning	5	5
Maintenance	28	24
Fuel	2	6
Chemicals	0	5
Overhead, others	17	17
Total	100	100

System Evaluation

As described above, System V (Dredging-Transportation-Dehydration and water processing-Unloading) was the most economical system. This is because:

- System II and II[1] require an unloading barge independent of other equipment, while in System V dehydrated cake is unloaded by conveyor system aboard the processing barge.

TABLE 1.3 COST RATIO BY EQUIPMENT

Configuration No.	System	Dehydration	Soil concent. (%)	Cost by Equipment (%) Dredge	Pusher	Processing barge	Unloading barge	Generator unit	Total	Cost ratio by configuration
1	I	None	50	63	36	--	--	1	100	0.41
2			25	60	38	--	--	1	100	0.46
3	II	Filter press	50	21	10	60	9	--	100	1.20
4			25	21	9	62	8	--	100	1.32
5	III	Centrifugal	50	17	8	69	7	--	100	1.53
6			25	17	7	69	6	--	100	1.61
7	V	Filter press	50	25	14	61	--	--	100	1.03
8			25	25	16	60	--	--	100	1.13
9		Centrifugal	50	26	15	60	--	--	100	1.0
10			25	26	16	58	--	--	100	1.07

- System V requires less tankage than II and II[1], thus the processing barge can be smaller.

Higher soil concentration in the dredged slurry reduces the total cost but the rate of cost increase due to reduction in soil concentration is not so drastic. It is noteworthy that low cost dredging, with rather low or medium soil concentration, would lower the total dredging cost.

System I, without dehydration and water processing, used as a reference, showed relatively lowest cost. This study did not include land reclamation costs, which should not be neglected in an actual case.

I. 5 CONCLUSIONS

The Committee concluded, at the time of this study, that the most economical system for dredging and processing of loose sediment containing toxic materials consists of the following sequence of component processes:

1. Dredging.
2. Transportation of dredged slurry-mixture of sediment and water.
3. Dehydration of dredged slurry and processing of separated water to discharge overboard.
4. Unloading of dehydrated cake to the land.
5. Disposal of unloaded cake (reclamation).

Although such a system has not yet been implemented, it is our hope and expectation that this study will pave the way to utilizing an effective system of dredging and processing of toxic sediments to the ultimate benefit of society.

PART II. ANTI-TURBIDITY OVERFLOW SYSTEM FOR A HOPPER DREDGE

II.1 PREFACE

Another serious problem about protection of the environment is turbidity accompanying dredging operations, especially hopper dredges.

Turbidity is defined as contamination or disturbance of water caused by dirty substances like dredged sediments or sludge.

In dredging operations by a hopper dredge, the excess water in the hopper is discharged overboard in the interest of high dredging efficiency. However, this produces turbidity of the seawater around the dredge and, by the action of tidal currents, winds, or trailing of the dredge itself, the disturbance is often spread over a wide area. Should some resort beach, fishing grounds, or marine cultivation farm (for seaweeds, pearls, or fishes) be in the proximity of the dredging site, the turbidity may cause serious damage. In some areas in Japan, where trailing hopper dredges have been engaged in dredging of harbors or navigation channels near seaweed cultivation farms, the dredging operations were sometimes restricted or suspended because of this problem.

In light of this problem, a joint study was made by Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI), the shipbuilder, and Tokushu-Shunsetsu Co., Ltd., the owner and operator of a hopper dredge. As a result, the Anti-Turbidity Overflow System (ATOS), which effectively prevents turbidity of the sea surface in hopper dredge operations, was developed and retrofitted on all the hopper dredges with hopper capacity of 1,000 cu.m and above now working in Japan.

ATOS was first introduced to the world in an award-winning paper given at the Seventh World Dredging Conference, San Francisco in July 1976. Since then, some improvements have been added to ATOS and tests have been conducted to collect further data to confirm the effects of ATOS. This paper reviews the development of ATOS first and then discusses the additional test data and analysis.

ATOS has been highly accepted in Japan and commended by the Secretary General of Science and Technology Agency, 1976, and by the Minister of Transport, 1980, for its contribution to sea environment preservation.

II.2 CONVENTIONAL OVERFLOW SYSTEM

The conventional overflow system most widely used now discharges the overflowed water onto the sea surface (Figure II.1) making the surrounding sea surface turbid (Figure II.2).

Another type of conventional overflow system is shown in Figure II.3 where an overflow chute is led to an underwater port on the hull side or bottom through which the excess muddy water is discharged. It would be expected that the sand particles or other substances contained in the muddy water might

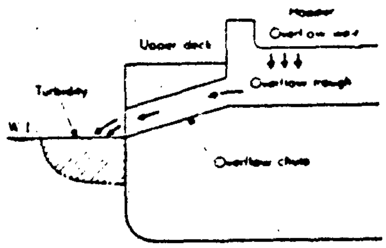

Figure II.1 Conventional overflow system (Ex. 1)

Figure II.2 Overflow of muddy water and turbid sea surface

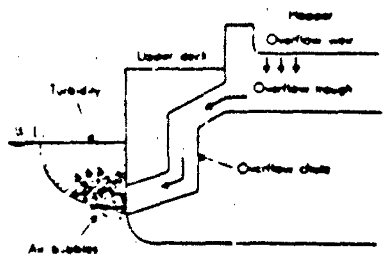

Figure II.3 Conventional overflow system (Ex. 2)

settle toward the seabed without causing turbidity of the sea surface. But this is actually not the case, as the disturbance rises up to the water surface (Figure II.4) and spreads widely over the surrounding area with little improvement in the turbidity problem (Figure II.5).

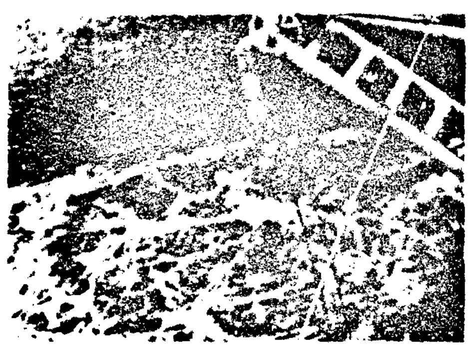

Figure II.4 Overflow through a chute opened underwater

Figure II.5 Turbidity abaft dredge

A third system is similar to the second one but with the overflow chute extended well below the hull bottom so as to discharge the water free of the agitation caused by the stern propeller. But this system is not as effective as would be expected either.

Figure II.6 shows an example of spreading of turbidity measured by aerophotography in the case of a 500-cu.m hopper dredge "Daisen-Maru" engaged in dredging silty sand off Sakaiminato, Tottori prefecture, northwestern part of Honshu Island, Japan. As shown here, turbidity remained on the sea surface for a long time and spread over a wide area as time passed.

Precisely how is the sea surface made turbid by the muddy water overflowed through various types of overflow systems? To answer this question and to probe into the mechanism of the turbidity and thereby devise a countermeasure to suppress the turbidity, model experiments were conducted and followed by actual dredging tests.

II.3 ANTI-TURBIDITY OVERFLOW SYSTEM (ATOS)

In this section, the develpment of ATOS is briefly reviewed. References (1) and (2) provide more details.

II.3.1 Model Experiments and Mechanism of Turbidity

Using 1/20 scale models of overflow system of "Tokushun-Maru No. 1," a 4,000-cu.m trailing hopper dredge, a series of model tests was carried out to probe into the mechanism of turbidity by simulating overboard discharge of the excess water, in some cases mixing fine sand into the overflowing water.

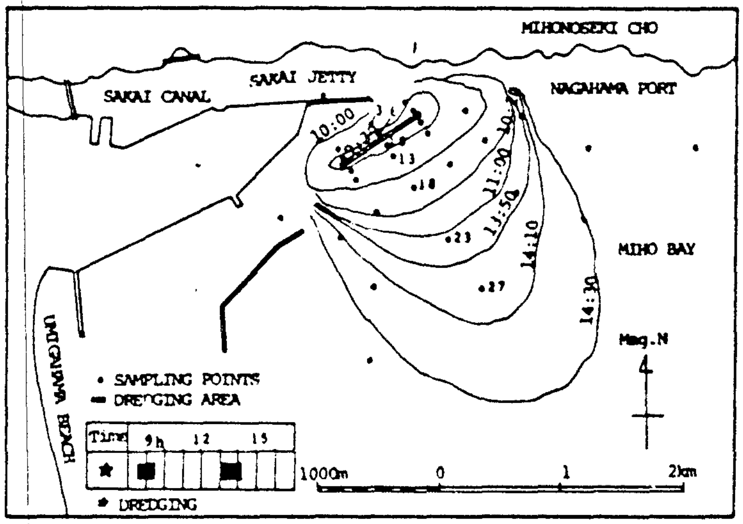

Figure II.6 Result of investigation on a turbidity spreading

As a result of the model experiments, the turbidity of the water surface was inferred to be attributable to an "air-lift" phenomenon with air bubbles contained in the overflowed water. In the overflow process, numerous air bubbles are generated and entrained into the overflowed water and discharged overboard, where the air bubbles well up to the water surface forcibly lifting surrounding solid particles, resulting in turbidity of the water surface. Accordingly, the turbidity of the sea surface was presumed to be preventable by the elimination of air bubbles from the muddy water discharged overboard, thus allowing solid particles of sand or other substances to settle rapidly toward the sea bottom.

Based upon this conviction, the Anti-Turbidity Overflow System was developed and retrofitted on "Tokushun-Maru No. 1" for an actual dredging test.

II.3.2 Anti-Turbidity Overflow System (ATOS)

The model experiments suggested that the overboard discharge of air bubbles could be prevented by three countermeasures:

(1) Minimizing the generation of air bubbles in the process of overflow,

(2) Removing air bubbles, if generated, from the overflowed water before they are discharged overboard,

(3) Discharging the overflowed water (once made free of air bubbles) with care to prevent entraining of air again.

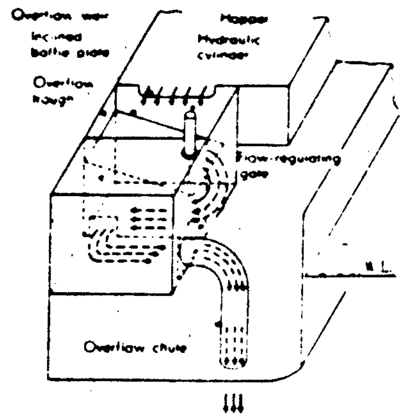

Figure II.7 Anti-Turbidity Overflow System

The Anti-Turbidity Overflow System (ATOS) shown in Figure II.7 embodies these three countermeasures, each of which is discussed below:

(1) The inclined baffle plate in the overflow trough receives the overflowed water before it gains falling energy and streamlines the flow, thus suppressing the generation of air bubbles.

(2) The overflow trough is divided into two parts to give the flow longer passage to permit the flowing water to remain in the trough long enough for the air bubbles still entrained to float up to the water surface and disperse. The flow-regulating gate, the essential part of ATOS, located at the entrance of or in the overflow chute, keeps the water in the overflow trough above a certain level. Model experiments showed that the water in the overflow trough must be maintained above a certain level to allow air bubbles to float up to water surface and disperse into the atmosphere before they reach the entrance of the overflow chute. The flow-regulating gate, driven by a hydraulic cylinder, is controlled remotely or automatically in response to a signal from a level gauge installed in the overflow trough.

(3) The overflow chute is enclosed and opened to the bottom of the dredge. The air could not be entrapped again and solid particles in the muddy water settle toward the sea bottom rapdily.

The successful application of ATOS to full-scale dredging operations is described in Section II.4.

II.3.3 Installation, Retrofitting, and Operation of ATOS

As described above, the configuration of ATOS is rather simple and ATOS can be readily installed on a new dredge during construction or retrofitted on existing dredges in service. In new construction, ATOS can easily be provided for during the normal design phase.

The operation of ATOS does not require special skill or experience because the remote or automatic control of the flow-regulating gate is the only apparatus to be adjusted during operation.

Figures II.8 and II.9 show the ATOS retrofitted on "Hakusan-Maru," a 1,300-cu.m hopper dredge owned by Ministry of Transport, Japan, and a diagram of automatic control, respectively.

The overflow trough near the chute inlet is fitted with an ultrasonic level sensor to transmit signals to the control board where the level transmitted is compared with the predetermined high level and low level. When the level goes out of the range between the high and low level, the control board automatically sends a signal to the hydraulic power unit to move the flow-regulating gate so as to bring the water level in the trough within the preset range.

Normally, the flow-regulating valve is operated between upper and lower points set by limit switches for smooth and precise regulation. Should the water level go higher than the upper alarm level or lower than the lower alarm level unexpectedly because of an abrupt change in flow volume or other reasons, the regulating gate is instantly opened fully or closed (as required) to prevent the overflow of muddy water beyond the hopper coaming, or overboard discharge of air bubbles. Quick and precise response to fluctuation of water level is a vital feature of this automatic control system, and ultrasonic sensing was selected in consideration of this and other favorable features.

The automatic control system of ATOS on "Hakusan-Maru" has been reported to be working smoothly and without trouble.

II.3.4 Dredges with ATOS

Since the introduction of ATOS, four out of five hopper dredges now in service in Japan have been equipped with ATOS. Table II.1 lists those four dredges with their pincipal particulars. In addition, the fifth dredge "Kairyu-Maru" (replaced by "Seiryu-Maru") was tentatively equipped with ATOS for dredging tests.

"Seiryu-Maru," the latest dredge, was equipped with ATOS from "birth." The other three dredges were retrofitted with ATOS, taking advantage of the time out of service for annual drydocking.

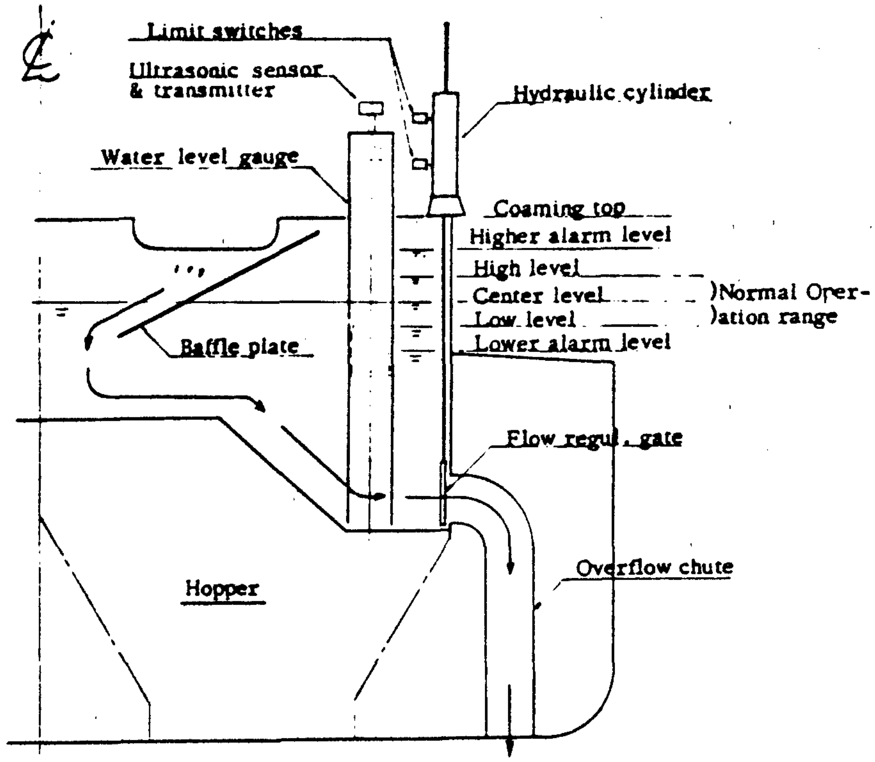

Figure II.8 Overflow system of "Hakusan-Maru"

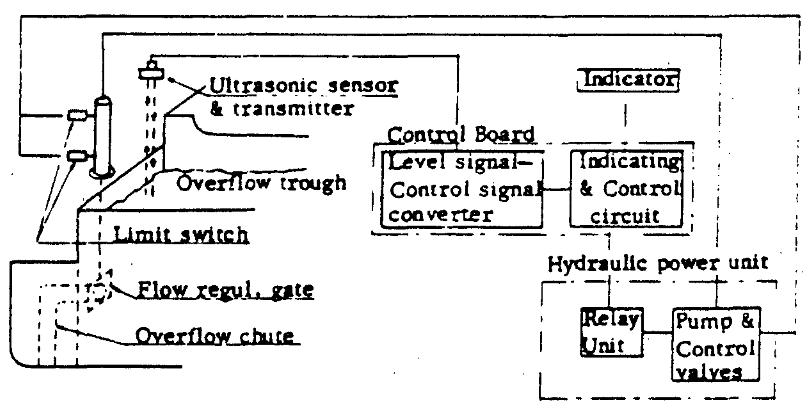

Figure II.9 Control diagram for automatic operation

II.4 EFFECTIVENESS OF ATOS WITH ACTUAL DREDGES

The effectiveness of ATOS has been confirmed by a series of actual dredging tests with the following hopper dredges.

II.4.1 "Tokushun-Maru No. 1"

This is the first hopper dredge equipped with ATOS. The effectiveness was very conspicuous on this dredge. As shown in Figure II.10, sea surface turbidity cannot be seen. Data on SS (suspended solid) concentration in the water sampled at 5 m below the sea surface around the dredge (when dredging soil of mostly sand) varied from 2 to 9 ppm, which is just slightly higher than before dredging. This fact implies that sand particles in the overflowed water settled directly toward the sea bottom after overboard discharge without causing surface turbidity.

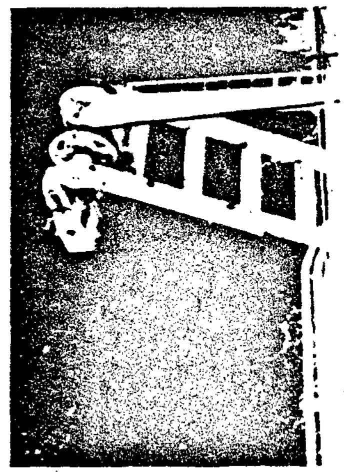

Figure II.10 Clear surface side by "Tokushun-Maru No. 1" with ATOS

II.4.2 "Kairyu-Maru"

This 2,000-cu.m hopper dredge was engaged in maintenance dredging of navigation channels in Nagoya Harbor where the seabed is covered with silt and clay mixed with sludge, i.e., soils of very small particles. To collect basic data for the planning of ATOS for a new dredge to be built (later named "Seiryu-Maru"), a series of dredging tests with "Kairyu-Maru" was carried out by the Fifth Port and Harbor Construction Bureau, MOT, and the Japan Work-vessel Association. ATOS was installed on the port side with the conventional overflow system on the starboard side to compare the effects of both systems under identical conditions.

Three cases were studied - overflowing the muddy water independently through ATOS and through the conventional system, respectively, and simultaneously through both systems. For each case, the transparency of the seawater at both sides of the dredge as well as at the stern was measured. In addition, seawater at the surface and 1 m below the surface was sampled for SS measurement.

TABLE II.1 JAPANESE HOPPER DREDGES EQUIPPED WITH ATOS

Descriptions	NAME OF DREDGE (Builder)			
	Kaiho Maru (IHI)	Hakusan Maru (IHI)	Tokusyun Maru No. 1 (IHI)	Seiryu Maru (MHI)
Length (b.p.)	85.00m	70.00m	106.00m	88.00m
Breadth	16.00m	13.50m	19.60m	16.00m
Depth	7.00m	6.00m	9.00m	7.20m
Draft (loaded)	5.80m	4.70m	6.90m	5.60m
Gross Tonnage	3,212t	2,181t	6,251t	3,526t
Speed	13.27kt	12.15kt	15.61kt	13.29kt
Dredging Depth (max)	17.0m	17.5m	27.0m	22.0m
Hopper Capacity	2,052m^3	1,355m^3	4,091m^3	1,700m^3
Propulsion Motors	1,000kW × 2	(Engines for Main Generator)	(Engines for Main Generator)	1,300kW × 2
Main Generators	1,520kW × 2	560kW × 2	1,480kW × 2	2,000kW × 2
Engines for Main Generators	2,400ps × 2	1,400ps × 2	4,700ps × 2	3,000ps × 2
Dredging Pumps	5,000m^3/h × 17m × 2	3,000m^3/h × 16m × 2	8,000m^3/h × 17m × 2	4,100m^3/h × 17m × 2
Crew	61	47	55	53
Date of Construction	1964	1965	1970	1978
Owner	Ministry of Transport	Ministry of Transport	Tokusyu Syunsetsu Co., Ltd.	Ministry of Transport

Figure II.11 Turbidity side by "Kairyu-Maru" without ATOS

Figure II.12 Clear sea surface side by "Kairyu-Maru" with ATOS

The results proved that ATOS is very effective against soil of small particles like silt and clay. Figure II.11 shows the turbid sea surface on the starboard side where the muddy water overflowed through conventional overflow system, while no turbidity can be seen either at the side or stern when overflowed through ATOS as shown by Figures II.12 and II.13. Table II.2 lists water quality data accumulated through these tests. Whereas the water quality at the sea surface is conspicuously deteriorated by overflowed water with the conventional overflow system, the excess water discharged through ATOS hardly degrades the water quality.

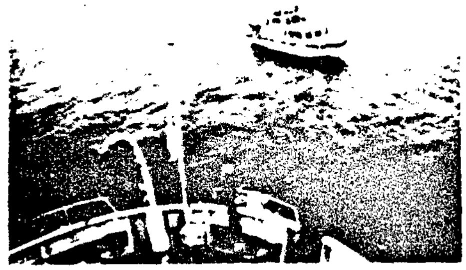

Figure II.13. Clear sea surface abaft "Kairyu-Maru" with ATOS

Figure II.14 shows the contrast in water quality, with and without ATOS, more clearly. SS concentration without ATOS went up rapidly with repeated dredging while it remained at the same level with ATOS throughout the tests.

II.4.3 "Kaiho-Maru"

ATOS retrofitted on "Kaiho-Maru" was tested by the Port and Harbor Research Institute together with the Fourth Port and Harbor Construction Bureau, MOT (3) (4). In the test with "Kairyu-Maru," seawater was always sampled at the side and abaft the dredge during dredging; in other words, the sampling spots moved with the dredge. Contrary to that case, sampling spots for "Kaiho Maru" were fixed at four positions (E, G, F, D), located downstream of the tidal current from the dredging site as shown in Figure II.15.

TABLE 11.2 QUALITY OF SEAWATER SAMPLED AT SIDE BY "KAIRYU MARU"

Test items	Test No.	Conventional overflow system				Anti-turbidity overflow system			
		Before overflow		During overflow		Before overflow		During overflow	
		Sea surface	1M below sea surface	Sea surface	1M below sea surface	Sea surface	1M below sea surface	Sea surface	1M below sea surface
Concentration of suspended solid (SS) (PPM)	1	9.0	8.0	370	370	3.5	5.0	8.5	10.0
	2	--	--	510	380	--	--	6.3	6.3
	3	4.5	10.0	85	190	6.5	6.5	1.6	6.3
	4	--	--	2000	410	--	--	7.0	6.6
	5	--	--	170	110	6.0	5.5	7.5	9.5
	6	--	--	--	--	--	--	5.0	10.5
	Avg.	6.8	9.0	627	272	5.3	5.7	6.0	8.2
Transparency (M)	1	1.25		0.30		1.70		1.80	
	2	--		0.40		--		1.90	
	3	1.40		0.30		1.60		1.80	
	4	--		0.05		--		1.60	
	5	--		0.20		1.70		1.70	
	6	--		--		--		1.60	
	Avg.	1.33		0.25		1.67		1.73	

Note: Some figures of transparency in case of overflow through the Anti-turbidity overflow system are greater than those of before the overflow. This is considered to be due to a slight difference in sampling spot of seawater.

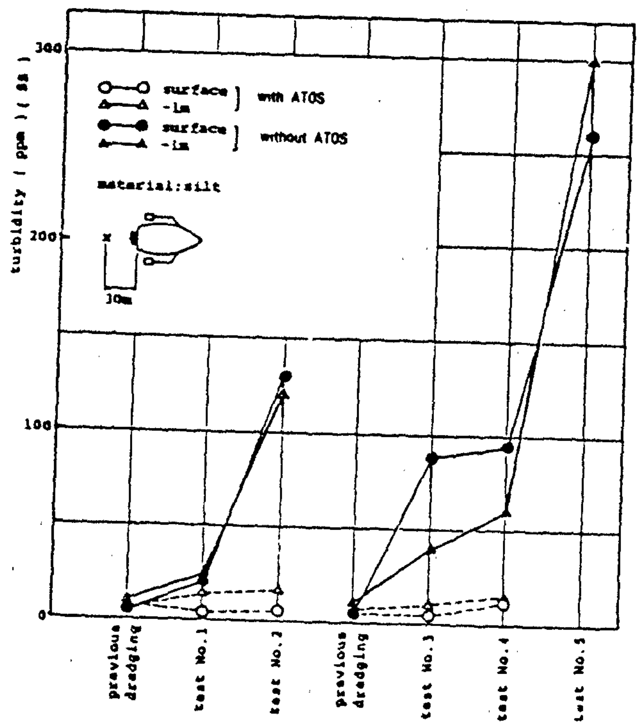

Figure II.14 Effect of ATOS on water quality, dredge "Kairyu Maru"

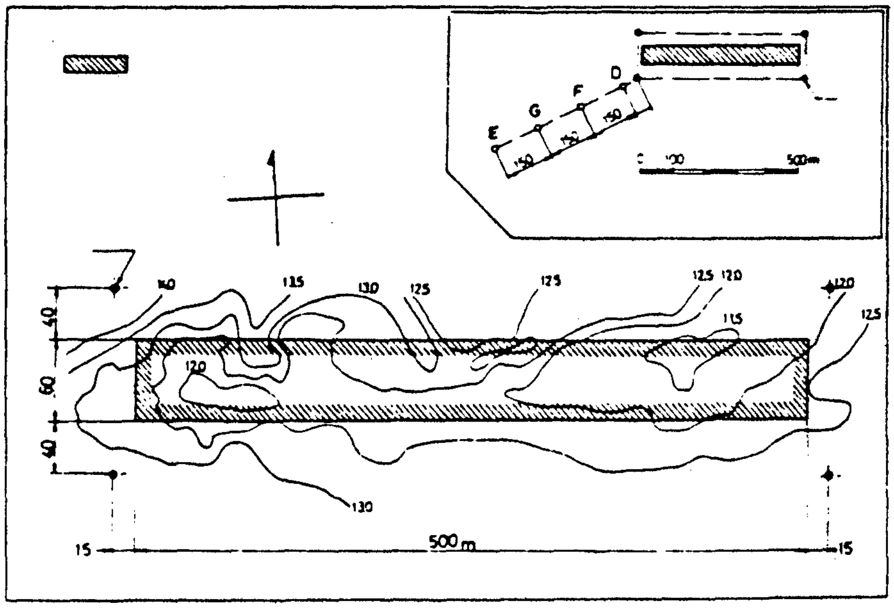

Figure II.15 Dredging site and sampling spots

At each spot, a sampling boat was assigned to sample seawater at depths of 0.5m, 3m, 5.5m, 8.0m, 10.5m, and 13m, as well as at the surface. Figure II.16 shows turbidity and sampling boats during the tests. The dredging site (Fig. II.15) was located in the middle of Kan-mon Strait, known for its swift current. Dredged material was silty sand.

Figure II.16 Dredging tests with "Kaiho-Maru"

An analysis of SS concentration in the sampled water is graphed in Figure II.17.

Without ATOS, turbidity increased with repeated dredging and SS concentration reached as high as 400 ppm at the end of the dredging tests. With ATOS, turbidity increased little at every depth and SS remained nearly constant at a level of 10 ppm. In this test, vertical distribution was also determined and a distribution pattern as illustrated in Figure II.18 is derived from theoretical analysis based on the collected data (4). ATOS has another

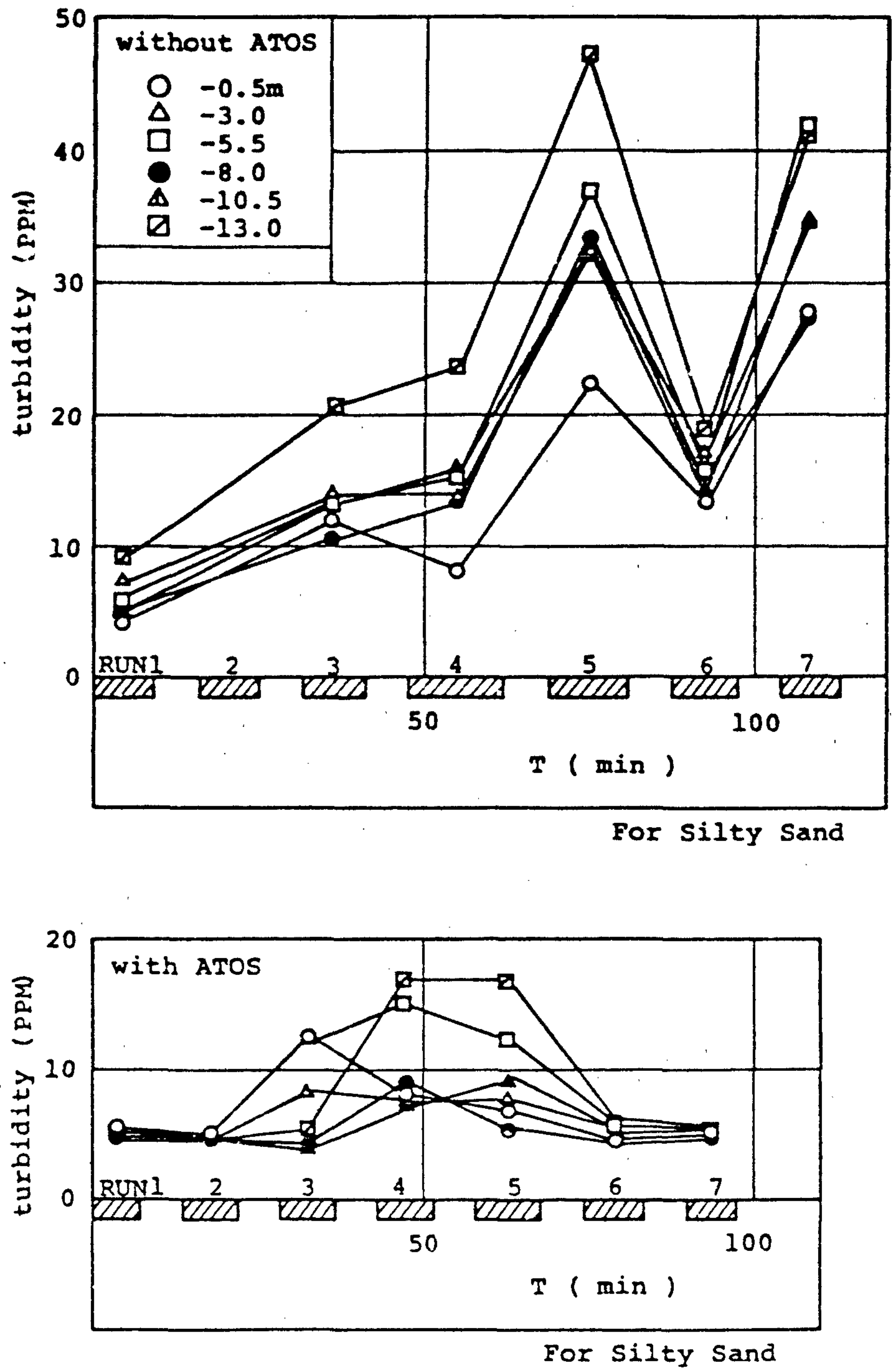

Figure II.17 Effect of ATOS on water quality, dredge "Kaiho Maru" (at point D)

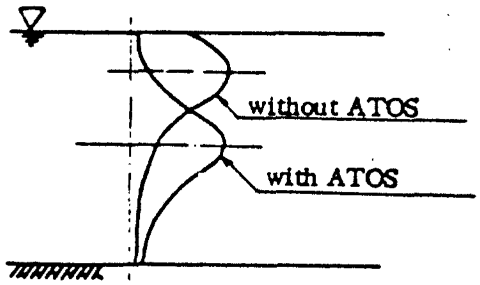

Figure II.18 Vertical distribution of turbidity

effect: the lowering of the distribution of turbidity well below the water surface. This implies reduction of the spreading of turbidity, because, in an area like an estuary where continuous maintenance dredging is required, the current velocity decreases as the water depth increases.

II.4.4 Other effects of ATOS

In trailing hopper dredges, seawater is used for cooling engines and various heat exchangers, fire fighting, washing, ballasting, etc. Seawater for all these purposes is taken by pumps through suction inlets on or near the hull bottom under the machinery room, normally located aft of the overflow chute. As easily understood, solid particles contained in the overflowed water could clog the strainers or filter in the pump suction line or damage pump impellers or packing. With ATOS, such solid particles settle rapidly toward the sea bottom before reaching the suction inlets, thereby avoiding these problems.

II.5 CONCLUSIONS

Through actual dredging tests, ATOS has proved to be very effective for preventing the turbidity of the sea surface that accompanies conventional dredging operation by hopper dredge.

To obtain the advantages of ATOS, the following three conditions must be carefully studied before application:

(1) The suppression of the generation of air bubbles in the process of overflow by providing an inclined baffle plate or other similar measures.

(2) The retention of the overflowed water above a certain level in the overflow trough at a speed slow enough for the ai. bubbles to rise up to the water surface and disperse into the atmosphere. But the flowing speed should not be too slow to avoid settlement of solid particles in the trough.

(3) The discharge of muddy water overboard underwater, preferably to the dredge bottom, through an enclosed chute to avoid contamination with open air, i.e., to prevent air bubbles from being entrained again.

Fortunately, ATOS has been welcome in Japanese dredging circles as a means of easing social problems. Japan is known for its fisheries and there are many cultivation farms or beds of yellowtail, pearls, or seaweed, etc., all of which are vulnerable to dirty water. Should turbid water flow into such farms or beds, the dredging operation would be subject to instant suspension resulting in social problems. As a matter of fact, "Kaiho Maru" was to be in such trouble before being equipped with ATOS, but she has been able to continue maintenance dredging in the Strait of Kan-mon where fertile cultivation farms of seaweed exist near the dredging site.

So far, ATOS has contributed to the easing of social problems arising from turbidity, but efforts for possible improvement of ATOS or development of other systems to prevent sea pollution will be continued by all people concerned with the problem in Japan.

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MOUNT ST. HELENS ERUPTION, CORPS OF ENGINEERS RESTORATION EFFORTS

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ABSTRACT

On 18 May 1980, Mount St. Helens in Washington State experienced a large magnitude volcanic eruption, which severely impacted the surrounding area and the channels of major streams having their sources near the mountain. One of the more significant impacts was the filling in of the flood control and navigation channels of the Cowlitz and Columbia Rivers. Immediately thereafter, the Corps of Engineers undertook a massive program to restore both navigation and flood carrying capacity of these streams. This paper summarizes primarily the dredging efforts and briefly addresses other Corps of Engineers activities as well.

INTRODUCTION

In late March 1980, Mount St. Helens in southwest Washington State began exhibiting earthquakes and minor steam and ash ejections, signaling a new era of activity for the 123-year dormant volcano. Minor eruptions continued, becoming larger as the weeks passed, resulting in a massive and explosive eruption on Sunday morning, 18 May 1980. On that morning, two magnitude 5 Richter scale earthquakes occurred at 8:32 and 8:34 Pacific Daylight Time. The upper north flank of the mountain, which for a few days previously had bulged outward as much as five feet per day, gave way in an immense landslide, instantaneously releasing the pressure of a plug of gas-charged magma that had risen within the crust below the volcano.

The eruption and blast disgorged an estimated four billion cubic yards of material from the top and center of the mountain, lowering its height by more than 360 meters and forming a huge crater more than a 1.6 kilometers in diameter. It is estimated that approximately one quarter of the three billion cubic meters of material emerging from the mountain was dispersed into the atmosphere in the form of volcanic ash which settled in varying thicknesses over hundreds of square miles to the northeast of the volcano. As much as five centimeters was recorded in some communities in eastern Washington, with thicknesses of 1 to 4 millimeters recorded in communities in Idaho, Montana, and Wyoming. Figures 1 and 2 show Mount St. Helens before and after the eruption.

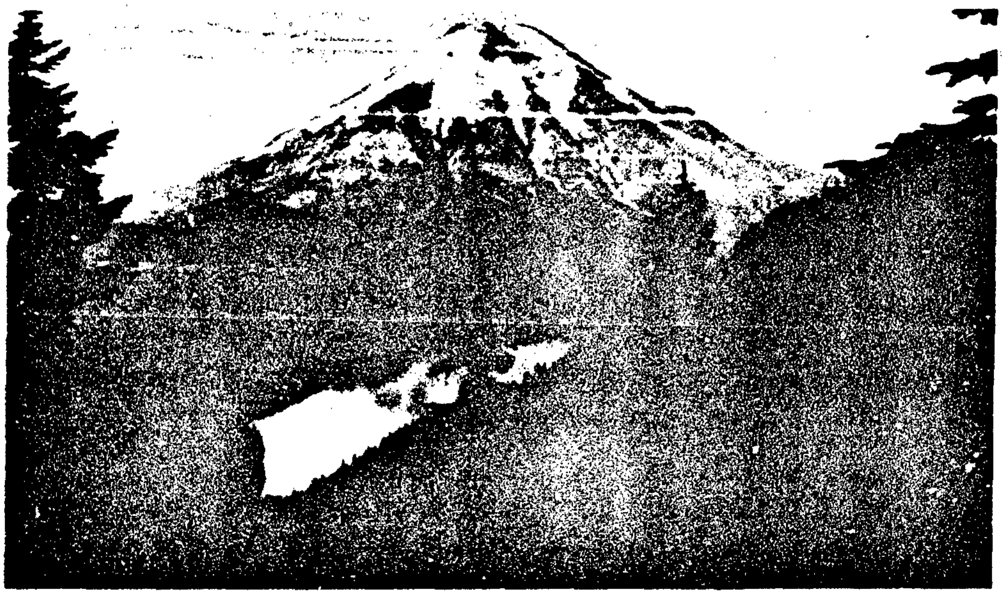


Figure 1. Mount St. Helens and Spirit Lake before eruption

Figure 2. Mount St. Helens and Spirit Lake after eruption

As shown on Figure 3, the blast and resultant mud and pyroclastic flows from the mountain's north side impacted the river basins of the Toutle, Cowlitz, and Columbia Rivers. It is estimated that approximately 3.2 billion cubic meters of material settled in the upper 22 kilometers of the north fork of the Toutle River, with a much smaller but still staggering 45 million cubic meters settling in the upper reaches of the south fork of the Toutle River. Mudflows in the following 24 hours, buoyed by melting mountain ice and waters displaced from upper Toutle River channels, carried more than 38 million cubic meters of material into 34 kilometers of the Cowlitz River from the mouth of the Toutle downstream, and deposited an additional 35 million cubic meters in the Columbia River, upstream and downstream of the mouth of the Cowlitz River near Longview. Those flows and volumes occurred in less than a 24-hour period after the eruption. The Toutle and Cowlitz rivers experienced two successive flood crests, the second crest occurring early on 19 May. At Castle Rock, it equaled a 250-year frequency flood. This flow came from less than one fourth of the river basin's drainage area. Columbia River infill took place between the hours of midnight and 5:00 a.m. on 19 May.

It is difficult to conceive of the tremendous volumes of material moving in the river channels in so short a period of time. Flood profiles did not exceed previous record flood levels in the Cowlitz and Columbia Rivers, although they did approach major flood levels in the Cowlitz River above Longview and Kelso. Mudflows in the lower river did not build up at any one location, but resulted in uniform layers of sand and gravel and other debris deposits throughout the floodplain of the lower Toutle and lower Cowlitz River valleys. Instead of the normally stained high-water marks as experienced in rainfall floods, almost everywhere the water flowed in the lower Cowlitz and Toutle rivers a dense layer of ash, sand, and gravel was left. What occurred could be likened to a large volume of material, with the consistency of "pancake batter," flowing at a high rate of speed along river valley floors and simply leveling out and settling as the flows continued downstream. Figures 4 and 5 show results of physical analysis of the mudflow materials deposited in the Cowlitz and Columbia Rivers. Figures 6 and 7 show the Toutle and Cowlitz River valleys after the floods.

WATER QUALITY IMPACTS

On the day of the eruption the massive mudflow into the North Fork and South Fork of the Toutle River not only resulted in enormous sediment transport, but also, because of the pyroclastic nature of much of the mudflow material, water temperatures in the river raised drastically. On 19 May it has been established that at the mouth of the Toutle River where it enters the Cowlitz River approximately 64 kilometers from the base of the mountain, temperatures were in the neighborhood of the 32 and 33° centigrade. Turbidity levels were nearly immeasureable; and measured suspended sediments peaked at between 1-1/2 and 2 million miligrams per liter for a peak river flow of approximately 1,700 cubic meters per second. On the following day, 20 May, temperatures and suspended sediment loads tapered off, but nonetheless, suspended sediment loads were well above 1 million miligrams per liter with corresponding river flows of only 60 or 90 cubic meters per second. For those two days there was more than 150 million tons of sediment passing from the Toutle River into the Cowlitz River. Turbidity levels at the Longview

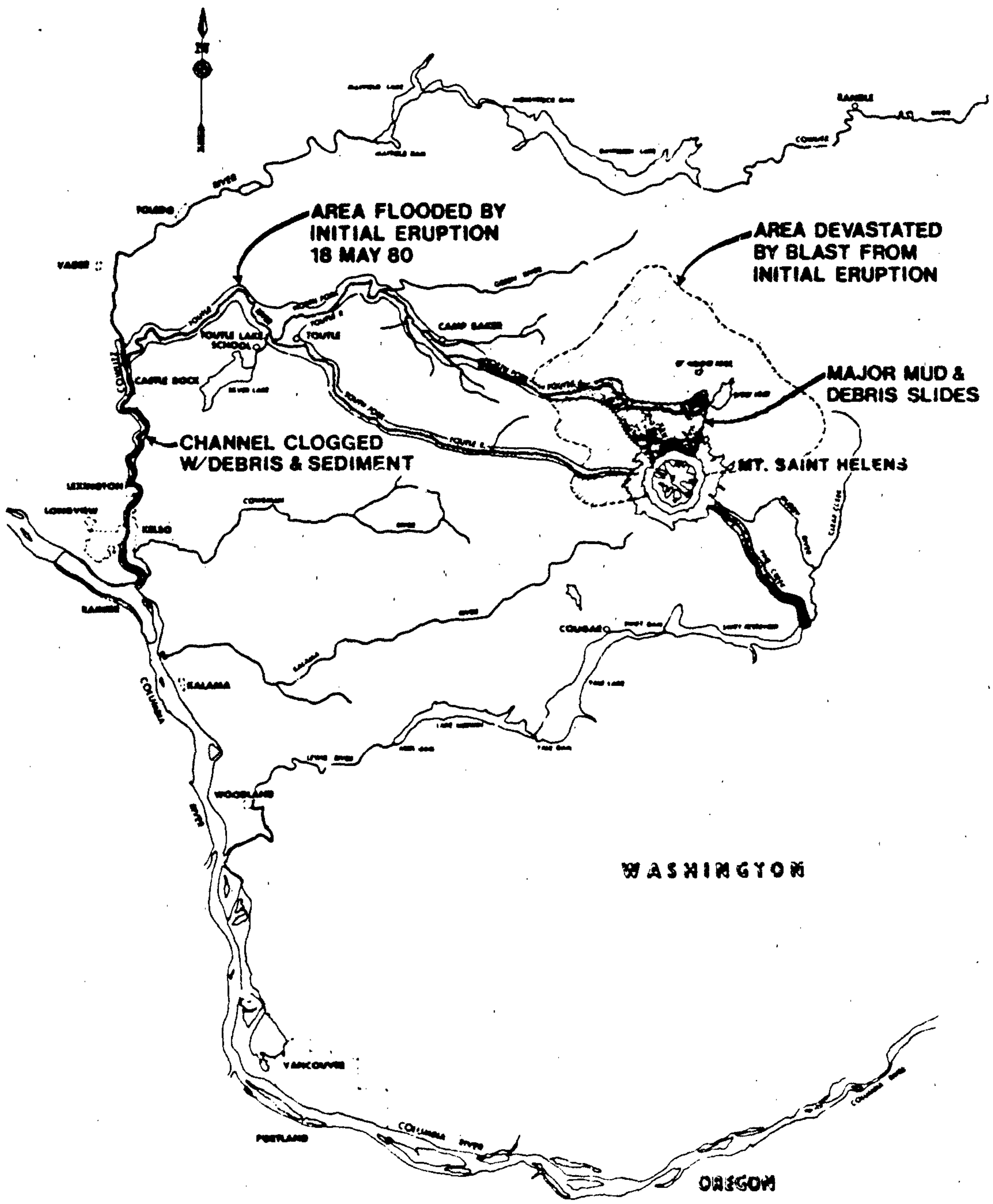


Figure 3. Area affected by eruption of Mount St. Helens

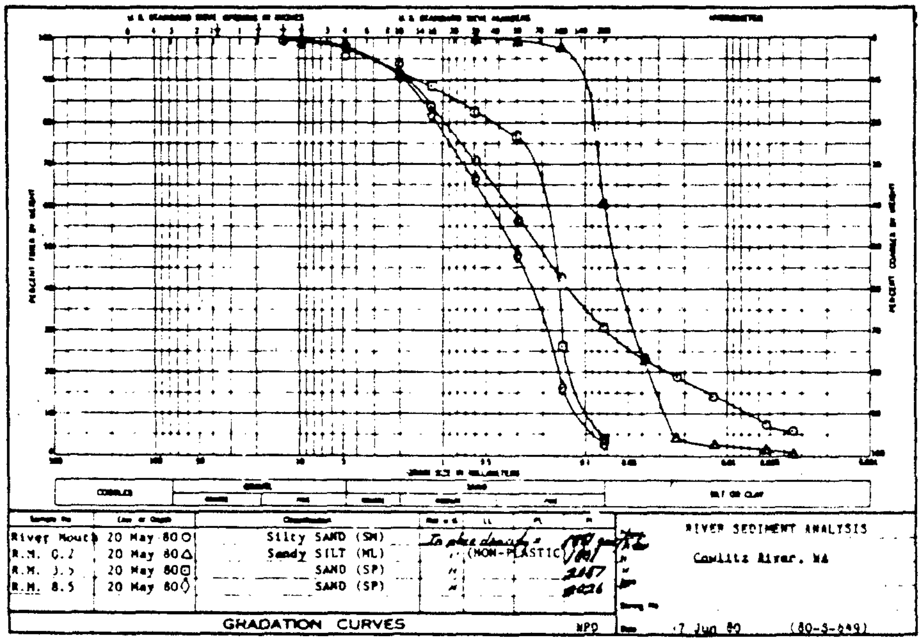


Figure 4. Physical analysis, Cowlitz River

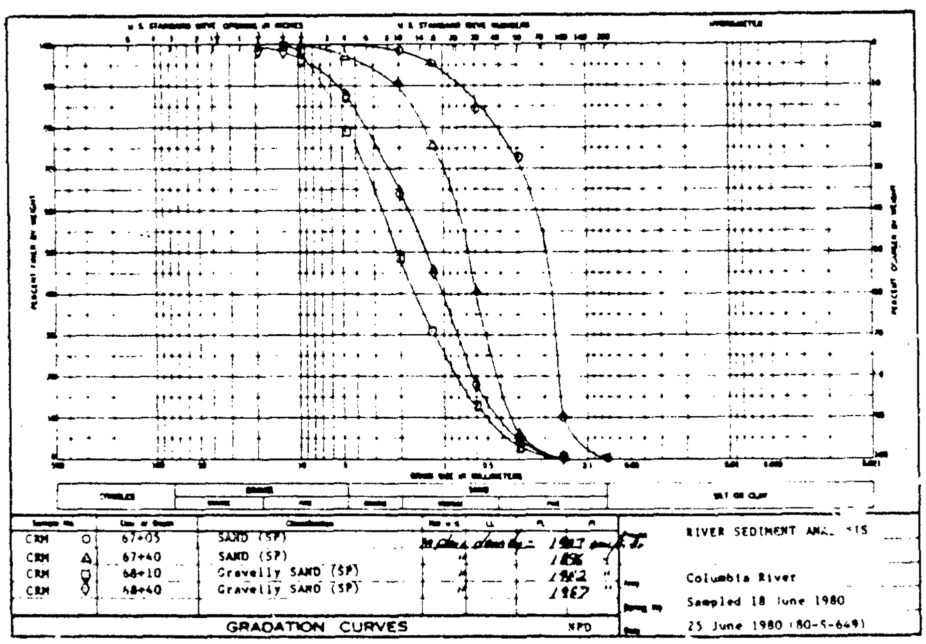


Figure 5. Physical analysis, Columbia River

water system plant, 24 kilometers downstream from the mouth of the Toutle River,on 19 May were above 50,000 JTU's (almost immeasureable). Water temperatures on 19 May in the Cowlitz River at that location were also above 30° centigrade. Water temperatures for the next few days quickly reduced to near normal levels of 8 to 15° centigrade, while suspended sediment loads reduced from 10 to 20 thousand milligrams per liter for the first week and gradually continued at fairly significant rates of from 6 to 15 thousand milligrams per liter with isolated peaks of 30 or more thousand milligrams per liter in following months. During infrequent rainstorms over the winter of 1980-1981, suspended sediment concentrations would increase significantly for several days and turbidity readings would often approach 7 to 8 thousand JTU's. During the summer of 1981, one year after the eruption, suspended sediment readings reached low points of 15 to 20 milligrams per liter with corresponding turbidity readings of near normal 5 to 7 JTU's. With the exception of the first few days after the eruption in May of 1980, dissolved oxygen readings were generally near the normal in a range of 8 to 12 milligrams per liter. There are no readings recorded for the first few days after the eruption for dissolved oxygen levels.

FISHERIES IMPACT

The initial high temperatures caused in the Toutle and lower Cowlitz Rivers by the eruption of 18 May immediately resulted in the killing of essentially all fisheries resources in those portions of the Toutle and Cowlitz Rivers impacted. Temperature readings of above 30 - 33° centigrade were recorded the day after the eruption in the lower Toutle River and near that figure in the lower Cowlitz River. Although those temperatures subsided rapidly in following days, the damage had already been done and fishery resources were essentially eliminated. Because of the continued high levels of sediment transport and turbidity readings experienced throughout the summer of 1980 and the fall of 1981, fisheries interests were fearful about the survial of fish attempting to return up these tributaries from the ocean and the Columbia River. However, in July of 1980, only six weeks after the eruption, Washington State Game Department officials used electroshocking techniques in the Green River, a tributary of the North Fork of the Toutle River, to ascertain the potential existence of fishery stocks. To their pleasant surprise, they encountered significant numbers of steelhead that could only have originated from Columbia River waters in the intervening period. This is especially significant because turbidity levels were still in the neighborhood of many thousands JTU's and up until this time those levels had been reported as potentially fatal to anadromous fish species. Late in the summer and early fall of 1980, the fall chinook and coho run from the ocean up the Columbia River also proved to be near record proportions and the runs entered the Cowlitz and traversed to the Toutle River in large numbers. So many of these fish returned to the hatchery sites on the Green and Cowlitz Rivers that the Game Department opened a special season for gill netters at the mouth of the Cowlitz in the fall of 1980 to harvest the excess numbers of those fish. Again, turbidity levels were at significant levels in the lower Cowlitz and Toutle river basins, but appeared to have no impact on the returning trends for these anadromous fish. In the late fall of 1980 and early winter of 1981, the traditional smelt run was observed in the Columbia River. Since smelt, although being an anadromous type species, are not prone

Figure 6. Toutle River valley after high density flood

Figure 7. Cowlitz River valley after eruptive floods (note how mobile homes floated on mudflow)

to return to their exact place of birth, but rather will often enter into any suitable stream to their liking, it was not anticipated that they would return in large numbers to the Cowlitz River as experienced normally on a annual basis. However, in 1981, the smelt run was near record proportions and a substantial portion of the entire run spawned in the Cowlitz River. Commercial and recreational dipping was allowed at high levels for many weeks in the lower Cowlitz River, in the presence of the large number of dredge plant working in these rivers. The National Marine Fisheries Service accomplished a series of tows with their nets to determine if smelt eggs were present, and whether eggs had hatched into larva since smelt larva do not stay in the gravel, but drift freely after they hatch. National Marine Fisheries Service in all tows observed the existence of both fertile smelt eggs and live larva in large numbers.

The apparent lack of impacts on the anadromous fish species in the Toutle and Cowlitz Rivers was a pleasant surprise for nearly all concerned. It demonstrated that those species generally could cope with the high suspended sediment and turbidity levels and the large number of dredging plant working in the stream 24 hours a day, 7 days a week, without significant impairment.

FLOOD CONTROL IMPACT

Thirty-four kilometers of the Cowlitz River from the mouth of the Toutle River downstream to the Columbia River were impacted with virtual elimination of natural channel capacities. Figure 8 illustrates profiles of the lower Cowlitz River before and after the mudflows. At the time of the eruption, lower Cowlitz River flows were about 170 cubic meters per second with a gage height of 9 meters. Those river flows after the mudflows on 18 and 19 May were essentially at bank-full capacity with a gage of 13 meters (4-meter rise). In addition, because mudflow materials remained in essentially all areas inundated, valley storage capacities for normal floods were severely reduced. The communities of Lexington and Castle Rock as well as the larger communities of Kelso and Longview (total population of about 60,000) were left virtually without flood protection.

The Cowlitz River channel, from about 2.5 meters immediately above the mouth of the Toutle River downstream to the Columbia River, infilled with depths of material varying from 1.5 to 5 meters. The lower reaches of tributary streams of the Cowlitz River were also infilled and blocked off by mudflow material. Drainage ditch outlets, storm sewer outlets, headwall structures, etc., were not only plugged but covered up with several feet of material. An immediate and unusual flood impact caused by the mudflow material was local flooding in many of the tributary stream drainage areas during the summer low flow periods. As a result of their entrances being dammed, residual flows from creeks and streams backed up and flooded buildings, roads, and other developed areas.

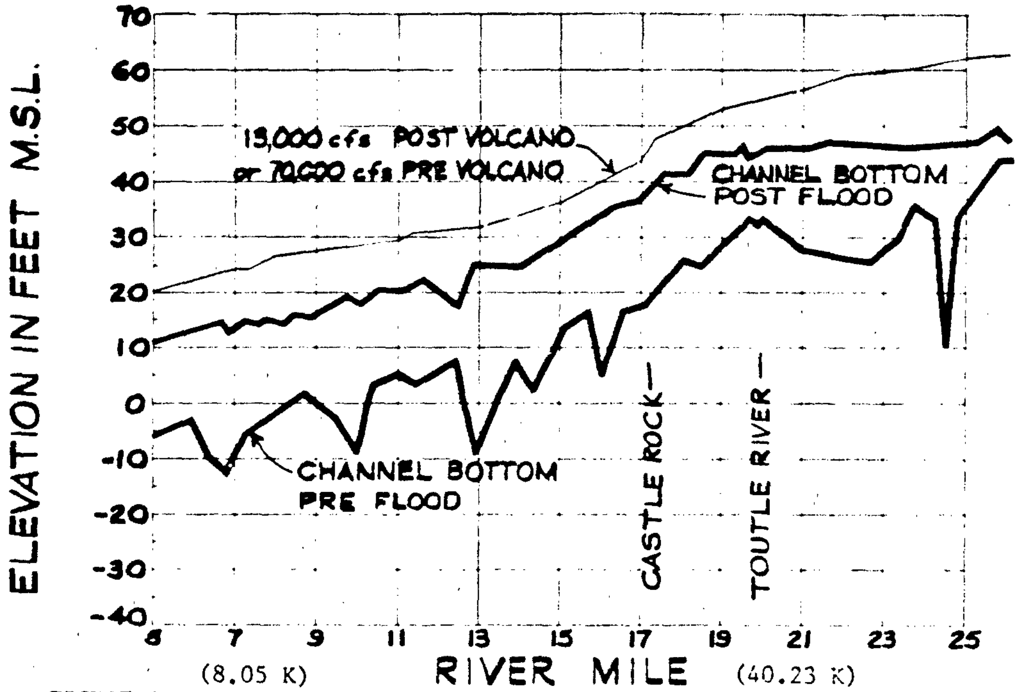


FIGURE 4 COWLITZ RIVER

Figure 8. Flood control restoration

Lower Cowlitz

Approximately 8.5 million cubic meters of infill was removed by pipeline dredges from the lower Cowlitz River (R.K. 0 to 14.5) by November 1980. Work in the lower Cowlitz River by dredges was phased out over the months of February, March, and April. Fifteen million cubic meters total was removed from the lower Cowlitz.

With 85 percent of the flood-carrying capacity eliminated by mudflow deposits, it was clear that channel excavation was required at an early date. The lower nine miles (14.5 kilometers) of the Cowlitz River passes through an urban area where the majority of the communities are protected by flood control levees. A lack of adequate disposal areas, or the extensive work required to prepare them, led to a decision that all work in the lower nine miles would be accomplished by pipeline dredges which could pump dredged materials some distances, contracted on an hourly rental basis. Dredging was started in this reach of the river with (letter) contracts to the two firms owning the only three 500-millimeter pipeline dredges available on the West Coast. Subsequent contracts for dredges used along this reach were on the basis of competitive bids for specified minimum size dredges.

Disposal areas were sparse and frequently several hundred to several thousand meters from the river channel. Recognizing the threat of flooding from the flood season beginning in November, landowners were extremely cooperative in providing the use of their lands for disposal of material at no cost to the Government.

Early dredging activities in the lower three kilometers of the Cowlitz River indicated that sediment transport and deposition were continuing at a very high rate and that progress at moving upriver would be extremely time-consuming. The major threat from flooding was in the reach of the river above kilometer 8. Consequently, two 500-millimeter dredges, the ART RIEDEL and HERB ANDERSEN, were taken overland from river kilometer 2.5 to kilometer 10 in order to accelerate arrival of dredging capacity in the needed area (Figure 9). Disassembly and reassembly methods for portable dredges, if normally followed, would require at least six weeks to accomplish. The owner, however, after extensive coordination with local police, utility companies, and officials, suggested moving the dredges in essentially one piece. The moves were accomplished in one day with virtually hundreds of workmen, both public and private, involved. This spirit of cooperation and assistance by the communities and contractors was evident throughout the recovery effort and contributed significantly to its overall success.

The ART REIDEL was out of service a total of seven days, the HERB ANDERSON for fifteen days. The heavy hauling equipment used to move the 350- and 500-ton load required 58 and 72 wheels, respectively. Figure 10 shows the ART REIDEL reassembled and in operation on the Cowlitz River.

Upper Cowlitz

On the reach of the Cowlitz from kilometer 15 to 36, the mudflow had deposited material over the majority of the valley floor for a width of about two kilometers. Landowners in this reach were willing to receive fill material on their lands to raise the area above flood level. It was determined that contracts for excavating the channel in this reach be on a fixed price basis by measurement of material in the disposal area. An option for establishing settlement markers removed one of the concerns to bidders. The river was broken into contract sections of two to five kilometers so that multiple contractors and maximum resources could be devoted to the work, providing the best likelihood of completion by late 1980. Specifications for the work in restoring the river channel were written for the opportunity of not only dredging contractors, but also contractors more accustomed to road building. Competition was keen with as many as 16 bids submitted on some jobs.

By November, approximately 12 million cubic meters of material was removed from the Cowlitz River between kilometers 15 and 36. By the time work was phased out in the summer of 1981, a total of nearly 43 million cubic meters had been removed from the entire Cowlitz River. A 1,400-cubic-meters-per-second channel capacity was achieved earlier in December.

Disposal Area Treatment

During the early spring months of 1981, after nearly a full year of dredging of the Cowlitz and Columbia River and disposal of materials in adjacent properties, a contract was awarded to a firm to dress up the disposal areas and fertilize and plant several types of grass seed in order to control blowing sand. Since the disposal areas essentially consisted of sands

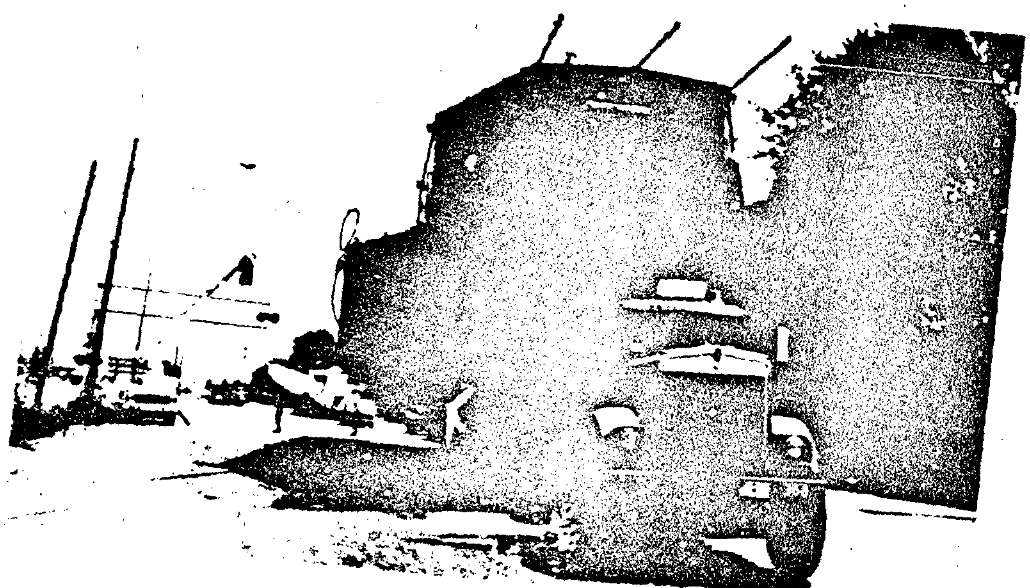


Figure 9. Overland move of ART RIEDEL

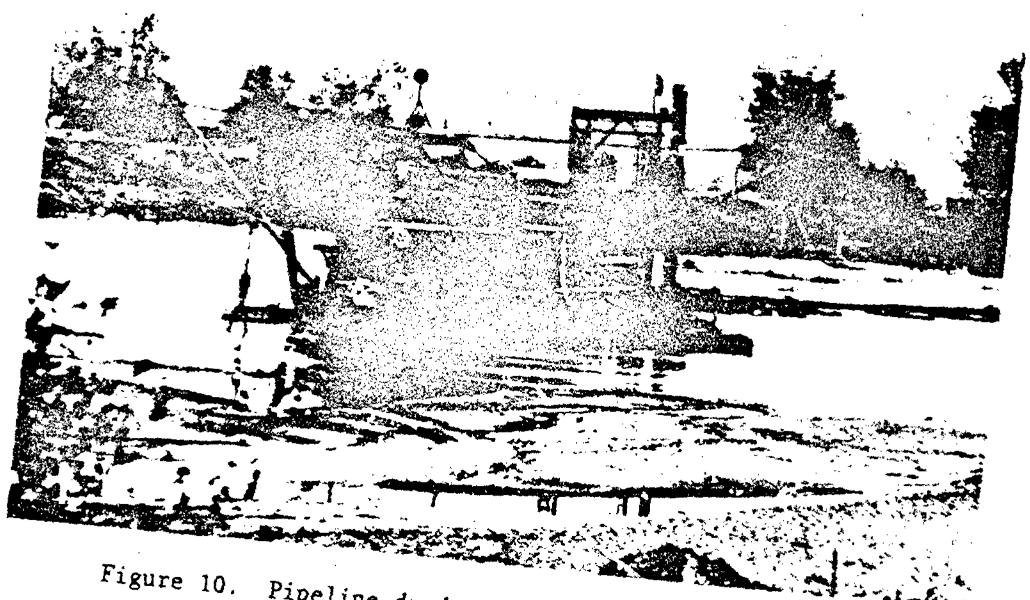


Figure 10. Pipeline dredge ART RIEDEL on Cowlitz River

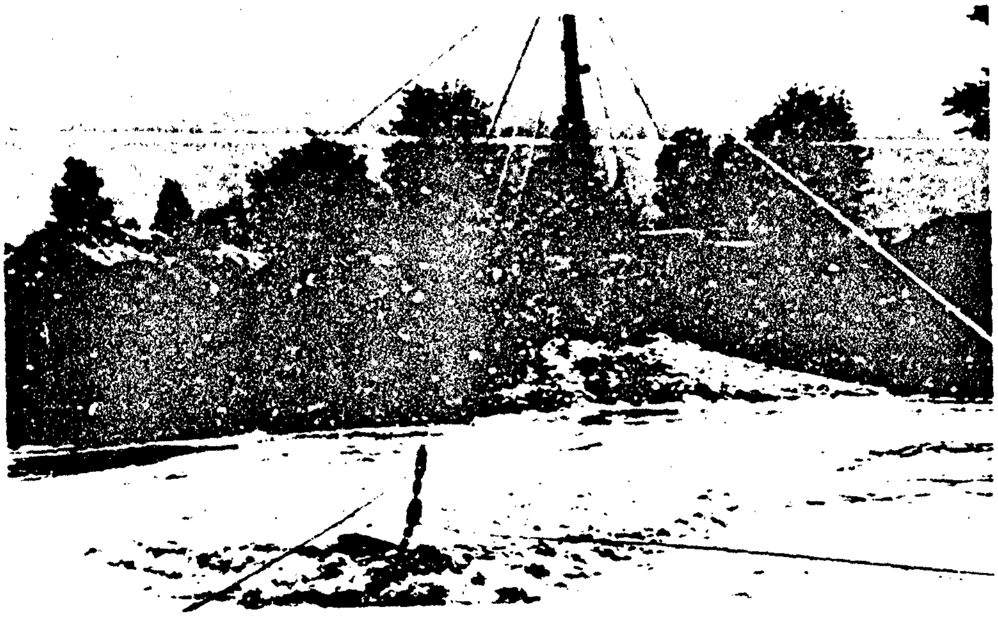


Figure 13. Highline on Cowlitz River

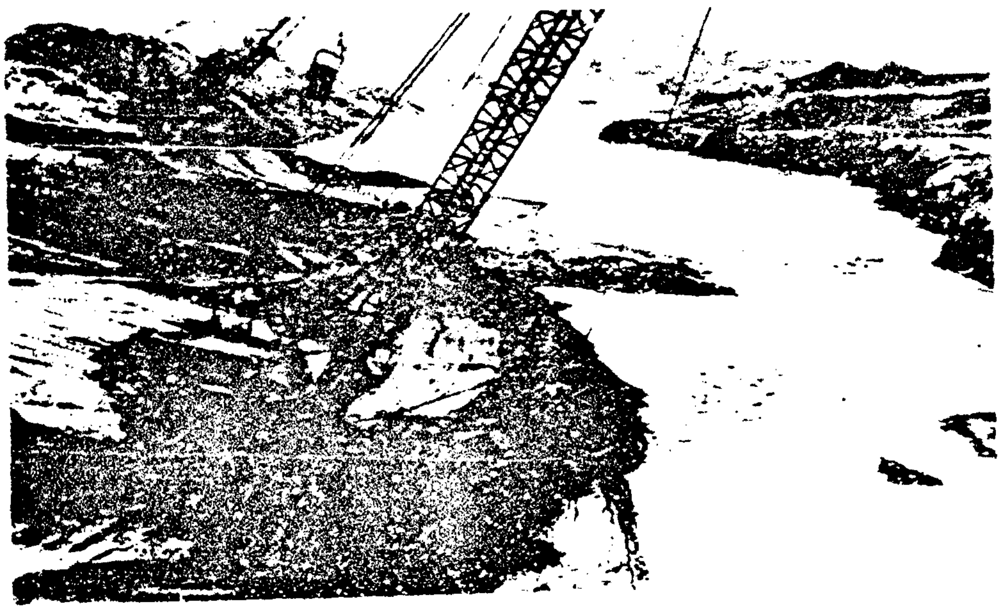


Figure 14. Draglines on Cowlitz River

and gravels, it was anticipated that a grass crop would not grow to lush proportions, but would provide the minimum desired cover. Since the disposal areas were mostly on private properties and were targeted for future developments of some type or for borrow sites to sell the materials for commercial purposes, no further treatment was contemplated.

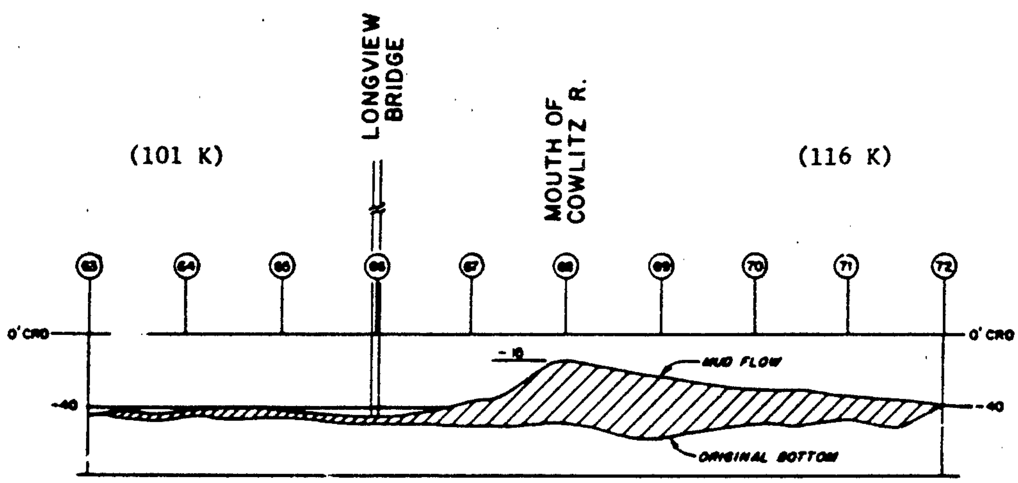
NAVIGATION IMPACT

The Columbia River navigation channel from the mouth to Portland, Oreg., and Vancouver, Wash., is maintained at a 12-meter depth, 183-meter width. The Cowlitz River enters the Columbia at river kilometer 52, and the Willamette River, which serves the Portland Harbor area, enters the Columbia at kilometer 160. The Columbia River serves primarily tug and barge and deep draft vessel traffic with commerce in excess of 30 million tons per year in those reaches. Prior to the eruption, a routinely maintained navigation channel existed in the lower 6.5 kilometers of the Cowlitz River with dimensions of 2.5 by 46 meters.

Maintenance of the 12-meter channel requires annual dredging of about 3.8 million cubic meters of primarily clean sand materials. In-place density of Columbia River sands is an average of 1,900 to 1,950 grams per liter. This yardage is normally removed from shoal areas existing throughout the 167-kilometer reach to the Portland area. Before the eruption, normal maintenance of the Cowlitz River channel was accomplished on a periodic basis about once every three years. Shoaling conditions usually required removal of only 115,000 to 190,000 cubic meters of gravelly sand materials.

As reported by the Columbia River Pilots Association, a deep draft vessel traversed the Columbia River channel in the vicinity of River kilometer 52 in an upstream direction without incident about 3:30 a.m. on 19 May. However, at 5:30 a.m. on 19 May another vessel progressing upstream ran hard aground adjacent to the mouth of the Cowlitz River and had to be assisted off by tugs later in the day. Hydrographic surveys were taken late that day after turbidity levels subsided enough to allow penetration of sonic fathometer signals. They revealed that navigation depths in the Columbia River had been reduced to 4.5 meters CRD (Low Water Datum) and navigation depths in the Cowlitz River were virtually nonexistent. Those depths essentially closed the Columbia River channel upstream of Longview to deep draft vessel traffic. Thirty-one deep draft vessels were trapped upstream in the Portland-Vancouver and Kalama harbors. An estimated 50 ships enroute to the area were forced to stand off or were diverted to other ports. The cost to ports, the communities, and industry mounted to millions of dollars per day from the disruption of deep draft vessel traffic in the Columbia River.

The major portion of the infill material in the Columbia River extended from river kilometer 101 upstream to river kilometer 116. Figure 11 illustrates the distribution of the material in comparision with normal channel depths. Based on surveys, approximately 10.7 million of the 34 million cubic meters deposited in the river infilled the 12- by 183-meter navigation channel in this reach.



COLUMBIA RIVER LONGITUDINAL PROFILE RM 63-RM 72

Figure 11

NAVIGATION RESTORATION

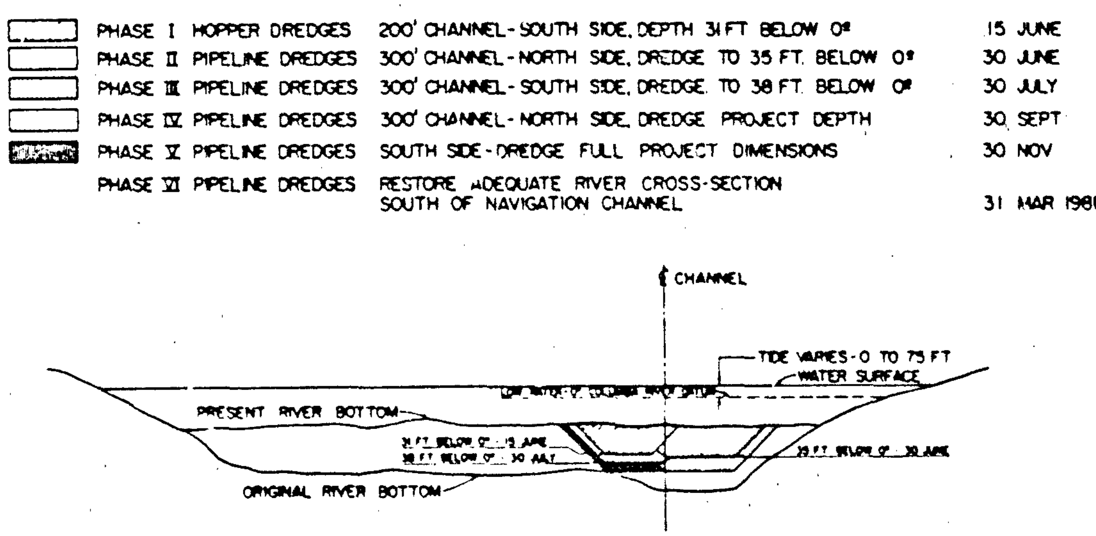
Dredging

With preliminary data available early on 19 May after the grounding of the HEOGH MASCOT, the U.S. Coast Guard closed the Columbia River to navigation at Longview. This information was transmitted to the Portland District that day and the hopper dredge BIDDLE, working at the mouth of the Columbia River, was immediately ordered to proceed to the area to begin emergency dredging. The following day, the District's other two hopper dredges, HARDING and PACIFIC, were recalled from Eureka, Calif., and Coos Bay, Oreg., respectively, to also begin work on the Columbia channel. The Port of Portland's 760-millimeter pipeline dredge OREGON, working under contract for the Corps in the vicinity of Astoria, Oreg., was ordered that day to mobilize at the site as soon as possible.

Representatives of the U.S. Coast Guard, the Columbia River Pilots Association, and the Corps of Engineers met on 19 May to develop plans for restoration of the channel and resumption of river traffic. On 20 May the plan for dredging was established as indicated in Figure 12. The hopper dredge BIDDLE started work on the Columbia River channel on 20 May. The BIDDLE started work on a 61-meter-wide emergency channel on the south edge of the 183-meter-wide authorized channel.

The U.S. Coast Guard established a safety zone through the blockade area. Deep draft vessels were restricted to passing through the area during a 2-hour "window" on the daylight high tide. This procedure provided the maximum depth available for deep draft vessels and minimized the interruption of dredging operations in the channel. Tug and barge traffic was ordered to use that portion of the river south of the emergency channel.

Marine contractors on the West Coast and throughout the nation were canvassed by telephone to determine the availability of large pipeline dredging plant. The first result of this solicitation was that the two largest West Coast dredging companies, General Construction Company of Seattle and Riedel International of Portland, agreed to the latter firm entering into a contract to furnish and operate equipment of both companies. Submission of preliminary cost and pricing data led to signing of the contract on 23 May. Five large pipeline dredges and two boosters would be furnished.



TYPICAL SECTION
COLUMBIA RIVER AT LONGVIEW

Figure 12. Timetable for restoration of Columbia River channel

Notice to proceed was immediately issued for mobilizing the dredges MCCURDY and WASHINGTON from Puget Sound to the Longview area. Negotiations continued to permit a definitized contract establishing rates for rental of the fully operated dredge plant on an hourly rental basis, plus a fixed price for mobilization and demobilization. Terms included in the contract provided the Government the option to determine which equipment to use and how it would be used on the project. Table 1 lists the dredges ultimately utilized for Columbia River dredging.

Providing disposal areas required full cooperation between contractors, local authorities, environmental interests, and various Federal, State, and local agencies.

Because of the urgent nature of the emergency restoration, environmental requirements were relaxed as necessary by Federal and State natural resource agencies, as long as all reasonable efforts to minimize impacts were pursued.

The 1.7 million cubic meters of infill in the channel project limits was removed generally on schedule and an unrestricted navigation channel was open to traffic by 30 November 1980. As of September 1981, a total of 18.3 million cubic meters was removed from the Columbia River in order to restore both navigation and hydraulic channel capacities.

Figures 13-16 show the various dredges and techniques used on the Cowlitz and Columbia Rivers.

Rainier Fill

The Columbia River channel in the vicinity of Longview immediately downstream of the mouth of the Cowlitz River is naturally wider than required for hydraulic passage of river flows. This condition, when coupled with extensive dredging normally conducted in the area to provide both the Federal navigation channel and the mooring basins for the Port of Longview industrial facilities, created an area where shoaling was accelerated because of the artificially deepened and widened channel. The deepening of the navigation channel from 10.7 to 12.1 meters in the late 1960's and early 1970's along this location included a plan for possible artificial narrowing by pile dikes or fill. However, because of the concern of many local interests in the area, the narrowing program was never accomplished. This fact, together with the new condition of millions of cubic yards of mudflow infill immediately upstream, raised the question of future ability to keep adequate navigation depths consistent in the Port of Longview reach. Compounding the problem was the probable large volumes of material to be transported into the area from natural erosion of mudflow deposits in the Toutle River system.

The services of a consultant familiar with marine channel design were secured to assist Portland District personnel in the review of previous plans for artificial works in the Columbia River channel area. A primary concern was placement of dredged mudflow material in such a manner as to provide long-term stability of the channel area. The plan proposed by the consultant is illustrated as the Rainier Fill in Figure 17. Federal and State agencies were apprised of the plan, and the landowner and the State of Oregon reached an agreement on transfer of ownership. The latter was made possible by

TABLE 1. DREDGES USED TO RESTORE THE COLUMBIA RIVER AND LOWER COWLITZ NAVIGATION CHANNEL

Name	Size	Pump Horsepower	Owner*	Date Started	Approximate CM Removed
Hopper Dredges					
BIDDLE	2340 CM	-	A	20 May 80	1,530,000
HARDING	2064 CM	-	A	22 May 80	880,000
PACIFIC	382 CM	-	A	21 May 80	250,000
Pipeline Dredges					
OREGON	762 MM	4985	B	22 May 80	4,800,000
MCCURDY	609 MM	3000	C	6 Jun 80	2,026,000
*WASHINGTON	609 MM	2900	D	7 Jun 80	2,100,000
OLLIE REIDEL	686 MM	4200	C	7 Jun 80	3,400,000
TILLAMOCK	305 MM	600	E	15 May 81	17,500
MISSOURI	559 MM	2500	D	23 Jun 80	3,750,000
HUSKY	500 MM	2800	F	18 Jun 80	2,750,596
ART REIDEL	500 MM	1850	C	9 Jun 80	3,060,000
H. ANDERSON	500 MM	1850	C	19 Jun 80	2,000,000
CORNELIA B.	500 MM	1900	G	13 Sep 80	1,400,000
MR. GUS	406 MM	900	C	20 Aug 80	1,150,000
HOWARD	406 MM	2700	H	7 Sep 80	1,530,000

*Purchased by Western Pacific - renamed LOFGREN

Name	Size	Pump Horsepower	Owner*	Date Started
Booster Pumps				
SUPER BOOSTER	609 MM	3500	C	23 Sep 80
OREGON BOOSTER	762 MM	3000	B	30 Jul 80
SUPER SNOOSE	686 MM	3600	C	
#1	500 MM	1000	C	17 Aug 80
#2	500 MM	1500	C	10 Oct 80
#3	500 MM	2500	C	19 Oct 80

*Owners:

A - Portland District, Corps of Engineers
B - The Port of Portland, Portland, OR
C - Western Pacific Dredging Corp., Portland, OR
D - General Construction Co., Portland, OR
E - Newport Dredging Co., Portland, OR
F - Manson-Osberg Construction Co., Seattle, WA
G - Coast Marine Construction Co., Portland, OR
H - Robers Dredge, Inc., La Crosse, WI

Figure 15. Large pipeline dredges on Columbia River. Mouth of Cowlitz River in background

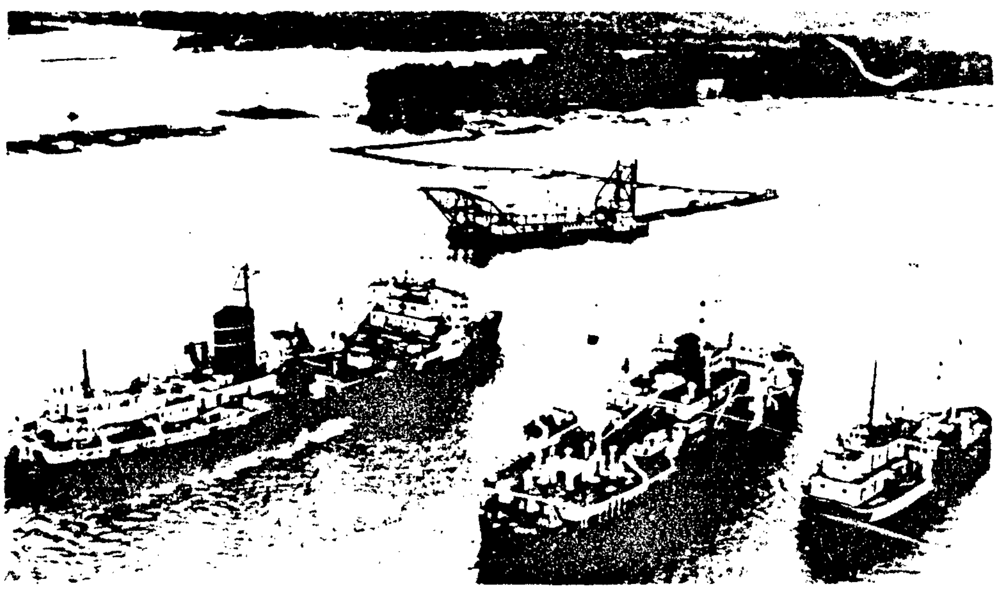


Figure 16. Hopper dredges BIDDLE, HARDING, and PACIFIC and pipeline dredge OREGON on Columbia River

timely action on the part of the State of Oregon in establishing a fair value for covered river bottom and by the riparian owner in agreeing to make payment to the State and to replace his waterfront structures that would be covered by the fill.

In addition to providing an area to dispose of approximately 4.6 million cubic meters of mudflow material, it is anticipated that the engineering of the plan will save millions of dollars in dredging costs in future years by retarding the settling of eroding mudflow materials in the Federal channel and Port of Longview mooring berths. It is expected the eroded mudflow materials will tend to continue on through the narrowed river area and deposit in areas less critical downstream. Dredging can then be scheduled on a more efficient basis and where disposal areas are more readily available.

Beeman Plan

Initial dredging efforts were directed toward restoration of the 12.1- by 183-meter navigation channel. In late June 1980, however, as extensive hydrographic surveys fully outlined the magnitude and location of the total 34 million cubic meters of infill, it was realized that excavation of the channel project would not be enough to provide long-term stability. The remaining mudflow materials in the river would continue to erode until the river reestablished its hydraulic section during high flow periods.

This eroded material would result in intermittent and unpredictable infill of the navigation channel downstream in future years. An engineering study was initiated to determine the extent of additional dredging required to provide a nearly stable hydraulic channel as soon as possible. A consultant was utilized to study these problems and recommend solutions to District personnel. Figure 17 illustrates the plan proposed by the consultant and adopted by the Portland District.

It was anticipated that a total of 6.9 million cubic meters in addition to the 10.7 million already excavated from the channel would have to be removed to provide a 90-percent reestablishment of the hydraulic section. The "90-percent" effort is all that was practical and recommended because restoration of the remaining 10 percent would not be cost-effective. Removal volume to improve the hydraulic capacity would involve increasingly greater volumes for each added percent of improvement. A contract for $10,386,000 was awarded in January 1981 for dredging of an additional 4.6 million cubic meters. This would supplement continued excavation by the Port of Portland's dredge OREGON to provide the stable hydraulic section. This project will be complete by June 1982.

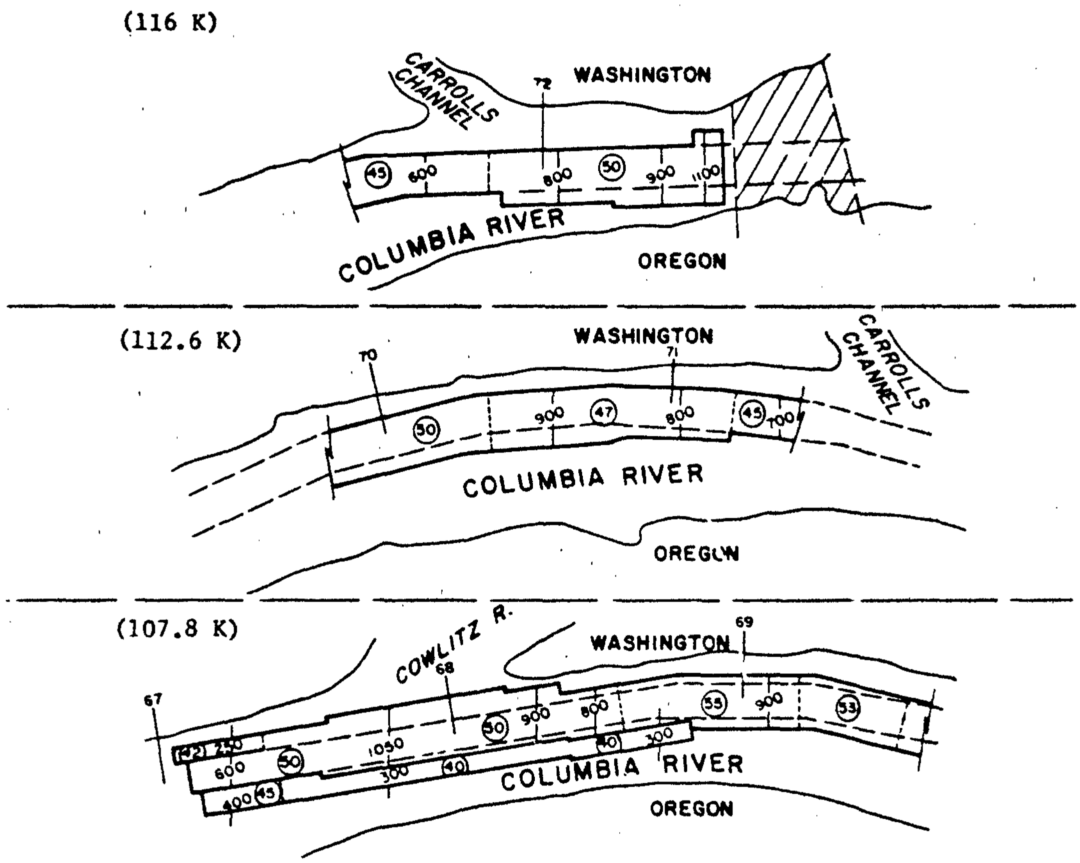


Figure 17. Ranier Fill plan proposed by consultant

<u>Sump</u>

In addition to the Rainier Fill and the additional hydraulic channel excavation as described above, measures were also considered to minimize future impacts of erosion of materials from the Toutle and Cowlitz River valleys and their transport into the Columbia River, resulting in possible disruption of navigation traffic. As part of the dredging operation accomplished in the first year, a sump was excavated at the mouth of the Cowlitz River to intercept material being transported down the Cowlitz. The purpose of the sump is to provide a location for a large dredge to remove the materials prior to their reaching the Columbia River channel. The sump currently being utilized is shown in Figure 18. Removal of up to 1.5 million cubic meters of additional material from the sump area was also provided as part of the contract discussed above. The material removed from the sump is being placed in a disposal area known as the Collins Estate. The Collins Estate consists of a privately owned large acreage of land that includes considerable wetland areas. The Portland District has diked off a portion of the site and will expand it only as necessary in future years to minimize impacts to the surrounding wildlife habitat and wetland area.

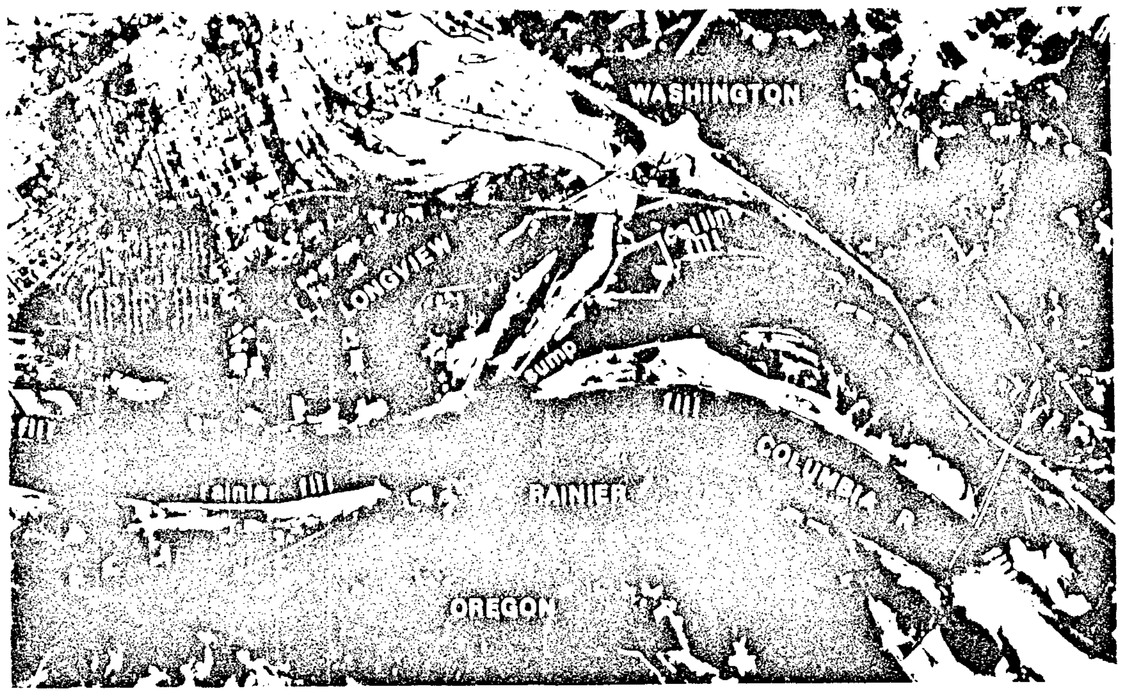


Figure 18. Locations of sump and fills on the Columbia and Cowlitz Rivers

OTHER CORPS ACTIVITIES

In addition to the massive dredging program described in the previous paragraphs to restore navigation channel depths and flood control protection levels, the Corps of Engineers utilized other measures in an attempt to restore channel capacities in the upper reaches of the Cowlitz and Toutle Rivers and to control future erosion of the mudflows in the Toutle River basin. In this manner, sediment transport into the Cowlitz and Columbia Rivers in future years could be minimized. In the Toutle River, contracts were let to remove sediments in the river channel and slope the banks of the mudflows in an attempt to confine the river channel to one location and retard erosion. In addition, large debris-control structures or dams were constructed on the North Fork of the Toutle near the base of the 22.5-kilometer-long mudflow from the mountain and on the South Fork of the Toutle a few kilometers above its junction with the North Fork. The debris structure on the North Fork consisted of a rock fill nearly 2.4 kilometers in length and about 11.5 meters in height. The South Fork structure was much smaller, being only approximately 152 meters in length and 8.5 meters in height. Both of these structures were designed for the purpose of trapping eroding mudflow deposits upstream. Then the deposits could be removed by excavation contracts in the following months and years and deposited nearby, thereby preventing them from being transported downstream to cause more significant damage to populated areas. Figure 19 shows a mudflow.

Levees around Castle Rock, the Lexington area, Kelso, and Longview were also improved, heightened, strengthened, and lengthened to provide full 500-year coverage under the channel conditions existing after the winter of 1980-1981. These levees were also protected with rock riprap throughout nearly their entire lengths to provide a long lasting and substantial degree of protection in the near future years. A short-term measure, which was accomplished during the summer of 1980, immediately after the eruption, consisted of the purchase of storage space in a private power company flood control reservoir on the upper Cowlitz River to reduce the impact of winter storms during the first winter of 1980 to 1981. Purchase of this storage was highly successful in that a large flood occurring during the 1980 Christmas holiday was stored in its entirety in the Cowlitz River with only the Toutle providing inflow into the Cowlitz River from kilometer 37 downstream. Flows of 1,360 centimeters per second were still experienced in the Cowlitz River downstream from Castle Rock from the Toutle River contribution to this rainstorm.

Several fairly large lakes were formed during the summer and fall of 1980 as a result of the large mudflow immediately adjacent to the mountain in the North Fork of the Toutle River valley. As this mudflow deposited depths of 61 to 183 meters of material in the 22.5 kilometers of the upper Toutle River valley, it closed off the entrance to many side canyons and tributary streams. Lakes were formed in the pockets at the bottom of those canyons (Figure 20). Several of these lakes were substantial in size as they developed and posed serious threats to sudden and catastrophic overtopping of the mudflow dike with possible disastrous consequences of this sudden rush of water and sediments downstream. One lake reached overtopping levels in the late summer of 1980, and an artificial channel was constructed to control its outlet. Two other large lakes formed throughout the winter of 1980-1981 and were predicted

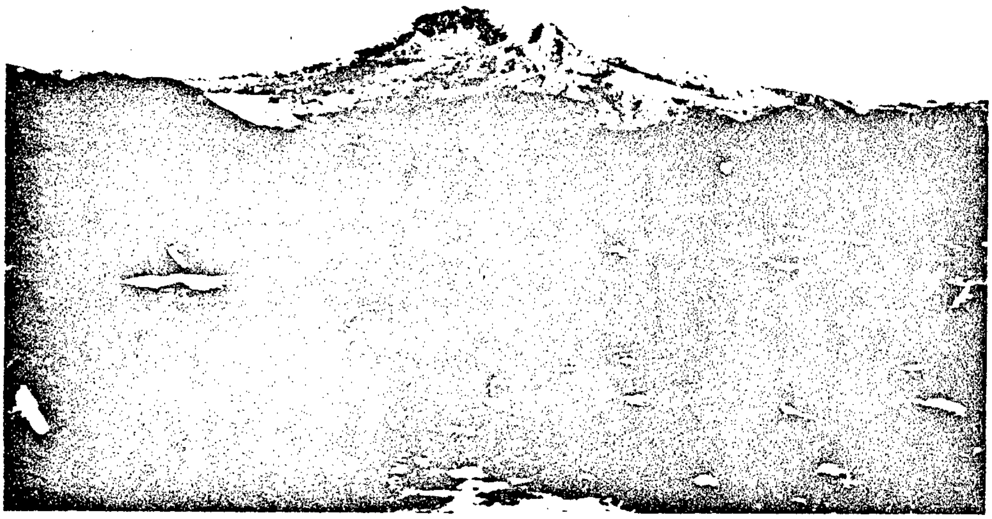


Figure 19. Mount St. Helens and mudflow in foreground

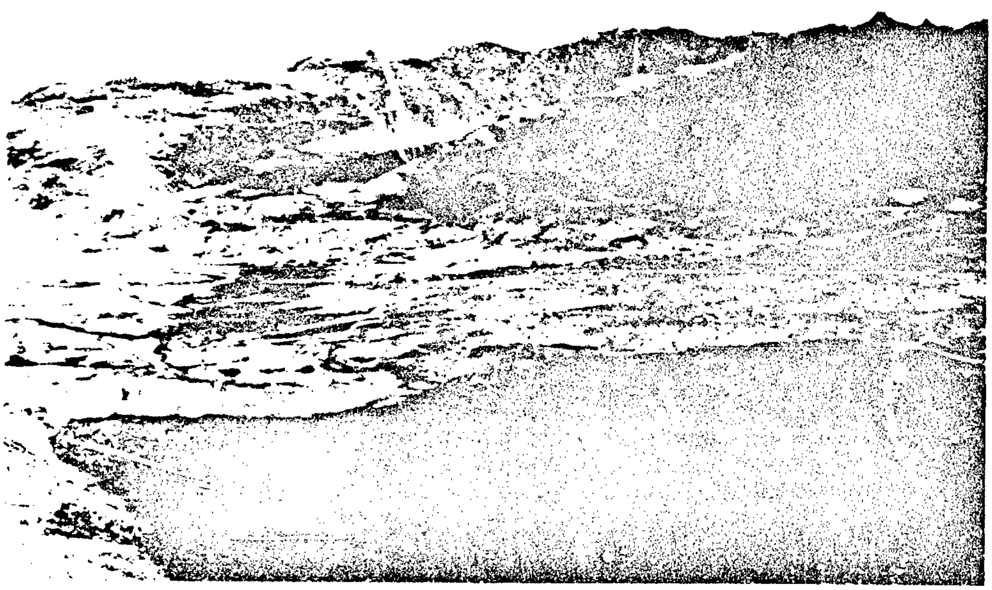


Figure 20. Lakes formed by mudflow dike across valleys

at the current rate of progress to overtop in the winter of 1981-1982. During the summer of 1981, contracts were let to provide stable outlet channels to those lakes so that they could be drained under controlled conditions and their levels stabilized for the long-term future.

ENVIRONMENTAL IMPACT STATEMENT

Immediately after the eruption, the Portland District staff began preparation of an Environmental Impact Statement (EIS) for the Mount St. Helens recovery operations. This was to provide the public, Federal, and State agencies an opportunity to review the alternatives considered and probable impacts to the environment from actions under way or proposed. A preliminary draft EIS was completed on 25 July 1980, and was sent to interested Federal, State, and local agencies for review. The final draft EIS was submitted to the Environmental Protection Agency on 19 Sept. 1980. The time frame for production of the initial draft was only 20 days; therefore, many procedural steps were abbreviated. Time did not permit a detailed and in-depth review of each topic discussed. The EIS will be supplemented in the future with updated information clarifying current options or new alternatives as conditions develop.

In addition to the EIS, early plan formulation for the restoration effort included an environmental task force of principal Federal, State, and local agencies. The task force continues to meet periodically to review current programs and future plans. The Corps of Engineers is attempting to accomplish the recovery work with strong consideration of recommended environmental protective measures proposed by the task force.

AD P002413

THE WATER QUALITY PRESERVATION MEASURES IN LAKE BIWA

M. Shirahase, Assistant Chief
Water Administration Department
Shiga Prefecture

LAKE BIWA IN OUTLINE

With a surface area of 673.90 square kilometers, Lake Biwa, the largest lake in Japan, occupies about one-sixth of the total area of Shiga Prefecture in the Kinki District of Western Japan.

Other geographical data concerning the lake are as follows:

Length (north to south)	63.49 km
Maximum width (east to west)	22.80 km
Overall coastline	235.20 km
Altitude (above sea level)	85.614 m
Maximum depth	103.58 m
Average depth	41.20 m
Volume of water stored	27.500 million m^3

The lake bottlenecks at the mouth of the Yasu River (Figure 1). At this narrowest part of the lake, Biwa-ko O-hashi (Grand Lake Biwa Bridge) is constructed, bridging a span of 1.35 km. Geographically, this bridge divides the lake into two parts, the northern part which is the primary lake basin and the southern part which is the secondary lake basin. The average depth of the northern basin is around 41 m, while that of the southern basin is only 4 m. This difference in shape between the two lake basins causes striking contrasts in terms of water quality, varieties of aquatic life, and all other aspects concerned.

Lake Biwa's ample supply of water is utilized for agricultural, industrial, and household purposes. The lake itself provides good fishing grounds and is a valuable recreation center. Often called the "water-jar for the Kinki area" the lake plays a vital role in supplying water for the 13 million people living and working in the Kyoto-Osaka-Kobe metropolitan district.

Improvement of the lake's water quality and other environmental protection issues are among the key current considerations in the prefecture's administrative policy. Concomitant with Japan's high economic growth, which began around 1960, the population increased sharply and industrial and agricultural activities became increasingly brisk. Regrettably, the pollution load for public water areas showed a corresponding substantial increase. Lake

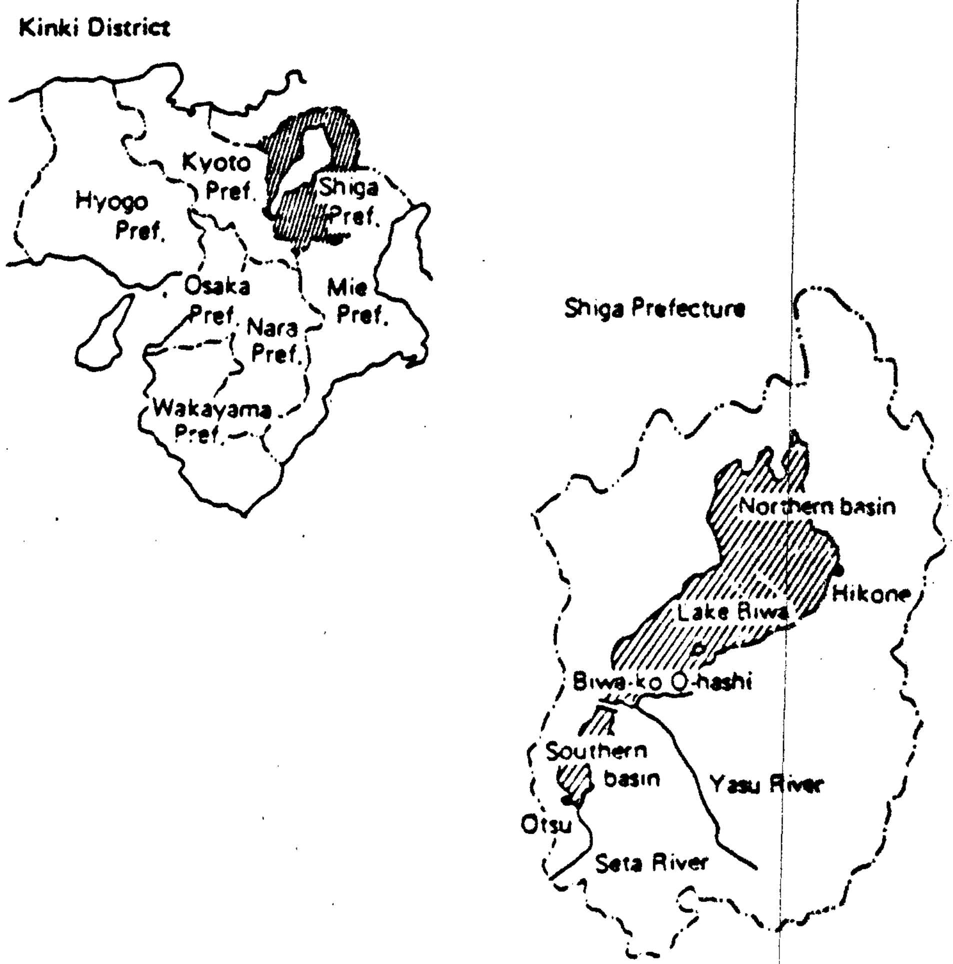


Figure 1. Shiga Prefecture showing Lake Biwa

Biwa became so contaminated that, in 1969, Shiga Prefecture instituted a pollution control ordinance of its own to regulate the amount of wastewater from factories and other business establishments.

As environmental pollution subsequently became a grave social problem threatening to damage the health and living environment of the citizens on a nationwide scale, the national government passed the Water Pollution Control Law in 1971. In order to strengthen the working of this law, in 1972 the prefecture instituted still another ordinance. In 1973, this new prefectural ordinance was totally amended to include more stringent regulations against water pollution.

WATER QUALITY OF LAKE BIWA

The national government's Basic Law for Environmental Pollution Control provides for desirable environmental quality standards to be maintained to protect the health and living environment of the citizens against air pollution, water contamination, and other environmental disruptions. For the purposes of this law, several area types are provided for application to individual water areas covered. As for Lake Biwa and the Seta River, specific environmental quality standards were made public by the 1972 notification of the Environment Agency, which applied the area types AA(a) and AA(c) to the northern basin and the southern basin, respectively, and the area type A(a) to the Seta River. (For drinking water, AA represents the top rating and A the second rating.)

In order to help promote the attainment of these standards, a study has been under way since fiscal year 1972 at nine fixed monitoring points specifically designated for this purpose (four in the northern basin, another four in the southern basin, and one in the Seta River). Results of the study on water quality conducted in fiscal year 1979 showed that the environmental standards for protecting the health of the citizens (comprised of nine items relative to toxic substances) were met at each monitoring point. With regard to the conditions of the living environment, it was found that the AA standards on DO (dissolved oxygen) were almost met at each monitoring point, while the standards on COD (chemical oxygen demand) were yet to be attained (Figure 2). On the other hand, the pH (potential of hydrogen) level exceeded 8.5 when the activity of phytoplankton was very brisk, indicating that the lake's water was weakly alkaline.

The capacity of the southern basin is rather small (200 million tons as compared with the 27,300 million tons capacity of the northern basin), and there are a large number of factories and other business establishments surrounding the basin. Consequently, the population density and pollution load per unit are much higher and the water quality of the southern basin is, on the whole, lower than that of the northern basin.

Since fiscal year 1966 the prefecture has been conducting a study of Lake Biwa's water quality with the assistance of the Construction Ministry's Regional Construction Bureau for the Kinki District at 48 fixed monitoring points to obtain basic data for protecting the lake from further pollution. According to this study, the water pollution of Lake Biwa had become progressively worse by degrees until about 1971 and 1972, after which the situation began to improve slightly for some time thereafter and then remained at almost the same level until 1976.

However, in late May and early June of 1977, an abnormally large number of plankton, predominantly Uroglena, appeared. These plankton were found growing in a considerably large portion of Lake Biwa. This was an indication that the lake was tending toward eutrophication, and about to enter a new phase. As feared, a freshwater red tide broke out in 1978-1981.

WATER QUALITY PRESERVATION MEASURES IN LAKE BIWA

Lake Biwa is a closed water area that reflects the results of all human activities within the prefecture. Accordingly, in formulating a long-range

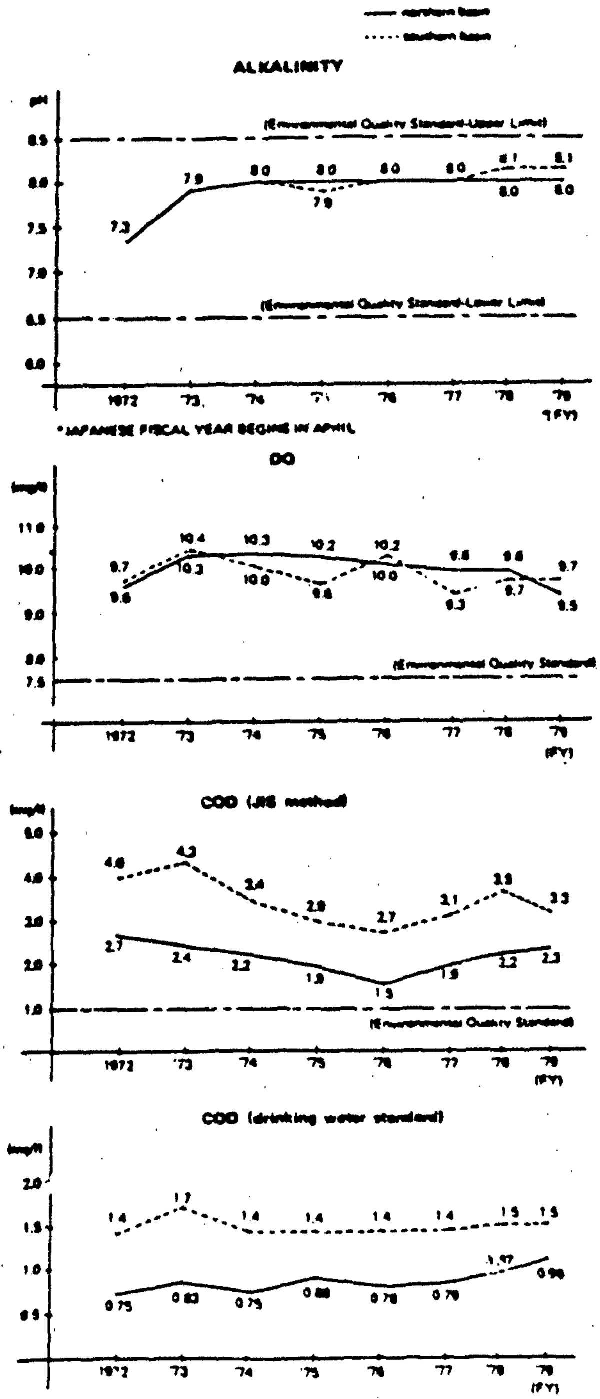


Figure 2. Environmental quality monitoring for Lake Biwa (Continued)

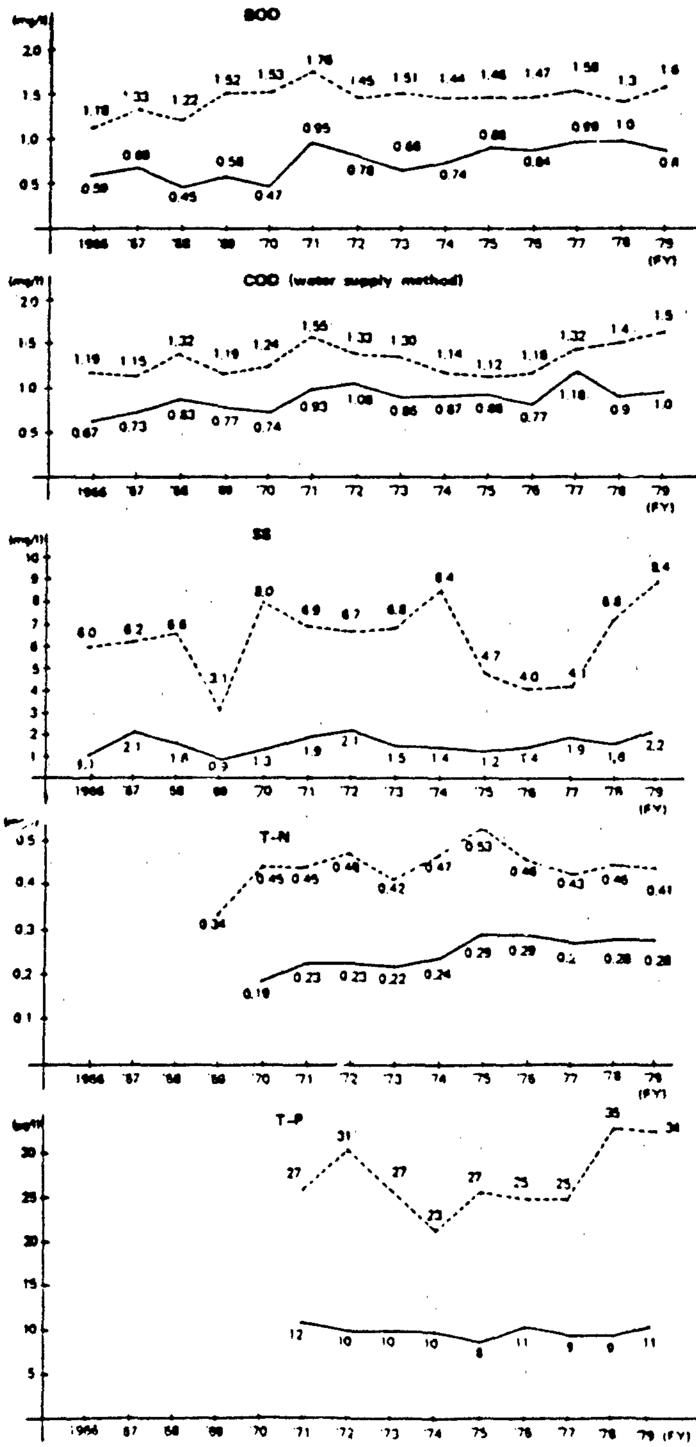


Figure 2 (Concluded)

prefectural policy, top priority should be given to comprehensive water conservation measures covering the lake and the inflowing river.

It is said that eutrophication is caused by such substances as nitrogen, phosphorus, vitamins, iron, maganese, and cobalt. Nitrogen and phosphorus, among others, are said to have a decisive influence. For this reason, and after receiving a report from the Prefectural Council on Water Quality, an Ordinance concerning the Prevention of the Eutrophication of Shiga Prefecture's Lake Biwa (appended to this paper) was established in October 1979 to regulate these two substances. This ordinance is supported by a consensus of the local inhabitants. Chapter 3 of this ordinance, Prohibition of the Use and Sale of Household Use Phosphate Detergents, is especially important.

However, for water quality preservation in Lake Biwa, not only is the regulation of nitrogen and phosphorus needed, but also the promotion of the improvement works concerned with water quality in the Lake is essential, as Chapter 1 of this ordinance provides. The representative water quality improvement works are dredging contaminated bottom sediment and sewage treatment of wastewater. These works have been promoted in accordance with the Lake Biwa Comprehensive Development Project which began in 1972. About 1 million cubic meters of bottom sediment is planned to be dredged, of which 50.000 m^3 of bottom sediment has already been dredged. However, problems still exist concerning dredging: the increasing cost of water treatment, the lack of land for sediment management, and the destruction of the biological system. Therefore, contaminated bottom sediment dredging works should be promoted positively to overcome these problems.

ORDINANCE CONCERNING THE PREVENTION OF THE EUTROPHICATION OF SHIGA PREFECTURE'S LAKE BIWA

(October 17, 1979 Shiga Prefectural Ordinance No. 37)

CONTENTS

Water, along with the air and soil, is the foundation for the existence of humankind.

Lake Biwa, so copiously full of this water, as Japan's biggest lake, even now while challenging us with a great task, brings forth limitless blessings.

Recently, due to factors such as the rapid development of urbanization, Lake Biwa is faced with deterioration of its water quality, particularly the abnormal situation of progressive eutrophication. Moreover, this is not due to the working of nature in Lake Biwa but has been caused by the daily living and commercial production activities of the inhabitants around Lake Biwa.

It is unforgivable for our generation to pollute Lake Biwa, which has sustained various human activities continuously from the time of unrecorded history.

Since water is a finite resource, Lake Biwa, surely the source of life of the people who share its benefits, is our great spiritual sustenance. We must without fail, by surmounting numerous difficulties, establish a new coexistent relationship between this water and humankind.

Particularly now, it is essential that we once more critically reconsider our lifestyle which has come to pursue things like prosperity and convenience, reflecting together upon Lake Biwa's multifaceted worth and the people's way of life and, with a bold and determined spirit, develop a comprehensive policy for conserving Lake Biwa's environment.

The people of our prefecture who live together with Lake Biwa, loving it and being grateful for its benefits, awakened to a sense of consciousness about environmental conservation, now have passionately come to develop a creative conservation movement.

We while developing these buds of self-reliance and cooperation, to clarify the respective duties of the prefecture, cities, towns and villages, and the prefectural citizens and business people, and to protect Lake Biwa by working together as a single group, resolving that we will bequeath a beautiful Lake Biwa to future generations, as a first step, enact this law to prevent the eutrophication of Lake Biwa.

CHAPTER 1 GENERAL PROVISIONS

(Purpose)
Article 1

This ordinance, relating to prevention of Eutrophication of Lake Biwa, by clarifying the respective duties of the prefecture, cities, towns and villages, and the citizens of the prefecture as well as the business people, and by devising means for controlling effluents, and other measures, has as its purpose the planning of the conservation of Lake Biwa's environment.

(Definitions)

Article 2

1. In this ordinance "Lake Biwa" means the "Lake Biwa" to which the regulations of the Rivers Act (1964, Law No. 167) apply, as well as that portion of the "Yodo River" of the Rivers Act which lies within and upstream of the Setagawa Watergate.

2. In this ordinance "Eutrophication" means a phenomena of progressively worsening water quality in an enclosed water area, caused by the profligate flourishing of algae and other aquatic plant life due to inflow into the enclosed water area of nitrogen or phosphorus containing substances (hereafter such substances are called "N/P Substances").

3. In this ordinance a "Designated Facility" means any facility, set up at a factory or business establishment, that discharges N/P Substance-containing sewage water or any other N/P Substance-containing sewage fluid (hereafter such sewage water or fluid is called "N/P Waste Liquid") and is designated by regulation under this ordinance.

4. In this ordinance "Public Use Water Areas" has the meaning defined by Article 2, paragraph 1 of the Water Pollution Control Act (1970, Law No. 138).

5. In this ordinance "Household Use Phosphate Detergent" means a synthetic detergent as defined by the Household Products Quality Labelling Act (1962, Law No. 104), that in accordance with the regulations based on Article 3 of the same law is required to be labelled as containing phosphate as an ingredient.

(Responsibilities of the Prefecture)

Article 3

1. The Prefecture shall establish and implement [illegible] and comprehensive measures concerning the prevention of the Eutrophication of Lake Biwa.

2. The Prefecture shall give all necessary assistance, as well as guidance and counsel, to the cities, towns and villages in connection with their measures for implementing the prevention of the Eutrophication of Lake Biwa.

(Responsibilities of the Cities, Towns and Villages)

Article 4

The cities, towns and villages shall earnestly endeavor to implement measures for preventing the Eutrophication of Lake Biwa which harmonize with the Prefecture's implementing measures and conform to the actual conditions in the relevant district.

(Responsibilities of the Prefectural Citizens)

Article 5

Prefectural citizens must, together with earnestly endavoring not to do acts that will casue the Eutrophication of Lake Biwa, cooperate with the Prefectural and cities', towns' and villages' implementing measures for the prevention of it.

(Responsibilities of Business People)
Airticle 6

1. Business people when conducting their business activities must, together with devising measures necessary for the prevention of the Eutrophication of Lake Biwa, cooperate with the Prefectural and cities', towns' and villages' implementing measures for the prevention of it.

2. Business people must make the greatest efforts to prevent the Eutrophication of Lake Biwa and may not use the fact that they are not technically in violation of this ordinance as an excuse for neglect in doing so.

CHAPTER 2 REGULATION OF EXHAUST DRAINAGE OF BUSINESS-INDUSTRIAL SITES

(N/P Drainage Standards)
Article 7

1. Drainage standards, in connection with nitrogen or phosphorous, which are for water that has been discharged from a factory or a place of business that has installed a Designated Facility (hereafter such a factory or place of business is called a "Business-Industrial Site") into a public Use Water Area (hereafter such discharged water will be called "Exhaust Drainage") will be called "N/P Drainage Standards" and established by regulation.

2. The Governor shall, when establishing or amending the N/P Drainage Standards, beforehand solicit the opinion of the Shiga Prefecture Water Quality Council.

(Report of the Installation of a Designated Facility)
Article 8

(The rest of this chapter, as well as Chapter 4, does not apply to those districts which are by regulation determined to be basins of rivers not draining into Lake Biwa.) Any person who discharges water from a factory or place of business within the Prefecture into a Public Use Water Area must, when planning installation of a Designated Facility, report to the Governor, in accordance with procedure established by regulation, the items listed under the following numbers.

(1) Full name or appellation and address. In the case of a legal person, the full name of its representative.
(2) The name of the factory or place of business and its address.
(3) The type of Designated Facility.
(4) The construction details of the Designated Facility.
(5) The method of using the Designated Facility.
(6) The method of treating N/P Waste Liquid to be discharged from the Designated Facility.

(7) The concentration of nitrogen and phosphorus in the Exhaust Drainage, the quantity of Exhaust Drainage, and any other items established by regulation.

(Interim Measures)
Article 9

When a certain type of facility has become a Designated Facility, among those persons who have actually installed one (including those who are constructing one), all who are discharging or will discharge Exhaust Drainage within the Prefecture must, within 30 days after the type of facility has become a Designated facility, report to the Governor, in accordance with procedure established by regulation, the numbered items of the previous Article.

(Report of Modifications in the Construction or the like of a Designated Facility)
Article 10

Those who have submitted a report according to the regulations prescribed under Article 8 or 9, must, before attempting to make modifications in any of the reported items (4) – (7), so report to the Governor in accordance with procedure established by regulation.

(Order for Modification of Plans, etc.)
Article 11

The Governor may, within 60 days of receiving a report made under the regulations of Article 8 or 10 of a Business-Industrial Site whose Exhaust Drainage he finds does not meet the N/P Drainage Standards at the place where the Exhaust Drainage is discharged (hereafter called "Discharge Outlet"), order the reporting person to alter his plans as appear in the report for the Designated Facility's construction details, method of use, or method of treating the N/P Waste Liquid to be discharged, or to abandon his plans for the installation of the Designated Facility reported under the regulations of Article 8.

(Restriction on Implementation)
Article 12

1. Those who have filed a report in accordance with the regulations of Article 8 or 10, during the 60 day period following the Governor's receipt of the report must not respectively install the Designated Facility of the report or modify the construction or method of using the Designated Facility or method of treating the N/P Waste Liquid discharged from it.

2. The Governor, when he finds that the contents of the items in a report made in accordance with Article 8 or 10 are acceptable, may shorten the 60 day waiting period provided by the previous paragraph.

(Report of Change of Name, etc.)
Article 13

When a person has filed a report in accordance with the regulations of Article 8 or 9, if any of the items mentioned in Article 8, numbers 1 and 2 has changed, or the use of the Designated Facility of the report has been discontinued, a report to that effect, in accordance with procedure established by regulation, must be made to the Governor within 30 days from the change.

(Succession)
Article 14

1. Any person who succeeds to the rights in, or rents, a Designated Facility from a person who has made a report concerning the facility in accordance with the regulations of Article 8 or 9, will be treated as succeeding to the status of the person who made the report.
2. When, following the making of a report concerning a Designated Facility in accordance with the regulations of Article 8 or 9, there is a transfer by inheritance or, in the case of legal persons, a merger, the heir, or surviving or succeeding legal person, will be treated as succeeding to the status of the person who made the report.
3. A person who, in accordance with either of the previous two paragraphs, succeeds to the status of a person who made a report in accordance with Article 8 or 9 must, within 30 days of succession, report that fact to the Governor.

(Limits on Discharge of Exhaust Drainage)
Article 15

1. A person who discharges Exhaust Drainage within the Prefecture must not discharge Exhaust Drainage that does not meet the N/P Drainage Standards at the Discharge Outlet of his Business-Industrial Site.
2. When a certain type of facility becomes a Designated Facility, with respect to water discharged from a Business-Industrial Site of a person who has actually installed one (including those who are constructing one), the previous paragraph's provisions will not be applied for a period of one year from the date the facility became a Designated Facility (or, when the facility is governed by regulations for unavoidable circumstances justifying an extension of this period, a period determined by regulation for such a facility). However, if at the time the type of facility in question becomes a Designated Facility the Business-Industrial Site already has some other Designated Facility, the above grace period will not apply.

(Improvement Orders, etc.)
Article 16

1. When the Governor finds that there is a risk that a person who is discharging Exhaust Drainage within the Prefecture is or will discharge Exhaust Drainage that does not meet the N/P Drainage Standards at the Discharge Outlet of his Business-Industrial Site, the Governor can both order that person to temporarily halt the use of the Designated Facility or halt the discharge of Exhaust Drainage and order the improvement, within a specified time limit, of the Designated

Facility's construction, method of use, or method of treating the N/P Waste Liquid that is discharged from the Designated Facility.
2. The provisions of Article 15 paragraph 2 correspondingly apply to orders made in accordance with the provisions of the previous paragraph.

CHAPTER 3 PROHIBITION OF THE USE AND SALE OF HOUSEHOLD USE PHOSPHATE DETERGENTS, ETC.

(Prohibition of Use, etc.)
Article 17

1. (In this chapter "Prefectural Interior" means the entire Prefecture except for certain areas excluded from this chapter's provisions by regulation, such as basins of rivers not draining into Lake Biwa, etc..) No one may use Household Use Phosphate Detergents within the Prefectural Interior.
2. No one may give Household Use Phosphate Detergents as a gift to a person who has a home or dwelling place within the Prefectural Interior.

(Prohibition of Sales, etc.)
Article 18

1. Those who sell commodities as a business and others who, under whatever name, receive a benefit from supplying commodities as a business (hereafter such persons are called "Distributors") must not sell or supply Household Use Phosphate Detergent wihin the Prefectural Interior. However, this restriction shall not apply to sales or the supply of commodities to persons who promise that they will not use the Household Use Phosphate Detergent within the Prefectural Interior and furnish a written Request giving their name, address, the purpose for purchasing or having it supplied, the amount, and any other items determined by regulation.
2. Distributors who sell or supply Household Use Phosphate Detergent to a person who has made the promise of the exception provided in the previous paragraph must preserve that person's written Request for one year from the date of such sale or supply.

(Instructions)
Article 19

1. When he finds that a Distributor is selling or supplying Household Use Phosphate Detergent in violation of the provisions of Article 18, paragraph 1, the Governor can demand that the Distributor furnish a report of all necessary information and give the Distributor any necessary instructions to obey that paragraph's provisions.
2. When a Distributor is not preserving the written Requests of Article 18, paragraph 2, the Governor can demand that the Distributor furnish a report of

all necessary information and can give the Distributor any necessary instructions to preserve the written Requests.

(Orders to Take Action)
Article 20

When a Distributor who has received instructions in accordance with the provisions of Article 19, paragraph 1 or 2, is selling or supplying Household Use Phosphate Detergent without obeying those instructions, the Governor can order the Distributor to remove the Household Use Phosphate Detergent from display or do any other necessary acts.

CHAPTER 4 RESTRAINT IN THE DISCHARGE OF NITROGEN AND PHOSPHORUS, ETC.

(Proper Use of Fertilizer, etc.)
Article 21

(This chapter does not apply to those districts which are by regulation determined to be basins of rivers not draining into Lake Biwa.) People professionally engaged in agriculture within the Prefecture, in order to avoid indiscriminately discharging drainage containing N/P Substances into Public Use Water Areas, must properly use fertilizer and control the use of agricultural water.

(Proper Disposal of Domestic Animal Waste)
Article 22

People who professionally engage in animal husbandry within the Prefecture, in order to avoid discharging domestic animal waste into Public Use Water Areas, must, along with endeavoring to install a disposal facility for such waste, properly dispose of it by such methods as soil restoration, etc..

(Miscellaneous Drainage Disposal)
Article 23

Everyone must try not to discharge indiscriminate amounts of food waste, etc. in miscellaneous drainage into Public Use Water Areas.

(Guidance and Counsel)
Article 24

The Governor, with respect to the provisions of Articles 21 – 23, will give the guidance and counsel necessary to accomplish their goals.

CHAPTER 5 MISCELLANEOUS PROVISIONS

(On-the-Site Inspections)
Article 25

1. The Governor, within the necessary limits for enforcing this Ordinance, may have his staff enter and make inspections of Business-Industrial Sites and Distributors' places of business, stores, warehouses, etc. and request reports of data or explanations from the persons concerned.
2. Those who, under the provisions of the previous paragraph, are authorized by the Governor to make on-the-site inspections must carry proof of their identity and official capacity and present it to the persons concerned.
3. The authority under the provisions of paragraph 1 to make on-the-site inspections must not be interpreted as permitting entries made for the purpose of criminal investigations.

(Prefectural Assistance)
Article 26

1. The Prefecture, in order to contribute to the promotion of the installation and improvement of facilities, etc. for disposal of N/P Waste Liquid, must endeavor to give assistance by financing, or acting as a go-between to obtain, the necessary funds, and giving technical counsel, etc..
2. When carrying out the measures of the previous paragraph, special consideration must be given to the situation of small and medium-sized enterprises.

(Monitoring Obligation)
Article 27

A person who has installed a Designated Facility must, in accordance with provisions established by regulation, measure the condition of the water discharged form his Business-Industrial Site and keep a record of the results.

(Rulemaking Authority)
Article 28

The Governor may, by regulation, establish all necessary provisions for the enforcement of this Ordinance.

CHAPTER 6 PENAL PROVISIONS

(Penalties)
Article 29

A person described by either of the two numbered items below may be punished by a fine of up to ¥ 100,000.

(1) A person who has violated an order of the Governor issued in accordance

with the provisions of Article 11, Article 16, paragraph 1, or Article 20.

(2) A person who has violated the provisions of Article 15, paragraph 1.

Article 30

A person described by any of the numbered items below may be punished by a fine of up to ¥ 50,000.

(1) A person who has, with respect to the provisions of Article 8, 9, or 10, failed to file a required report or filed a false report.

(2) A person who has violated the 60 day waiting period required by Article 12, paragraph 1.

(3) A person who has refused to allow, obstructed, or evaded an on-the-site inspection provided for by Article 25, paragraph 1 or refused to make a report of data or give information requested under the provisions of that paragraph.

Article 31

A person who has failed to file a report of changes as required by Article 13 or a report of succession as required by Article 14, paragraph 3, or who has filed a false report, may be punished by a fine of up to ¥ 30,000.

(Multiple Penalities)

Article 32

When a person who is the representative official of a legal person, or employed as an agent, employee, etc. of another person or a legal person, has violated any of the penal provisions of Articles 29 – 31 in connection with that other person's or legal person's business, in addition to punishing the actual violator, the various fines of those Articles may also be imposed on the other person or legal person whom the violator represents or is employed by.

(Effective Date)

This ordinance's provisions shall go into effect on a day, not later than one year after this Act's promulgation, determined by regulation.

WATER POLLUTION CONTROL PROJECTS IN RIVERS AND LAKES IN JAPAN

Kanenobu Hagiwara
Urban River Division, River Bureau
Ministry of Construction

TABLE 1 NUMBER AND TOTAL LENGTH OF RIVERS (1980)

	River basins	Rivers	Total length (km)
Class A rivers	109	13,267	85,757*
Class B rivers	2,615	6,615	33,561

* Length administered by national government is 9,945 km among total length.

TABLE 2 NUMBER OF SAMPLING SITES FOR WATER QUALITY INVESTIGATION IN CLASS A RIVERS*

Year	Number of sampling sites
1969	142
1970	524
1971	662
1972	727
1973	746
1974	837
1975	874
1976	886
1977	915
1978	953
1979	979
1980	997

* Section administered by national government.

TABLE 3 PERCENTAGE OF BOD ANNUAL MEAN VALUE IN CLASS A RIVERS

Value of BOD (ppm)	1978 (%)	1979 (%)
1 under	25.9	28.4
1 - 2	39.4	40.7
2 - 3	15.3	14.3
3 - 5	9.7	8.2
5 - 8	4.7	3.6
8 - 10	1.2	0.8
10 - 20	3.4	3.1
20 - 30	0.6	0.7
30 - 50	0.3	0.1
50 - 100	0.1	—
100 over	0.1	0.1
Total	100.0	100.0

Number of sampling sites 1978 : 876
1979 : 879

TABLE 4 CHANGE OF BOD ANNUAL MEAN VALUE IN CLASS A RIVERS

	%			Number of sampling sites
	3 ppm under	3 - 10 ppm	10 ppm over	
1970	58.7	23.6	17.7	521
1971	59.6	24.2	16.2	661
1972	71.3	20.2	8.5	727
1973	72.6	20.0	7.4	746
1974	75.9	17.4	6.7	837
1975	82.3	12.7	5.0	874
1976	83.2	13.1	3.7	895
1977	81.6	13.7	4.7	852
1978	80.6	14.8	4.6	876
1979	83.4	12.6	4.0	879

TABLE 5 PERCENTAGE OF BOD ANNUAL MEAN VALUE IN CLASS A RIVERS, CLASSIFIED BY REGION (1979)

Value of BOD (ppm)	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu
1 under	55	9	27	45	42	18	40	40	15
1 - 2	35	64	29	29	34	32	40	42	52
2 - 3	10	23	13	17	14	20	9	7	12
3 - 5		3	16	8	5	5	8	7	12
5 - 8			8	1	4	3	2	2	7
8 - 10			2			4			
10 - 20			5		1	13	1	2	1
20 - 30						4			1
30 - 50									
50 - 100									
100 over						1			

TABLE 6 THE YEAR'S WORST FIVE RIVERS IN BOD (CLASS A RIVER)

Year	Rank	River	Number of sampling sites	BOD annual mean value (ppm)
	1	Yamato River	8	19.7
	2	Ayase River	2	19.0
1978	3	Turumi River	4	13.8
	4	Ibo River	6	7.7
	5	Tama River	10	6.8
	1	Yamato River	8	13.9
	2	Ayase River	2	13.4
1979	3	Turumi River	4	13.4
	4	Ibo River	6	7.3
	5	Tama River	10	6.1

TABLE 7 RATIO OF SAMPLES EXCEEDING WATER QUALITY STANDARD FOR BOD IN CLASS A RIVERS

Water quality categories	Water quality standard for BOD	1978 (%)	1979 (%)
AA	1 ppm	55	53
A	2 ppm	31	27
B	3 ppm	33	29
C	5 ppm	50	50
D	8 ppm	42	31
E	10 ppm	53	43
Total		36	32

Number of sampling sites 1978 : 889
1979 : 890

TABLE 8 RATIO OF SAMPLES EXCEEDING WATER QUALITY STANDARD FOR BOD IN CLASS A RIVERS (Classified by Region)

Region	1978 (%)	1979 (%)	Number of sampling sites, 1979
Hokkaido	6	5	63
Tohoku	33	27	120
Kanto	51	47	150
Hokuriku	22	21	70
Chubu	15	11	89
Kinki	61	54	121
Chugoku	36	37	100
Shikoku	24	24	45
Kyushu	38	33	132
Total	36	32	890

TABLE 9 RATIO OF SAMPLES EXCEEDING WATER QUALITY STANDARDS RELATING TO PROTECTION OF HUMAN HEALTH TO THE TOTAL NUMBER OF SAMPLES TAKEN IN CLASS A RIVERS

Substances	Water quality standard	1978 (%)	1979 (%)
Cyanide	N.D.	0	0
Alkylmercury	N.D.	0	0
Organic P	N.D.	0	0
Cadmium	0.01 ppm	0.10	0.05
Lead	0.01 ppm	0.05	0.01
Chromium VI	0.05 ppm	0	0
Arsenic	0.05 ppm	0.24	0.21
PCBs	N.D.	0.10	0
Total Mercury	0.005* ppm	0	0

* Annual averages.

TABLE 10 BUDGET FOR RIVER WATER PURIFICATION

million yen

Fiscal year	Budget belonging to ministry of construction (A)	Budget for river works (B)	Budget for river wate. purification (C)	B/A (%)	C/A (%)	(Reference) Budget for sewage works (D)	D/A (%)
1972	3,592,024	415,403	3,060	11.56	0.085	218,340	6.08
1973	4,869,436	521,870	3,023	10.72	0.062	346,772	7.12
1974	5,250,219	524,068	3,265	9.98	0.062	308,372	5.87
1975	5,809,068	544,108	3,528	9.37	0.061	392,432	6.76
1976	6,768,693	658,425	4,677	9.73	0.069	478,210	7.07
1977	7,989,545	801,268	5,565	10.03	0.070	612,265	7.66
1978	10,026,180	1,083,318	7,922	10.81	0.080	877,871	8.76
1979	11,756,589	1,335,116	8,506	11.36	0.072	1,128,662	9.60
1980	12,121,467	1,343,534	8,228	11.08	0.068	1,199,558	9.70

TABLE 11 DREDGING VOLUME OF SLUDGE IN RIVERS AND LAKES

1000 m^3

Fiscal year	National works	Prefectural works	Total
1958 - 70	--	7,004	7,004
1971	125	952	1,077
1972	119	949	1,068
1973	195	1,140	1,335
1974	146	656	802
1975	166	545	711
1976	157	654	811
1977	125	882	1,007
1978	200	860	1,060
1979	288	804	1,092
1980	353	594	947
Total	1,874	14,985	16,859

TABLE 12 DREDGING VOLUME OF SLUDGE IN RIVERS AND LAKES, CLASSIFIED BY REGION

1000 m^3

Region	Number of rivers	Total plan	(%)	1980	1981	1982
Hokkaido	1	700	1.5	186	90	424
Tohoku	2	215	0.5	121	6	88
Kanto	30	20,533	43.1	6,382	382	13,769
Hokuriku	5	1,486	3.1	276	22	1,188
Chubu	10	9,294	19.5	2,260	126	6,908
Kinki	17	11,385	23.9	2,834	142	8,409
Chugoku	14	2,305	4.8	350	79	1,876
Shikoku	4	265	0.6	114	30	121
Kyushu	[illegible]	1,446	3.0	975	61	410
Total	92	42,629	100	13,498	938	33,193

TABLE 13 UNIT COST OF DREDGING OF SLUDGE IN RIVERS AND LAKES (1980)

Unit cost yen/m^3	Kanto and Kinki	Other Regions	Total
1,000 under	--	1	1
1,000 - 2,000	7	6	13
2,000 - 3,000	4	8	12
3,000 - 4,000	6	11	17
4,000 - 5,000	3	6	9
5,000 - 6,000	5	3	8
6,000 - 7,000	5	--	5
7,000 - 8,000	4	1	5
8,000 - 9,000	2	--	2
9,000 - 10,000	2	--	2
10,000 over	5	--	5
Total	43	36	79

TABLE 14 METHOD USED FOR DREDGING OF SLUDGE IN RIVERS AND LAKES (1980)

Instrument	Case
Clamshell grabbing crane	12
Pump dredger	23
Grab dredger	30
Tractor shovel (and bulldozer)	10
Backhoe	12
Dragline	1
Others	3
Total	91

TABLE 15 TRANSPORT METHOD OF SLUDGE (1980)

Instrument	Case
Dump car	40
Barge	18
Pipeline	9
Tractor shovel	1
Barge and dump car	6
Pipeline and dump car	5
Flat ship and dump car	3
Others	7
Total	89